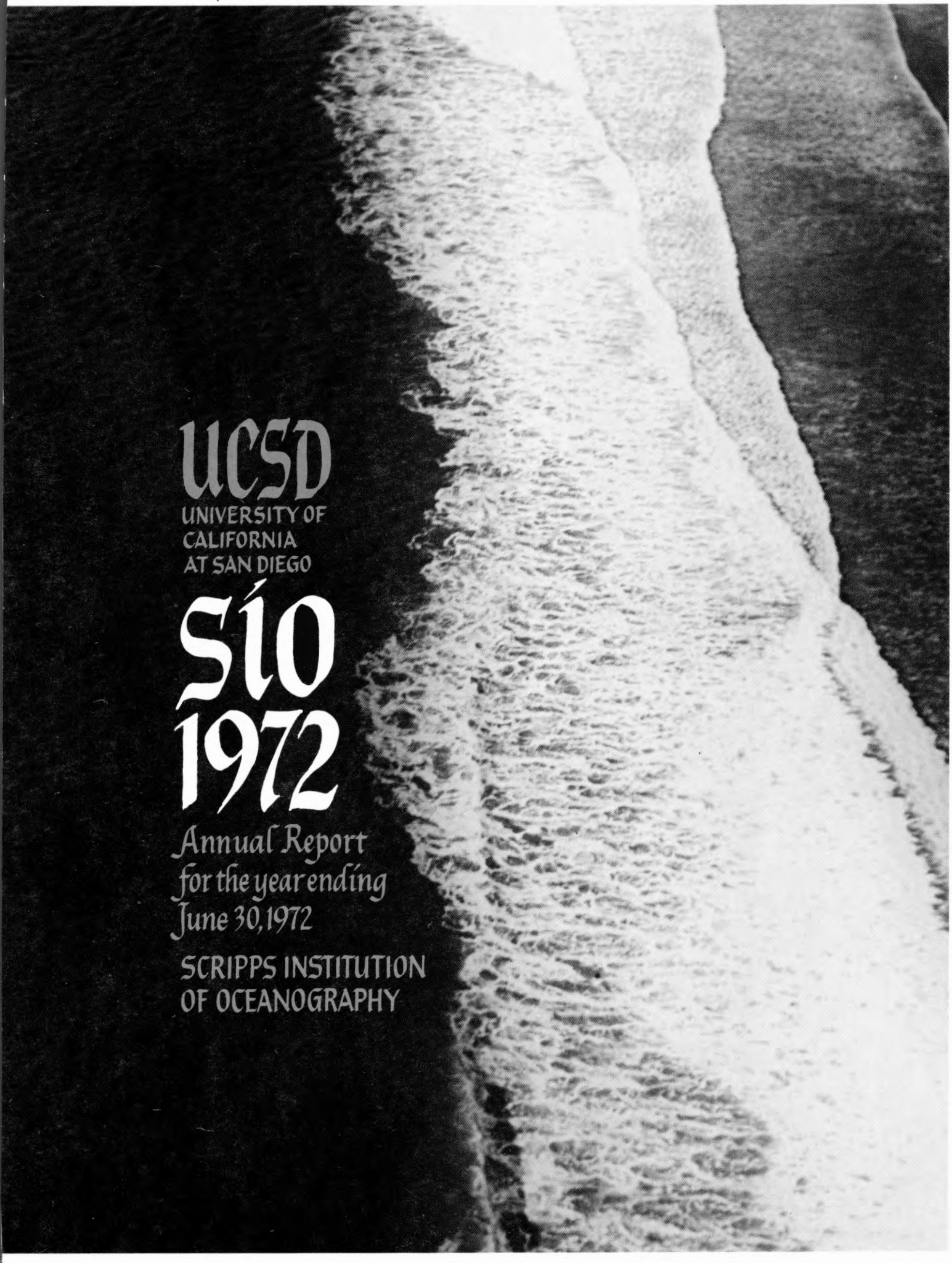

UCSD

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CALIFORNIA
AT SAN DIEGO

SIO 1972

Annual Report
for the year ending
June 30, 1972

SCRIPPS INSTITUTION
OF OCEANOGRAPHY

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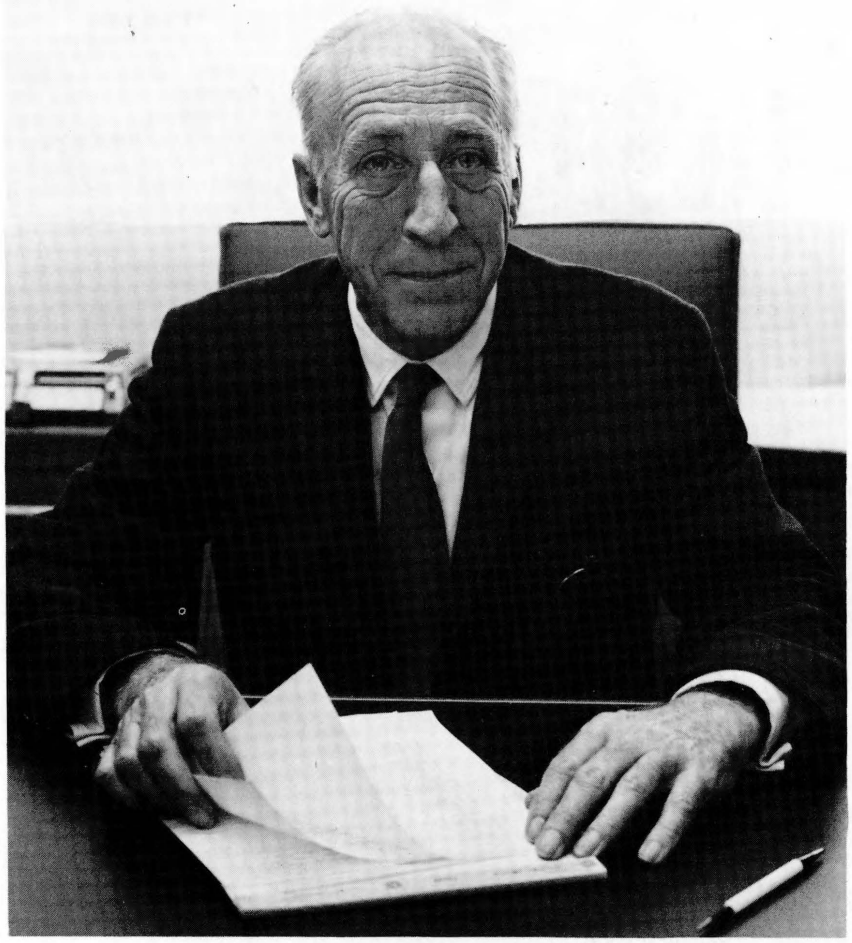

Former director of Scripps Institution and of its Marine Physical Laboratory and vice chancellor for academic affairs in the fledgling days of UC San Diego, Dr. Carl Eckart, professor of geophysics emeritus, was honored in 1966 with the Alexander Agassiz Medal of the National Academy of Sciences for his "perceptive and far-ranging analysis of the motions of the sea and the forces behind them." In 1972 he was the recipient of the William Bowie Medal of the American Geophysical Union "for outstanding contributions to fundamental geophysics and for unselfish cooperation in research." He joined Scripps and MPL in 1946, and over the years, in his quiet, unassuming manner, influenced scores of students at UCSD and Scripps and earned the respect of his colleagues in his many administrative posts.

Glasheen Graphics

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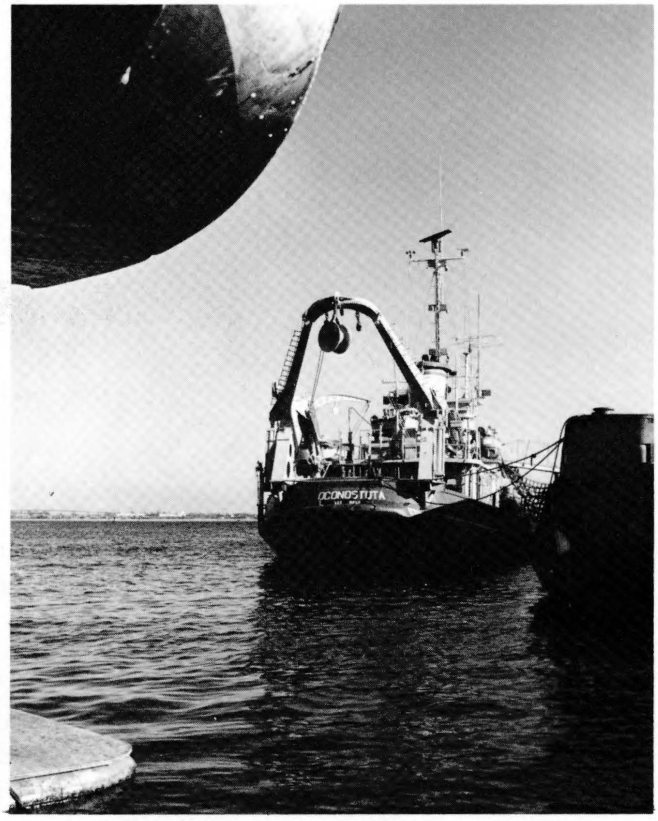


INTRODUCTION

Despite the buffeting and lashing of the budgetary revolution in Washington and the complex effects of the demographic changes on higher education, the Institution seems to have prospered, at least measured by its spending increment.

Nevertheless, major changes in oceanographic research are in the offing. Perhaps the most marked will be greater reliance on remote sensing of its environment and less dependence on manned platforms—ships. It seems to mark an era of demanding "more science for a buck." Foremost in this development is the use of radar for remote sea-state sensing and its concomitant meteorological applications. This would appear to be a genuine step forward, both in science and economy. There are other similar developments of longer standing that are coming more to the fore—capsules, towed fully instrumented "fish" and underwater manipulators in general.

Increasing emphasis is being placed, however, on the development of satellite programs for oceanographic measurements. Unquestionably, electromagnetic surface sensing on a global scale can be accomplished very economically and will be very valuable for estimates of biological productivity using a variety of techniques, surface currents, temperature and heat flow, and surface contaminants. It appears attractive (but as yet economically unproven) as a communications link for moored and drifting buoys. There seems no way to use remote sensing from satellites to perform the bulk of subsurface biological, physical, and chemical research necessary for the full studies of the oceans.

Above all, other than certain gravity measurements, marine geology and marine geophysics can only be performed from ships with occasional assists from airplanes. This very important field of research is not only basic to our understanding the evolution of the earth, it is also the fundamental exploration tool for the determination of the mineral wealth of the sea floor. The budgetary pressures that are developing are forcing reductions in the national oceanographic fleet—governmental and academic—and this at a time when the number of federally supported research programs requiring the use of ships is actually increasing. Under these circumstances those branches of oceanography for which ships are indispensable are likely to be squeezed the worse, unbalancing a field in which the interdisciplinary approach is fundamental to its progress. It will be our policy, therefore, to devote our efforts and resources to maintaining the vitality and strength of the earth sciences in the face of these debilitating forces.

It is ironic that this development emerges at the end of a decade of the greatest advances in the earth sciences, marked by the acceptance of the concepts of plate tectronics, sea-floor spreading, and continental drift. This burst was spearheaded by the Deep Sea Drilling Project and symbolized by the cruises of the D/V *Glomar Challenger*. But perhaps the Deep Sea Drilling Project spearheaded an operational concept in the ocean sciences to an unacceptable limit. There now exists a whole host of multi-institutional—sometimes international—large-scale programs such as GEOSECS, MODE, NORPAX, MARMAP, MESA, GATE, CUEA, and so on that, in numbers, carry considerable dangers. There are great values to be gained in occasionally assembling talent in large scale to attack important problems with adequate resources. But the situation matures to this point only after many years of knowledge accumulated slowly and sometimes painfully, and based on a pattern of a large number of scattered, small, grant-supported programs with an occasional breakthrough. The great danger of an overemphasis on "big science" is the absorption of manpower away from independent small research. Nothing could be duller and more atrophying than insensitive committee-directed research. Clearly, balance is called for, and at this time more support is called for the small individual grants.

Our graduate teaching program continues to prosper. While the Institution's teaching resources have not expanded, and thus the student population remains constant, the placement problem after graduation does not exist; there are ample opportunities for all our graduates. In addition, the funds for student support on research projects seem to be holding up. Finally, the level of incoming graduate students is continually improving, at least measured by their grade-point average and first-year performance.

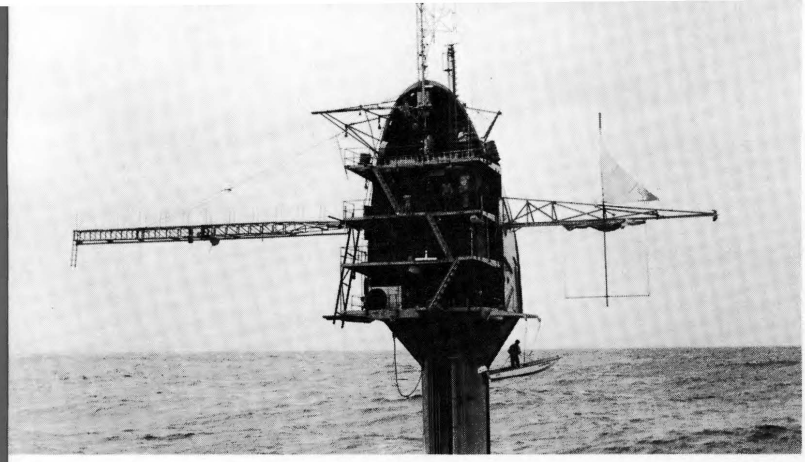
This year marked the passing of Professor Emeritus George McEwen. Professor McEwen had a long and distinguished career in the Institution, but had been largely inactive during my seven-year tenure. Yet his presence was felt and his passing removes an honored link with the past.

William A. Nierenberg

William A. Nierenberg, Director
Scripps Institution of Oceanography

Dr. William A. Nierenberg, director of Scripps Institution, received his Presidential commission as chairman of the National Advisory Committee on Oceans and Atmosphere from Secretary of Commerce Maurice H. Stans, left, at the committee's first meeting in Washington on December 6, 1971. Dr. Robert M. White, at right, administrator of the National Oceanic and Atmospheric Administration, assisted at the ceremony. The 25-member advisory group was appointed in October, 1971, by President Nixon to assess and report annually on all federal programs in marine and atmospheric science.

NOAA Photograph



R/P FLIP

R/P ORB

SEAGOING OPERATIONS

Nimitz Marine Facility and the Fleet

During Fiscal Year 1972, Scripps Institution operated seven research vessels: *George Melville, Thomas Washington, Alexander Agassiz, Alpha Helix, Oconostota, Ellen B. Scripps,* and *ST-908*. The *George Melville, Thomas Washington,* and *Alpha Helix* were engaged in major expeditions. The fleet spent 1,246 days at sea and logged 128,391 nautical miles.

R/V *Melville* was at sea between Singapore and Guam on Antipode Expedition at the beginning of the year, with Dr. John G. Sclater in charge. Several proposed drilling sites for the Deep Sea Drilling Project were surveyed on and to either side of the north-south trending Ninety East Ridge. After the ship passed south of the Philippines, three weeks of geophysical studies were undertaken in the Philippine Sea. Upon the vessel's leaving Guam on July 27, 1971, the scientific program was under the overall direction of Dr. Harmon Craig. This was the final shakedown for subsequent GEOSECS Expeditions scheduled to begin in 1972. The vessel arrived in Tonga on August 24. A short leg from Tonga to Pago Pago for geological observations followed. Dr. George G. Shor, Jr., departed Pago Pago aboard *Melville* on September 11 on the final leg of Antipode. En route to San Diego, air gun, magnetic, and wide-angle reflection observations with sonobuoys were taken. The vessel arrived in San Diego on October 3.

The next six months were taken up with *Melville* ship modifications, equipment tests, and short local cruises. On March 11, 1972, *Melville* departed San Diego for the Gulf of California on Hypogene Expedition. The role of chief scientist was shared by Drs. Henry W. Menard, Pat Wilde (Institute of Marine Resources, Berkeley), and James W. Hawkins. Observations of geological and geophysical nature were taken. Scientific equipment and winch tests were conducted during part of May and June. On June 7, the ship left San Diego on the first leg of Cato Expedition, en route to Honolulu. Dr. John A. McGowan headed the scientific party. R/V *Melville* logged 186 days at sea and steamed 26,975 nm during the year.

On July 1, 1971, R/V *Thomas Washington* was in Yokohama, Japan, engaged in Leg VII of Aries Expedition under the leadership of Dr. Bruce A. Taft. The primary objective of this phase of the expedition was to measure the Kuroshio Current, by making hydrographic, current velocity, and directional observations. Leg VIII of Aries Expedition from Yokohama to Honolulu, headed by Dr. Thomas W. Davies, was geological in nature and included coring, dredging, and sonobuoy measurements. A short, extra leg under the direction of David Muus, was added in Honolulu to service North Pacific buoys. The final leg of Aries from Honolulu to San Diego was devoted to physical oceanographic studies under co-chief scientists Drs. John A. McGowan and Charles S. Cox.

Following a six-week upkeep period, R/V *Thomas Washington* was engaged in a student-training cruise and two brief preparatory cruises for South-Tow Expedition, which began on January 5, 1972. Leg I of South-Tow, under Dr. Robert R. Hessler, studying samples of abyssal benthic communities, took the ship from San Diego to Papeete, Tahiti, via Pitcairn Island. Leg II from Papeete to Valparaiso, Chile, was led by Dr. John D. Mudie, who was also the coordinator for the entire expedition. En route to Valparaiso, deep-tow observations were taken. Legs III and IV, directed by Robert L. Wisner, were devoted to concentrated sampling and studies of deep-water fishes in the Chile-Peru Trench. Current measurements were also taken. Dr. Fred N. Spiess was scientist in charge of Leg V, with its comprehensive deep-tow surveys, and the year's operations were completed by Dr. Mudie with additional deep-tow studies. The vessel spent 296 days at sea and steamed approximately 37,300 nm.

R/V *Alpha Helix* completed the final leg of the Antarctic Expedition, from Honolulu to San Diego, during the first month of the fiscal year. Bruce Robison, of Stanford University's Hopkins Marine Laboratory, led a team of scientists engaged in under-way physiological observations. After an overhaul period in San Diego, the ship commenced a series of relatively short operations. Dr. Reuben Lasker used the vessel from October 4-8 in the Santa Catalina Channel, studying shark livers. The period October 13-22 found the ship seeking whales off the Southern California coast, with Dr. Gerald L. Kooyman as scientist-in-charge. Dr. Michael M. Mullin was in charge of the next cruise, which took the ship to the North Pacific Gyre from October 27-November 24. General hydrography and a series of bongo net tows were accomplished. A ten-day study of whale acoustics followed the Mullin cruise, again headed by Dr. Kooyman. In the vicinity of Catalina Island, the period January 3-21 was devoted to an intensive study and electro-physiological experiments on the visual system of squid under Dr. G. David Lange.

Alpha Helix then headed south to the Gulf of California on Aztec Operation for two weeks—with Dr. James Mathewson, of California State University, San Diego—for a study of toxic element distributions in coastal ecosystems. On February 28, 1972, the ship departed for Cold Bay, Alaska, and the Bering Sea Expedition. A variety of physiological investigations was conducted under Drs. Robert W. Elsner, L. Keith Miller (University of Alaska), and Kooyman, and UCSD graduate student Richard Doyle, in the Bering Sea and Bristol Bay areas. The ship departed Dutch Harbor June 12 for the Hawaiian Islands. Approximately three weeks were spent in Honolulu for vessel maintenance and preparation for the Solomon Islands Expedition that followed. R/V *Alpha Helix* spent 237 days at sea and logged 18,260 nm.

R/V *Alexander Agassiz* was engaged primarily in biological sampling the first half of the year. Cruises were mostly of short duration. Exceptions were those of Shirley Imsand, conducting oblique trawls, hydrographic casts, and dip netting, from August 23-September 10; Robert P. Huffer and Richard G. Schwartzlose, mooring a 40-foot General Dynamics buoy, followed by a Marine Life Research Group program from October 5-21; then with Dr. Robert R. Hessler and Francis J. Rokop conducting deep-water trawling, dredging, coring, and photography from October 22-26. After a shipyard overhaul in November, and three short local operations, R/V *Agassiz* began a series of MLRG cruises off the coasts of California and Baja California.

R/V *Oconostota*

R/V *Alpha Helix*

The ship logged 24,255 nm during the year, and she was at sea for 203 days.

R/V *Ellen B. Scripps* conducted numerous short trips the first half of the year. Programs and scientific leaders included William Johnson, conducting temperature gradient studies; Dr. Michael C. Gregg, testing a microstructure recorder; Tetsuo Matsui, conducting studies of the rat tail and sable fish; Dr. Russ E. Davis, studying wave height movements; Dr. Frank E. Snodgrass, conducting deep-current studies; Dr. Charles S. Cox, testing a microthermograph recorder; Dr. Edward R. Sholkovitz, conducting coring and biological sampling.

Also Dr. William H. Thomas, conducting sewer outfall studies; Andrew Soutar, making box coring and current meter studies; Meredith Sessions, testing free-fall vehicles; Dr. Theodore D. Foster, conducting geothermal heat-flow studies; Dr. Paul K. Dayton, operating graduate student cruises; Barbara M. Hickey, calibrating STDs; and Alan D. Jones, testing sonobuoys.

On March 31, the ship departed on the Iguana Expedition, which lasted until the latter part of May. Dr. George G. Shor, Jr., took the vessel down the west coast of Baja California, Mexico, and Central America, and on to Guayaquil, Ecuador. Seismic refraction work was accomplished, and air gun and magnetic profile observations were taken. The ship worked with the University of Hawaii's R/V *Kana Keoki,* and returned to San Diego May 22. For the remainder of the year, R/V *Ellen B. Scripps* carried out short-duration operations off the Southern California and Baja California coasts. She spent 166 days at sea, and logged 14,011 nm.

R/V *Oconostota* and *ST-908* limited their activities to coastal waters. The former was involved in a variety of data-gathering cruises and three operations that included towing FLIP. Total operating days were 102, and total distance steamed came to 5,796 nm. R/V *ST-908* performed a number of tasks in inland waters, along with sampling exercises in near-shore coastal waters. She steamed 1,776 nm, and was at sea for a little over 56 days.

Major Expeditions

Antipode Expedition. What may well be the thickest sediment sections in the world, measuring 16,460 m, or more than six km, exist in the Indian Ocean's Bay of Bengal, between India and the Malayan Peninsula.

The generally accepted principle of sea-floor spreading, first recognized as operative and fundamental to major plate movements in large ocean basins, has been documented in an area close to island arcs or chains, such as that in the Lau Basin, between Tonga and the Fiji Islands.

These were but two of numerous findings resulting from Scripps Institution's Antipode Expedition, which ended October 3, 1971, as R/V *George Wallace Melville* returned to San Diego.

The 15½-month, 60,000-nm, geological-geophysical expedition into the Pacific and Indian Oceans ranks as the second-longest expedition in the history of Scripps. The longest Scripps cruise was that of R/V *Argo* during the 'round-the-world Lusiad Expedition of 1962-63, a voyage of some 83,000 nm, principally in the Indian Ocean.

Antipode was chosen as the name for the cruise because *Melville* worked for nine months in the Indian Ocean, and for nearly half that period in regions near Mauritius, which is almost geographically opposite San Diego.

Melville left San Diego June 15, 1970. Her crew was rotated during the cruise, and she was captained by three masters, beginning with Noel L. Ferris, then Alan W. Phinney, and, en route to San Diego from the Indian Ocean, John W. Bonham. Only one crew member, veteran Second Officer Geoffrey C. Clark, served aboard ship the entire expedition.

Antipode's scientific investigations were sponsored mainly by grants from the National Science Foundation and contracts with the Office of Naval Rseearch.

The expedition was a multi-nation effort that also saw numerous Scripps graduate students participating as members of various scientific parties.

Aboard at various times were scientists from Mauritius, France, India, Kenya, the United Kingdom, the Republic of South Africa, Japan, and West Germany. Twelve other American universities and colleges were represented among the scientific parties.

Chief scientists directing the several segments of the expedition were Dr. Robert L. Fisher (three legs), cruise coordinator, who also handled the same assignment for Scripps's earlier Monsoon, Lusiad, and Circe Expeditions in the Indian Ocean; Dr. Harmon Craig; Dr. Joseph R. Curray (two legs); Dr. James W. Hawkins; Prof. John D. Isaacs; Paul J. Liebertz; Dr. Richard H. Rosenblatt; Dr. John G. Sclater (two legs); and Dr. George G. Shor, Jr. (three legs).

The expedition encountered a set of problems that delayed her progress. *Melville,* like her sister *Knorr* at Woods Hole Oceanographic Institution, is driven by a new-type (in the U.S.) propulsion system: vertically mounted, multi-bladed, cycloidal propellers—one near the bow, a larger one near the stern. She is designed to move forward, backward, sideways, or to rotate, and to remain stationary over a fixed point in a 35-knot wind and a one-knot current.

The ship sustained a chipped aft-cycloidal crown gear that reduced her speed and capabilities during Indian Ocean operations from early October to mid-December, 1970.

She remained in Port Louis, Mauritius, 23 days over Christmas and the New Year, undergoing replacement of the gear, which had to be custom made and flown in from the manufacturer's plant in West Germany.

Bay of Bengal Studies

Expedition highlights, as reported by chief scientists, included these:

Dr. Curray and his colleagues, continuing investigations in the northern Indian Ocean and the Bay of Bengal Deep-Sea Fan begun in 1968 during Scripps's Circe Expedition, determined by seismic refraction that the maximum thickness of the sediment section that spills southward from the Ganges River and forms the floor of the Bay of Bengal is estimated at 16,460 m.

"This is one of the thickest sediment columns in the world," Dr. Curray reported, "and it covers an area of some 3,463,538 sq. km—3,226 km in length and 1,613 km in width."

The mud-and-sand sediment forming the Bengal Fan, eroded from the upthrust Himalaya Mountains, is thickest under the

continental shelf just offshore of the Ganges River delta.

The fan's surface is scored by a network of confined channels that carry turbulent masses of sediment and water at high velocities. The submarine channels are built up above the surrounding surface of the fan and have high, natural levees on each side. Some channels measure as much as 16 km across.

Dr. Curray's investigations were made in collaboration with Dr. Russell W. Raitt, of Scripps, and Dr. David G. Moore, of San Diego's Naval Undersea Research and Development Center.

Dr. Curray's work was delayed some three weeks as *Melville* stood by off Colombo, Ceylon, from April 5-26, because of the political situation in that region. Between April 18 and 26, however, she did conduct research on a limited basis in an area within 805 km of Colombo, readily available to evacuate U.S. personnel and citizens, if necessary, during Ceylon's internal strife. This evacuation was not required, however, and the ship continued her scheduled operations April 26.

Lau Basin Investigations

Late in the cruise, *Melville* covered some 2,500 nm of track in surveying the Lau Basin, between Nuku'a'lofa, Tonga, and Pago Pago, American Samoa.

Dr. James W. Hawkins, chief scientist aboard, together with several Scripps graduate students who formed the scientific party, said the leg's objective was to test an hypothesis about the origin of the Lau Basin. This hypothesis suggests that the Lau Basin was formed by crustal dilation.

According to the hypothesis, developed from data collected on Scripps's Nova and Seven-Tow Expeditions, the Tonga and Lau Island chains are slowly spreading apart, and basaltic lava is leaking out of the fractures formed during rupturing of the basin floor. Several large fracture zones were identified and symmetric anomaly patterns were found on tracks crossing ridges in the basin.

"This process would be somewhat similar to the sea-floor spreading at mid-ocean ridges, a factor that is believed to have generated the crust under the ocean basins," Dr. Hawkins said.

"The results of this leg of Antipode seem to confirm this hypothesis. Rocks dredged from ridges and seamounts in the Lau Basin are nearly identical to those found on mid-ocean ridges, and the geophysical data indicate that the Lau Basin has the physical characteristics of an area undergoing dilation."

Previously it had been assumed that the sea-floor spreading process was more or less restricted to the large ocean basins, and it had not been documented in an area close to island arcs such as the one in the Lau Basin.

Mid-Indian Ocean Ridge Operations

Prior to repairs and restoration of *Melville's* speed, range, and weather tolerance, the main program of the October-December, 1970, segment of Antipode, under Dr. Fisher's direction, was rock dredging and bottom photography near the triple-junction of the central, southeast, and southwest branches of the Mid-Indian Ocean Ridge.

"The Mid-Indian Ocean Ridge is part of a world-girdling system of earthquake-prone submarine mountain chains where new crust is being created and emplaced as volcanic rock, and from which huge fracture-bounded plates or crustal-upper mantle fragments are moving toward border areas or continents," Dr. Fisher explained.

"Special efforts, notably successful, were made to dredge coarse-grained igneous rocks of the lower crust of upper mantle which are exposed by faulting along, and especially across, the spreading ridge.

"One cross-fracture discovered by a Scripps ship in 1968, the Marie Celeste Fracture Zone 805 km east of Mauritius, is as wide and as long as the Grand Canyon, and twice as deep.

"On Antipode, this fracture zone yielded anorthosites, gabbros, basalts, and peridotites characteristic of deep portions of the oceanic crust; also minor amounts of extremely silica- and alkali-rich differentiates usually thought to be indicative of land areas."

After Christmas, with *Melville's* normal cruising speed restored, underway programs such as echo-sounding and magnetic and sediment-thickness studies became a larger part of the ship's scientific program.

With Dr. Fisher as chief scientist again, the ship worked north along the Central Indian Ridge, confirming and extending Scripps's 1968 findings that the non-seismic north-south trending Chagos-Laccadive Plateau probably was joined to the similarily non-seismic Mascarene Plateau until about 20 million years ago.

"On splitting, both these plateaus grew longer through volcanic extrusions to the north and south, respectively, and were separated, at rates of one to two cm a year, by development of the intervening and widening Central Indian Ridge," Dr. Fisher said.

During the 35-day traverse from Mauritius to Mombasa, Antipode's longest leg, *Melville* surveyed and sampled four of the sedimented sites proposed for drilling by the Deep Sea Drilling Project's *Glomar Challenger* in early 1972. She put into Mombasa, Kenya, in mid-February, after a brief stop at Mahé in the Seychelles Archipelago.

Comoro Islands Operation

In a change of pace from the geological-geophysical investigations of the expedition work in the Indian Ocean, *Melville* spent 18 days off the east coast of Africa, working in the western vicinity of Aldabra Islands, off the Comoro Islands, and near Kenya.

Objective of the scientists, headed by Prof. John D. Issacs, was to attempt to photograph or to take specimens of the elusive "living fossil" of extinct fishes, the coelacanth *Latimeria,* of which only some 60 individuals have been preserved. All but one of the 60 collected so far were caught off the Comoros.

Professor Isaacs reported that no coelacanth was observed, but that by means of Scripps-developed, baited, autonomous movie and still cameras, photographs of other fish in the area were taken.

A large number of specimens was collected by fish traps and hook-and-line fishing for study at Scripps. Most of the fishing and photography occurred on steep, volcanic seamounts.

Many varieties of fish were caught between near-surface waters and 18 m. On the other hand, the photographs, taken at depths ranging from several hundred meters to 3,049 m, show only sharks, eels, and shrimp to be present in any quantity.

Philippine Sea Studies

Dr. Richard H. Rosenblatt is mapping the distribution of deep-sea fishes in the Philippine Sea after examining samples collected

R/V *Thomas Washington*

R/V *Ellen B. Scripps*

from this region during Antipode.

He and his colleagues found differences in the catch of the deep-sea fish fauna even though there were no differences in physical conditions in the deep-water environment.

This leads him to believe that distribution of deep-sea fishes is greatly affected by processes going on at the surface of the sea, especially as they relate to availability of food.

Dr. Rosenblatt's program of mid-water trawling recovered a yet-to-be-named genus of deep-sea angler fish.

"We also took samples of a newly discovered species of viper fish, and filled in distributions of a large number of deep-sea fish species," he said.

Manila-to-Mauritius

Paul J. Liebertz was scientist-in-charge for Antipode's Manila-to-Mauritius track, during which heat-flow measurements were taken in the northeastern Indian Ocean.

GEOSECS Shake-Down Tests

Dr. Harmon Craig and colleagues from the United States, Japan, India, and West Germany ran shake-down tests on equipment and scientific procedures to be used in the GEOSECS (Geochemical Ocean Section Studies) program. This is the first major program to be conducted during the International Decade of Ocean Exploration.

Working in the vicinity of the Tonga Trench, the scientists studied the Western Boundary Current, using high-precision *in situ* measurements of temperature, salinity, and depth. The distributions of natural radioisotopes, stable isotopes, dissolved gases, and trace elements in this area were also studied.

Data collected during Antipode helped scientists to plan work station locations for the multi-nation GEOSECS program, which is designed to provide baseline information about deep-water circulation as it affects climate, oceanic mixing, and conditions governing the production of sea life.

Padang-Singapore and Singapore-Guam Operations

Between Padang, Sumatra, and Singapore, Drs. John G. Sclater, Theodore Foster, and Russell W. Raitt and their collaborators investigated the magnetic anomaly pattern of the upper crust in the western portion of the Wharton Basin, an extensive deep region lying south of Sumatra and northwest of Australia.

Dr. Sclater said an understanding of the magnetic anomaly lineations enables scientists to determine the age and process of formation of the subsediment of the ocean floor. Specifically, Dr. Sclater hopes to work out a time scale for what may well be the most ancient part of the Indian Ocean floor. Four detailed surveys of critical areas were made on the Padang-Singapore leg to study the anisotropy in the velocity of sound near the earth's crust-mantle boundary and to help select sites for Deep Sea Drilling Project holes in the northeast Indian Ocean. Anisotropy studies provide information about differences in the crystal structure and stresses in mantle rock, as a means of better understanding the development of the earth's crust and the mantle beneath it.

After departing Singapore, *Melville* sailed east through the Sulu and Celebes Seas to Davao, Mindanao, to pick up replacement heat-flow gear and thence worked across the Philippine Sea, dodging two typhoons en route to Guam.

The scientific objective of this program was to study the age and method of formation of marginal basins lying westward of the Marianas island chain. The basins are separated from the North Pacific proper by a deep trench and may have a different history of formation than the crust in the North Pacific. This research was a cooperative venture involving Drs. Sclater, Dan Karig of the University of California at Santa Barbara, and Masashi Yasui of the Japan Meteorological Agency.

Seismic Reflection Operations

In a study similar to that conducted by Dr. Raitt in the northeastern Indian Ocean, Dr. George G. Shor, Jr., and his associates measured anisotropy of the earth's mantle in the northwest Pacific, southern Bering Sea, and just south of the Arabian Sea.

Working on three legs of Antipode, Dr. Shor also surveyed sites for proposed Deep Sea Drilling Project core drillings.

On the final leg of the expedition, he and his colleagues carried out 30 wide-angle seismic reflection operations using an air gun and small explosives as sound sources and electronic devices called sonobuoys that receive signals "bounced" off sediment layers of the ocean floor and relay them back to the ship for recording and interpretation.

En route home from Pago Pago, Dr. Shor and his party also retrieved four moored current meter arrays—two just north and two just south of the equator, some 1,200 nm south-southeast of Hawaii—put down in April, 1971, during Leg 4 of Scripps's Aries Expedition.

Moored in the Equatorial Undercurrent, the meters were installed as part of a joint Scripps-Massachusetts Institute of Technology-Harvard-Woods Hole Oceanographic Institution program to study fluctuations of near-surface and bottom currents at the equator.

Major Expeditions

Aries Expedition. It is possible that higher organic productivity sometimes observed behind islands may be accounted for by increased mixing of the waters produced by the islands' disturbance of current flow.

A volcanic seamount, now submerged 1,585 m below the surface of the ocean between the Hawaiian Islands and Japan, probably stood as a land mass millions of years ago.

Eleven hundred twenty-nine km northwest of Midway Island in the Pacific, scientists charted one of the largest flat-topped sub-marine mountains or guyots, ever discovered in the world ocean.

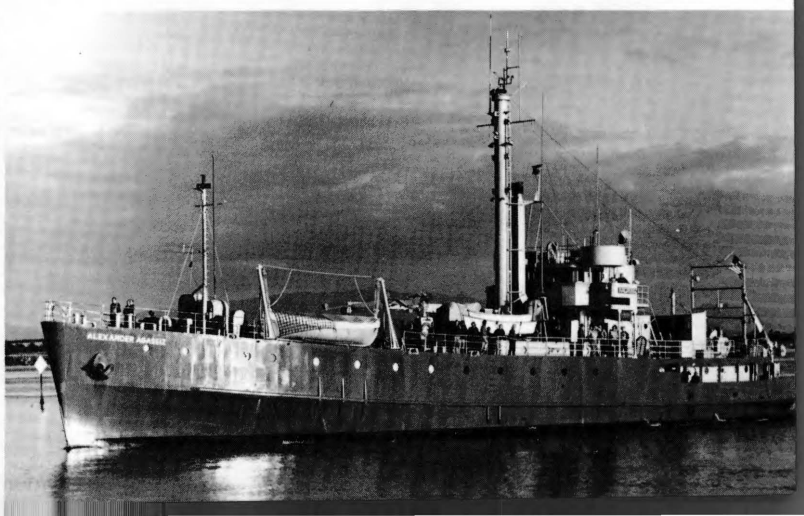
Investigators at Scripps Institution listed these and other discoveries as R/V *Thomas Washington* steamed into Scripps's Nimitz Marine Facility October 15, 1971, to conclude the Aries Expedition.

During 11 months of work sponsored by the Office of Naval Research, the National Science Foundation, and the State of California, the vessel logged more than 53,000 nm in the western Pacific betwen Antarctica in the south and Japan in the north. She was captained at different times by three men: John W. Bonham, Noel L. Ferris, and James L. Faughn. The ship's crew rotated once midway through the expedition. The vessel left San Diego November 14, 1970.

Dr. Bruce A. Taft, assistant professor of oceanography at Scripps, coordinated plans for the expedition and served as chief scientist for two of the eight legs. Other chief scientists were Dr.

R/V *ST-908*

R/V *Alexander Agassiz*



Prime Minister Seewoosagur Ramgoolam of the Indian Ocean Island of Mauritius, second from right, is introduced to Mrs. Marie Jantsch, of Scripps, by Dr. Robert L. Fisher, during reception aboard R/V Melville *as she was tied up at Port Louis quay in November, 1971. Dr. Fisher, coordinator for Antipode Expedition, was chief scientist for this particular leg of expedition. Noel C. Ferris, master of* Melville, *is in center, with Geoffrey C. Clark, second mate, at far right.*

Antipode Expedition

Edward Brinton, Dr. Charles S. Cox, Dr. Thomas W. Davies, Dr. Jerry L. Matthews, Dr. John A. McGowan, David A. Muus, and Joseph L. Reid.

Plankton-Current Correlations

After the vessel departed San Diego for Wellington, New Zealand, via Papeete, Tahiti, she sailed southward for 3,000 nm as Dr. Brinton and his colleagues investigated the plankton populations within and bordering the equatorial currents. In these operations, multiple nets were towed at as many as ten depths at once. This technique, developed at Scripps, gives reliable estimates of the vertical distribution of the plankton.

In general, the scientists sought to learn about the relationships of oceanic plants and animals to the currents in the equatorial belt and to find out why the equatorial currents are fertile whereas the currents to the south are extremely poor in marine life.

Studies by Dr. Elizabeth Venrick during the expedition showed that the southern part of the tropical belt was not as barren as it first appeared to be. The plant plankton, upon which the marine food chain depends, was concentrated not in the surface layer as would be expected but, instead, at more than 152 m.

Dr. Brinton made another observation, "A broad east-west belt of water south of the equator was found to contain types of plankton that are known, on the basis of earlier expeditions, to come from the far western part of the ocean. This seems to contradict the notion that currents typically flow toward the west in this particular zone, at 10 to 20 degrees South. The ship proceeded westward, making two more transects of this anomalous zone and establishing that its characteristic fauna does extend continuously east-west."

Water Circulation

The *Thomas Washington* logged 8,500 nm between New Zealand and Antarctica during water circulation studies carried out by measuring water characteristics and velocity.

"The coldest, densest water in the ocean—about −2° C—is found in the Ross Sea," Reid, chief scientist for these Antarctic investigations, reported.

During these studies, measurements of temperature, salinity, oxygen, and nutrients were made from the surface to the ocean floor at 60 positions.

These measurements were used to trace the outflow of water from the Ross Sea into the open Antarctic Ocean for estimating the contribution of the Ross Sea water to the heat budget of the ocean-atmosphere system. The warmer waters enter the ice-covered Ross Sea from the open Antarctic and are cooled. They then flow back out again near the bottom, rather than at the surface.

Seventeen free-vehicle instrument drops were made and all recovered. Five of these were drops of baited cameras taking photographs of fish. The other drops were current meters designed to measure the velocity near the ocean bottom.

Zooplankton net hauls were made at 20 stations, and at three locations samples were taken for determination of tritium, carbon dioxide, oxygen isotopes, alkalinity, radium, and various gases.

Plankton Communities

During March, 1971, Dr. McGowan and his colleagues continued earlier studies of the structure of planktonic communities in the vast south central gyre of the Pacific, approximately 805 km south of Papeete. They investigated grazing habits of herbivores, the manner in which marine plants take up nutrients, and the competition among marine predators and among their prey.

In a different oceanic region such as the California Current, the immigration into and emigration out of the Current by marine organisms is an important factor. This inward-outward movement is at a minimum in a relatively stable area like the gyre, a factor making it easier for scientists to study the interactions between competitors and between predators and prey.

In the central North Pacific Gyre, similar studies of planktonic communities were conducted by Dr. McGowan on the last leg of the expedition, between Honolulu and San Diego. In addition, the scientists collected a variety of marine animals—fish, squid, plankton—to analyze their body content of lead, mercury, DDT, PCB, and other pollutants.

Oceanic Mixing Processes

Dr. Cox and his colleagues were also aboard during the last leg of Aries. They measured the variation of salinity and temperature at various stations along the track of the ship. Such measurements were taken on a scale as small as an inch and through the greater part of the ocean depths.

These small-scale measurements form the "imprint" of the mixing processes taking place in the ocean; that is, they are a measurement of the way that frictional stresses are transmitted through the ocean and the mechanisms by which the deeper waters are mixed upward into surface layers, bringing along nutrients to the top. Measuring such mixing processes provides a method for determining how carbon dioxide and other elements are diffused through the ocean.

Pacific Equatorial Undercurrent

Dr. Taft focused investigations on the Equatorial Undercurrent in the central Pacific. The Equatorial Undercurrent is a strong (up to 3.5 kn) eastward-flowing subsurface current which is found in a narrow band 403 km wide along the equator in all oceans.

A study of the distribution of temperature and salinity in the vicinity of Jarvis Island was carried out. Jarvis Island lies 65 km south of the equator at 160° W and is located in the strong flow of the Undercurrent.

The Jarvis Island survey provided a description of the effect

R/V *Melville*

of the island on the flow of the Undercurrent and the change in water properties from one side of the island to the other. The character of the mixing processes around the island will be deduced from these data. It is possible that higher productivity sometimes observed behind islands may be accounted for by increased mixing of the waters produced by the islands' disturbance of the large-scale flow. These measurements will clarify these mixing processes.

At 150°W, where the Pacific Equatorial Undercurrent was discovered in 1952, moorings with current meters were installed which were then picked up by R/V *George Melville* in September. These moorings, which were in place for five months, are providing a long record of velocity variation in the Undercurrent and the deep water underneath the Undercurrent. Measurements from the ship at the time the moorings were put in showed the Undercurrent at 100 m had a speed of 3.5 kn, and the Undercurrent extended all the way up to the surface. The unusual "surfacing" of the Undercurent is thought to be due to the decreased strength of the Trade Winds during this month.

The current measurements at the equator were a joint Massachusetts Institute of Technology-Woods Hole Oceanographic Institution-Harvard-Scripps Institution research program. A related program to measure the distribution of noble gas concentrations in equatorial waters was carried out by Dr. Rudolf H. Bieri of Scripps.

Kuroshio, A Deep Boundary Current

Dr. Taft also studied the Kuroshio, a deep boundary current that flows south of Japan and is analogous to the Gulf Stream in the Atlantic Ocean. The behavior of the Kuroshio is unique in that occasionally there are very large shifts of the current away from the coast that persist for many years. On this leg an intensive study of the path of the Kuroshio was made to determine the detailed behavior of the current as it flowed along the coast of Japan.

Temperature measurements down to 450 m were used to fix the position of the current. These path-position data, in conjunction with velocity measurements near the sea bottom, will be used to determine the factors that control the position of the current. The shipboard measurements indicated that the Kuroshio extends all of the way to the sea bottom (a vertical distance of more than 4,000 m).

Ultimately it is hoped that an explanation as to why the position of the Kuroshio can change so drastically will be forthcoming.

Volcanic Seamounts

A vast outpouring of volcanic matter on the sea floor 140 million years ago in a 7,770,008-sq km area between the Hawaiian Islands and Japan was indicated in geological studies of the submarine Mid-Pacific Mountains.

Dr. Matthews, chief scientist aboard the *Thomas Washington* between Honolulu and Tokyo, said approximately 40 dredging operations on nearly 20 seamounts revealed coral reefs atop submerged volcanic peaks.

"By studying fossil materials taken from the reefs, we were able to date the reefs and get an idea about when the peaks became submerged," he said. "Knowing the age of the reefs puts a restriction on the age of the crust of the sea floor, for the reefs are younger than the volcanic seamounts on which they rest. Throughout the large area we crossed, we found the reefs, or atolls, to be about the same age. We believe this to be an indication of a vast outpouring of lava on the sea floor at the same time throughout the area."

Dr. Matthews said he and his colleagues were impressed when one dredge haul on a seamount 1,463 m below the surface brought up round, smooth cobbles up to eight inches in diameter.

Although the seamount is now submerged, finding the cobbles led the scientists to conclude that the volcanic peak at one time, millions of years ago, stood as a land mass above the surface of the ocean.

Guyot Discovered

In late July and all of August, 1971, the *Thomas Washington* logged almost 10,000 nm of survey track from Yokohama to Honolulu in conducting geological and geophysical investigations in the region of the southern Emperor Seamounts and the Hess Rise.

"The most spectacular discovery during this leg of Aries was the charting, in the southern Emperors, of one of the largest guyots so far discovered in the world ocean," Dr. Davies, the leg's chief scientist, reported.

"This guyot lies 1,129 km northwest of Midway Island and had previously been shown on charts as several shallow soundings. But survey work by the ship revealed a single large guyot 113 km long and 73 km across, rising 4,576 m from the surrounding sea floor to within 457 m of the surface.

"Dredging on the top of this guyot produced samples of coral reef debris that proved this had at one time been a coral atoll or perhaps an island similar to Kwajalein Atoll in the Marshall Islands."

Buoy Servicing

In early September, under the direction of Muus, the *Thomas Washington* recovered one buoy and serviced three others located approximately 1,000 nm north of the Hawaiian Islands. These unmanned, moored buoys were placed as part of Scripps's North Pacific Study, an investigation of air-sea interaction.

On the same two-week leg, Dr. Russ E. Davis ran tests on a newly developed instrument designed to be towed behind a vessel to measure the height of ocean waves.

The final leg of Aries from Honolulu to San Diego was devoted to biological and physical oceanographic studies conducted under co-chief scientists Drs. McGowan and Cox.

Antarctic Expedition. After logging some 28,700 nm during 11 months of biological research in such contrasting environments as Antarctica and Eniwetok Atoll, Scripps Institution's research vessel *Alpha Helix* returned to San Diego on July 23, 1971. This experimental biological laboratory, a national facility sponsored by the National Science Foundation (NSF), served as home base for 65 scientists from 21 U. S. and four foreign institutions during six research programs. The vessel left on the expedition August 14, 1970.

The six investigative teams participated in varying studies as those pertaining to the venemous sea snake; the starfish and east Pacific reef communities; Antarctica fishes, mammals, and birds; fish that live at great ocean depths; and the metabolism and growth of the coral reefs of Eniwetok Atoll.

Co-principal investigators for the NSF-funded expedition were Drs. Andrew A. Benson and Walter F. Garey.

Capts. Terry Hansen, Robert B. Haines, and Lawrence E. Davis divided the master's duties aboard ship. The ship's track took the *Alpha Helix* down the western coast of North and Central America, to the Galápagos Islands, on to Palmer Island, Antarctica, westward to Eniwetok Atoll in the Marshall Islands, and back to San Diego via Honolulu.

Seldom do Scripps research vessels tie up at far-off ports at the same time. This rendezvous in Adak, Alaska, occurred in July, 1970, during* Melville's *(foreground) stopover on Antipode Expedition and the port call by* Thomas Washington *during Seven-Tow Expedition.

Phil Rapp

Dr. Garey provided the following resumé of expedition results based on field reports from, and conversations with, scientists involved in the studies:

Sea Snake Investigations

Dr. William Dunson of Pennsylvania State University headed a team of workers who carried out physiological and ecological studies of the highly venemous sea snakes (Pelamis) off western Central America. At that time, relatively little was known about the biology of this most successful group of marine reptiles, and many discoveries resulted from the studies of the tolerance of the sea snake to changing temperature, salinity, and the functioning of its salt gland. Oceanographic factors which limit the movements of the snakes along the western coasts and their population dynamics were also examined.

The sea snake appears to be a passive creature that floats in drift lines where the "blue" Pacific water meets the "green" coastal water. Here, outside the heavy surf, the sea snake presents no particular menace to swimmers along the Pacific coasts. The construction of a proposed, sea-level canal in Central America, however, could provide access into the Atlantic for the sea snake where it could concentrate along the beaches, endangering swimmers.

Dr. Dunson's group found that, although the sea snake thrives in warm water, it is quickly killed by slightly raising the water temperature to 34° C. They suggest, by heating a section of water in the proposed canal to 35-38° C., creating a thermal barrier that would prevent the movements of sea snakes and other temperature-sensitive organisms between the oceans.

Lack of Reef Development

A research program under Dr. William A. Newman was concerned with reefs on the Pacific and the Caribbean coasts of Panama and with the status of the coral-eating starfish, *Acanthaster,* on the Pacific side. The results from this study suggest that *Acanthaster* is not a current problem, and also provide an explanation for the lack of any significant reef development there.

Seasonal upwellings of the nutrient-rich deeper waters in the Gulf of Panama and the Gulf of Chiriqui on the Pacific side support high biological productivity. It was pointed out, however, that large tidal ranges to seven meters, dilute surface waters, high turbidity, and a shallow thermocline constitute an environment unfavorable to coral growth. The corals found here mostly form thin veneers over volcanic rock, with their upper limit growth being below the level of the lower low tides.

Opposite conditions exist near the Gulf of San Blas on the Caribbean coast, where a moderate tidal range of one meter occurs, fresh water dilution is slight, and warm waters extend well below the depth limit for corals. Here the coral reefs flourish.

Submarine terraces on both the Pacific and Caribbean sides indicate generally comparable histories related to the sea level since the Pleistocene period. A sea-surface terrace on the Caribbean coast suggests, however, a small elevation or a recent higher stand of the sea of a meter or more.

Studies of Deep-Ocean Fishes

In the waters off the Galápagos Islands, Dr. Peter Hochachka, (University of British Columbia) as chief scientist, directed a team of scientists who investigated the effects of temperature and pressure on enzymes and muscle proteins of fishes found at different depths.

A free-vehicle system, incorporating a vertical set line and elliptical traps, successfully caught fish at depths of greater than 1,609 m and delivered them to the surface in a condition suitable for experimentation. Only then could their almost totally unknown biochemistry and physiology be investigated. Mid-water organisms were collected by trawling.

Director Nierenberg, left, presents plaque indicating worldwide tracks of Scripps research vessels over 22-year span to P. G. Trapani upon his retirement as marine superintendent, as Mrs. Trapani watches. Occasion took form of barbecue at Nimitz Marine Facility.

Nelson Fuller

It was found that enzyme reaction rates were variously affected by changes in pressure. Some were activated, others were inactivated, and still others were uninfluenced by pressure changes. Certain enzymes which were inactivated by a decrease in the surrounding pressure again became active when the pressure was re-established. The enzymes of mid-water organisms proved to be far more pressure-resistant than those from benthic organisms.

The preparations from the muscles of the benthic fish revealed that the subunit composition of myosin, a contractile protein, is of a simpler make-up than that found in mammalian muscles. This simpler structure is possibly indicative of more primitive interactions of the thin and thick filaments in the muscles of these deep-sea fish.

An additional finding concerned the production and storage of cholesterol in the benthic fishes. The liver constitutes the principal site of cholesterol manufacture in animals, but the swimbladder gas glands in the deep-sea fishes studied contained ten times more cholesterol than the liver tissues.

Antarctic Vertebrates

Fifteen scientists headed by Dr. Edvard A. Hemmingsen studied various physiological problems, particularly those of thermoregulation and cardiovascular function, of representative vertebrates at Palmer Station, Antarctica.

The group reported that the large webbed feet of the giant petrel served as important heat exchangers with the environment, and measurements of blood flow to the web revealed that the maximum blood flows through the skin of the web

Scientists aboard R/V Melville *during Antipode Expedition break up manganese nodules dredged in the Indian Ocean. Scientifically interesting rocks are often coated with manganese.*

were greater than those previously reported for any animal. Proof of vasodilator innervation to the skin was obtained from these experiments.

The blood of the young Adelie penguins was found to have a lower affinity for oxygen than that of adults. This observation is contrary to those obtained in all similar studies of other vertebrates. This feature can be considered a specialized adaptation to the habitual diving of the adult penguin.

A study of three species of penguins and several other Antarctic birds showed that their heat loss to the environment, resulting from respiratory gas exchange, is lessened by a counter-current heat exchange in the nasal passages. A unique active control of this heat-loss mechanism was discovered.

Thermoregulatory responses of resting, swimming, and treadmill-walking penguins were studied to achieve a better understanding of the central nervous system regulation of internal body temperature in these animals. Similar experiments were conducted with two species of fishes.

The team utilized a pressure chamber to simulate deep dives, up to 70 m for penguins and blue-eyed shags. These birds exhibited little lung collapse and seemed poorly protected from the build-up of nitrogen pressures during the dive. None of the species showed a well-developed, breath-hold diving ability, and in most respects they did less well than marine mammals.

Respiratory studies were conducted on ice fish, which lack the oxygen-binding pigment, hemoglobin, in their blood. Their basal metabolic rate was found to be somewhat lower than that of other fishes. While experiencing the stresses of exercise or a reduced oxygen supply, they selectively increase their water ventilation rather than blood circulation. It was discovered that they compensate for a lack of hemoglobin by a blood volume and cardiac output much larger than normally found.

Coral Reef Metabolism

Chief scientist Dr. Robert Johannes (University of Georgia) led a research effort at Eniwetok Atoll that was centered about metabolic activities of coral reef communities. Luxuriant reef communities grow and maintain themselves despite the impoverished water washing over them. Intriguing questions are posed by this relationship.

Studies at Eniwetok showed that the metabolic processes of the reef organisms are not limited by available nitrogen, since a surprising and extremely high nitrogen-fixing capability was exhibited by a reef community. The natural process of nitrogen-fixing involves the conversion of atmospheric nitrogen into nitrogen compounds, with the organisms most widely known for this conversion being the legumes (*i. e.,* alfalfa and clover). Measurements made in the Eniwetok research indicate that the nitrogen-fixing per area of reef surface was proceeding at a rate equivalent to that in an alfalfa field. This production balances the export of nitrogen from the reef in other forms. The nitrogen-fixing ability of the reef is of great importance, as the first major products of this fixation are amino acids, essential components of protein molecules.

The cycling of phosphorous was found to be another example of the extraordinary efficiency exhibited by reefs in areas where nutrient concentrations are low. Plants and animals of the reef live in intimate relationship with each other. The inorganic phosphorous excreted by animals, that would otherwise be lost to the water, is taken up by plants and converted into organic compounds that are excreted back into the animal. The reef cycling of phosphorous thus prevents losses of this nutrient that would occur if animals and plants were spatially separated.

Particulate organic carbon was found to increase three-fold as sea water flowed across the reef into the lagoon. This indicates that the reef community not only supports itself but also organisms downstream on this exported organic matter.

Experiments were conducted on the effect of oil slicks on coral exposed to the air at low tide. Since the tissues died where oil adhered, but not elsewhere on the colony, the scientists felt that oil spills present a significant danger to corals in areas of large tidal fluctuations.

Four holes were blasted in the reef in order to understand the geological history underlying the living reef community. Three of these sites revealed possibly four different species of sclerosponges. Until a year earlier, the group of organisms represented by these sponges was considered to have become extinct during the Cretaceous period. Previous to that period they were important reef builders.

Honolulu-to-San Diego Work

The Honolulu-to-San Diego leg of the expedition was directed by Bruce Robison from Stanford University. The principal study concerned the ecology and distribution of mid-water fishes in the eastern North Pacific.

Organisms collected in trawl operations were utilized for the following research studies:

Chemical and photometric assays were performed on light-producing organs of fishes.

The concentration of DDT and heavy metals was measured in plankton and neuston, animals that dwell at the air-sea interface.

DDT concentrations were also determined in surface and sub-surface planktonic crustaceans.

Asst. Dir. J. D. Frautschy points toward cliffs north of Scripps Pier for visitors from Colombia, who conferred with Scripps scientists about problems related to oceanography and marine resources in their country. From left: Joaquin Fonseca, Acting Undersecretary for Internal Organization Affairs; Capt. Juan Pablo Rairan, oceanographer, Colombia Oceanic Commission; Dr. Gabriel de J. Acevedo, marine biologist, Division of Natural Resources, National Planning Department; and Maj. Julio Londono, of the Foreign Office, Boundary Section.

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 was chaired by Dr. Edward L. Winterer, professor of geology, who has been succeeded by Dr. Joseph L. Curray, professor of geology. Dr. Richard H. Rosenblatt, associate professor of marine biology, was vice-chairman. He has been succeeded by Dr. Michael M. Mullin, associate professor of marine biology.

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.

Graduate student Michael A. Barnett separates catch of deep-water organisms taken with mid-water trawl during Aries Expedition. Angler fish (in hand) and a prawn, twice normal size, will be preserved in jars, labeled, and included in Scripps's permanent collection.

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

tal, and theoretical methods of the basic sciences to the understanding of the solid earth, ocean, atmosphere, and the solar system. Principal sub-programs 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 island, abyssal plains, and dep-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.

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 1971, 41 new students began their graduate studies. Of these, 6 were in marine biology, 2 in geophysics, 8 in biological oceanography, 2 in physical oceanography, 5 in marine chemistry, 10 in applied ocean sciences, and 8 in geological sciences. Thirteen were California residents, 23 were from out-of-state, and 5 were from foreign countries. Enrollment at the start of the 1971 school year totaled 164 students.

During the Academic Year 1971-72, 14 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 Barbara B. Hemmingsen, James D. Irish, and John P. Greenhouse are indicative of the varied subjects chosen by candidates for the doctoral degree.

Dr. Hemmingsen's dissertation is entitled "A Mono-silicic Acid Stimulated Adenosinetriphosphate from Protoplasts of the Apochlorotic Diatom *Nitzschia alba*." The abstract of her dissertation follows:

> The diatom cell wall consists of amorphous silica surrounded by a complex organic matrix. The silica is presumably formed from mono-silicic acid since diatoms require this compound for growth and division. There is evidence that metabolic energy, probably in the form of ATP, is required for mono-silicic acid uptake, and that the uptake proceeds against a concentration gradient. In other biological systems, *e.g.*, red blood cells, frog gastric mucosa, and various plants, the acting transport of a substance has been linked in some manner with a membrane-bound ATPase, whose activity is stimulated by the same substance transported. Thus, it is of interest to examine diatoms for a membrane-bound ATPase which is stimulated by mono-silicic acid.
>
> The marine, apochlorotic diatom, *Nitzschia alba* Lewin and Lewin, was used in this study. The nutritional characteristics and optimum conditions for its cultivation in defined medium are described in Appendix II [of the dissertation]. This diatom will, under certain conditions, form protoplasts. Thus, the preparation of membranous material is not complicated by the necessity of removing the rigid cell wall. Also, since this diatom lacks chloroplasts, the preparation of membranous material is greatly simplified.
>
> Protoplast formation was followed by quantitative visual observations; conditions were determined for maximum protoplast formation in the shortest possible time. Protoplasts appear when exponentially growing cells are placed in a calcium and/or magnesium deficient nutrient medium.
>
> Small membranous fragments in vesicular form were obtained (at 41,000 x g) from osmotically lysed protoplasts after a low speed (100 x g) centrifugation had removed cell walls and unlysed protoplasts, and a higher speed centrifugation (10,800 x g) had removed the mitochondria. Large membranous fragments in a vesicular form resulted from a low-speed centrigation (150 x g) of the protoplast lysate.
>
> The activity of a Mg^{2+}–dependent ATPase associated with the various fractions was measured at pH 8.2 in Tris-HCl buffer at 30°C. The inorganic phosphate liberated was measured, after removal of the nucleotides by absorption on activated charcoal. ADP, AMP and β–glycerolphosphate were not hydrolyzed.
>
> Addition of 0.1 mM mono-silicic acid increases the activity of the ATPase of the large and the small membrane fragments, but not that of the mitochondria. The increase in activity is proportional to the concentration of mono-silicic acid up to about 0.2 mM; there is a slight increase in activity at higher concentrations. Germanic acid, a chemical which specifically and competitively inhibits the growth of diatoms and possibly the uptake of mono-silicic acid, stimulates the activity of the ATPase at about 0.5 mM and inhibits at 2.0 mM or higher.
>
> The rate of mono-silicic acid uptake by exponentially growing cells is thought to be about 12 μmoles/10^8 cells/hour. If it is assumed that one μmole of ATP is required for each μmole of mono-silicic acid taken up, and if the total activity of the ATPase in the presence of silicic acid is related to 10^8 cells, then up to 30 percent of the possible activity is present in both the high-speed and low-speed membrane fractions.
>
> On the basis of these results, it is concluded that there is a membrane-bound mono-silicic acid stimulated ATPase in the diatom *N. alba*. It is possible that this enzyme is somehow involved in the uptake of mono-silicic acid. The effect which germanic acid has on its activity lends support to this hypothesis.

Dr. Irish's dissertation is entitled "Australian-Antarctic Tides." He is now a faculty member on the staff of the Department of Oceanography, University of Washington, at Seattle. The abstract of his dissertation follows:

To measure the Australian-Antarctic tides, three deep-sea instrument capsules were dropped for one month between Australia and Antarctica along longitude 132°E. Records of temperature, pressure, and current velocity were obtained. From the temperature-pressure records obtained during the capsule descents, temperature minima were discovered just above the sea floor for the two northern capsules. Below these minima, the temperature increased adiabatically. The southernmost capsule showed a relative minimum just below the surface, then a temperature decrease to the bottom.

The velocity records were dominated by 3 cm/sec inertial currents while tidal currents were less than 1 cm/sec. The mean flow showed great variability, with changes as great as 6 cm/sec (reversing the direction of flow) over a period of 10 days.

The capsule pressure records were compared with the Antarctic and Australian coastal records. The observed diurnal tide can be interpreted as a Kelvin wave moving westward along the Antarctic coast, and a slightly smaller one traveling eastward along the south coast of Australia. The amplitude and phase vary smoothly from Australia to Antarctica. The semidiurnal tide is not well fit by a Kelvin model. The velocity is too great along the Australian coast, and too small along the Antarctic coast. The phase is smooth from Antarctica to the northernmost capsule, then changes abruptly at Australia, perhaps indicating a dissipative boundary with respect to the semidiurnal tide.

Dr. Greenhouse's dissertation is entitled "Geomagnetic Time Variations on the Sea Floor off Southern California." Dr. Greenhouse is now a member of the faculty in the Department of Earth Sciences, University of Waterloo, Waterloo, Ontario, Canada. The abstract of his dissertation follows:

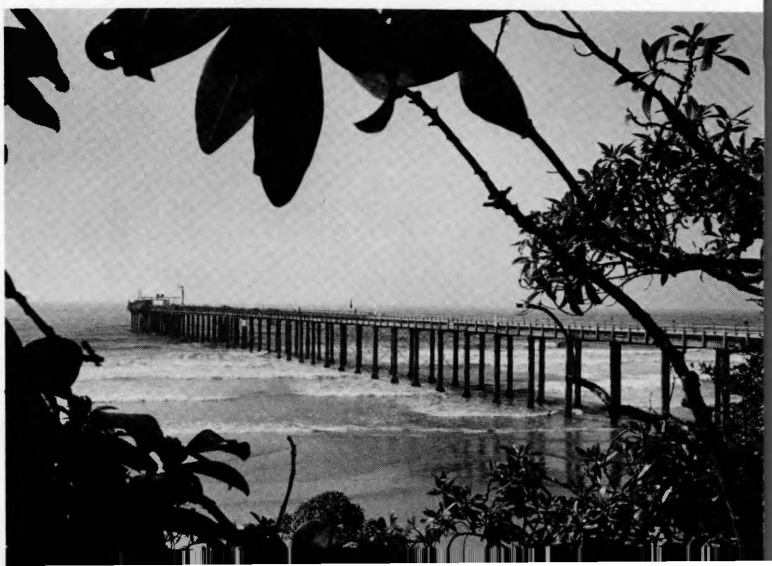
The discovery in recent years that the terrestrial heat flow through oceanic and continental regions is comparable, despite the known depletion of radioactive elements in the oceanic crust relative to the continental crust, suggests that large, lateral temperature gradients should exist where these two regimes meet. The electrical conductivity of silicate rocks is known to be strongly dependent on temperature, so that the ocean-continent transition may also be characterized by a lateral variation in the electrical conductivity of the upper mantle. The "geomagnetic coast effect" phenomenon, basically an enhancement of the vertical geomagnetic variation field at coastal stations over a wide range of frequencies, has sometimes been cited as evidence for this deep conductivity anomaly.

In the present work, we examine the data from 12 three-component fluxgate magnetometers placed on the sea floor off southern California with the object of determining the relationship of magnetic variation anomalies to lateral variations in the suboceanic conductivity structure. Most of these stations are positioned near a cross section normal to the coast and through La Jolla and the wide southern California continental borderland, but one instrument recorded on a cross section through Cambria, north of Point Conception, on which measurements of oceanic electric fields have been made previously by Cox *et al.* (1970).

Within the accuracy of our data and the ability of the modeling techniques used to represent the physical processes involved, the behavior of the vertical and horizontal geomagnetic variation fields along the borderland cross section, from one cycle per day to two cycles per hour, appears to be primarily related to variations in the depth of the ocean layer. In particular, the data do not appear to indicate the existence of a very large, sharp lateral variation in the conductivity beneath the borderland, as has been proposed for the upper mantle beneath the continental slope off Cambria by Cox *et al.* The data from our single station on the Cambria cross section also do not appear consistent with the presence of such a feature. The borderland data may, however, detect a smaller or less abrupt conductivity contrast beneath the transition. A comparison of the vertical field data with computed models suggests that isoconducting surfaces beneath the coast rise gradually beneath the outer borderland, attenuating the anomalies due to the strong bathymetric contrast at the borderland edge. The concept of the borderland as a tectonically active region relative to the adjacent Peninsular Range province is consistent with heat-flow measurements and current theories of the region's Cenozoic history.

The present data are best suited to detecting lateral variations in the conductivity and estimates of the absolute conductivity structure are necessarily crude. The diurnal harmonic amplitudes in the vertical field at two stations 250 and 350 km beyond the borderland edge are attenuated very little if at all relative to those measured simultaneously at a continental station (Tucson) at roughly the same latitude. Again this is contrary to what one would expect if very high conductivities rise to shallow depths beneath the ocean relative to the adjacent continent, but it may reflect lateral inhomogeneity in the suboceanic conductivity in this region. The results of a simulated magnetotelluric sounding made using the horizontal field attenuation at four distant sea-floor stations are consistent with a one-dimensional suboceanic model having moderately higher conductivities, primarily in the upper 100 km relative to the adjacent continental block. The maximum conductivities within the lithosphere for this model are again significantly lower than those predicted by Cox *et al.*

Nelson Fuller



RESEARCH ACTIVITIES

Advanced Ocean Engineering Laboratory

Presently in its fourth year of conducting advanced engineering research in several diverse fields, the Advanced Ocean Engineering Laboratory was established in the Scripps Director's Office under contract with the Office of Naval Research and with financial support of the Advanced Research Projects Agency (ARPA), a Washington, D.C., government agency.

Fiscal year 1972 witnessed continued support of a contract in advanced oceanographic engineering comprised of (1A) Stable Floating Platform (Dr. Fred Spiess, principal investigator); (1B) Benthic Array (Drs. Walter H. Munk and William A. Prothero, Jr., co-principal investigators); (1C) Nearshore Engineering (Dr. Douglas L. Inman, principal investigator); (1D) Wave Breaking in Deep Water (Drs. W. G. Van Dorn and R. E. Davis, co-principal investigators); and (1E) Electromagnetic Roughness of the Ocean Surface (Drs. W. A. Nierenberg and Walter H. Munk, co-principal investigators), a joint program with Stanford University under the direction of Dr. Allen M. Peterson.

Also, during the last quarter of the year, a contract was received to study the interaction between internal and surface waves and their relationship with other natural phenomena in the air/sea interface. This Internal/Surface Wave Interaction Program consists of (2A) Microprocesses (Dr. Charles S. Cox, principal investigator); (2B) Mid-Water Thermal Structure (Drs. Walter H. Munk and Frank Snodgrass, co-principal investigators); (2C) Measurements of Surface Internal Wave Interaction (Dr. Carl H. Gibson, principal investigator), and (2D) Atmospheric Measurements (Dr. Charles Van Atta, principal investigator).

(1A) The Stable Floating Platform Program was established to support ocean research by designing, building, and demonstrating the feasibility of large, FLIP-like, stable floating platforms stationed at sea. Late in 1971, however, ARPA changed its objectives from research support to technology relevant to very large platforms (multi-purpose "floating islands"). Under this new concept, many modules would be connected, decked over, and constructed upon, thereby providing a wide range of possible uses, such as ship's port, drilling operations, nuclear power plants, airports located away from populated areas, fishing and processing stations and other possibilities.

(1B) A deep-water instrument capsule, known as Benthic Array, is a fully self-supporting adaptation for deep-ocean utilization of a high-performance, quartz vertical accelerometer developed by Drs. Robert D. Moore and Barry Block at the La Jolla Laboratories of the University's Institute of Geophysics and Planetary Physics. This instrument package will provide increased technical knowledge for a better understanding of the earth. Work on oceanic structure, seismicity, ocean earthquake mechanisms, and lateral variations in the mantle will be aided by these measurements. Several encouraging sea tests having been made during 1972, additional tests will be carried out with ONR funding.

(1C) Studies in Advanced Nearshore Engineering have been directed toward understanding and controlling the movement of sand in harbors and in nearshore waters. Devices called "phase dependent roughness elements" have been developed for such possible uses as prevention of beach erosion, keeping harbor entrances free from build up, and the directing of sand toward pumping stations.

(1D) An anticipated two-year program in Wave Breaking in Deep Water was begun in January, 1972. The program's objective is to complete a set of prediction curves, supplementary to those now available for predicting sea state, whereby engineers concerned with the adverse effect of wave conditions can determine the statistical probability of wave breaking and the associated spectra of velocities, acceleration, and impact forces. First-year efforts will be devoted to laboratory and field investigation of the factors controlling breaking waves in deep water (such as those that occur in the open sea under storm conditions). During the second year, laboratory results will be supplemented, where necessary, by field measurements in the open sea, in order to generalize the former to prototype conditions.

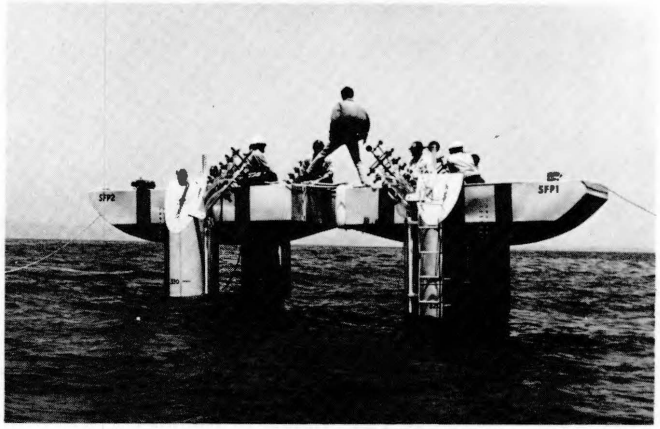
(1E) The Electromagnetic Roughness of the Ocean Surface Program (radar studies) is being conducted jointly by two groups, one at Stanford University, and one at Scripps. The work uses HF radio waves scattered from the ocean surface to measure the statistical properties of this surface, particularly the ocean wave directional spectrum. The major proportion of work during the year involved experiments using LORAN A radio signals to measure the directional spectrum of ocean waves, 30 MHz radio waves backscattered from the ocean to measure the non-linear scatter of radio waves from the ocean, and 30 MHz radio waves backscattered from the sea to measure the importance of the second-order scatter of radio waves.

The Internal/Surface Wave Interaction Program is being undertaken as a cooperative effort by Scripps and 11 other government/commercial/University contractors. Scripps's individual projects are progressing under the direction of five principal investigators. Individual projects and cognizant prin-

Wayward beach hikers are given clear indication of men at work during investigations by Shore Processes Laboratory staff. Sign says: "Wave Study Instruments in Surf."

Eighth-scale model of Stable Floating Platform shows two modules in a vertical, coupled attitude during ocean tests off Coronado Strand conducted by Advanced Ocean Engineering Laboratory technicians.

Advanced Ocean Engineering Laboratory



cipal investigators are noted above, 2A-2D. In these diverse but related investigations, Scripps personnel will explore, among other areas, the structure and dynamics of temperature and salinity in the ocean, the history of thermal structure within several 100 m vertical segments of the water column, the effects of internal waves on surface wave patterns, and the near-surface atmospheric layer (wind speed, wind direction, and humidity). As planned, there will be oceanic and laboratory measurements, in addition to theoretical work. A scientific trip is scheduled to be conducted aboard FLIP during November, 1972, and several more tentatively in 1973. AOEL is anticipating a three-to-five-year program effort.

Center for Marine Affairs

In July, 1970, with funds from a Ford Foundation grant, the Center for Marine Affairs (CMA), was established, with Dr. Warren S. Wooster as director, to bring together interdisciplinary research teams, including specialists in the social sciences, law, government, and other fields outside the natural sciences, to investigate marine problems affecting the entire scientific community.

During its initial years, CMA conducted experimental studies in two areas—the conditions for freedom of oceanic research, and marine science and international pollution policy. For these studies, three or four visiting fellows were appointed for eight- or nine-month periods. Other participants, including those from Federal agencies, joined for shorter periods. In each case, a month or so before the end of the study, visiting and local experts joined in workshop discussions of the study topic and resulting papers. In the light of these discussions, the papers were then revised for publication.

In the Center's first major study, an interdisciplinary team explored the problems that can arise when oceanic research is to be conducted in marine or submarine areas falling under the jurisdiction of foreign countries. Topics considered included the institutional arrangements for facilitating access to such regions, the legal framework within which coastal state jurisdiction is exercised, the nature of restrictions that have been applied, and the requirements and attitudes of both scientists and coastal states.

While restrictions on access were found to be neither so frequent nor serious as many had feared, nevertheless they appear to be manifestations of a process which could make access for research in extensive areas of the oceans more difficult in the future. That process consists of the growing "politicization" of marine science. As the volume of long-distance research has grown, more formalized procedures have been instituted by states for processing access requests from foreign researchers. Formalized procedures have, in turn, rendered requests susceptible to bureaucratic delay as well as to the ups and downs that characterize political relations between states.

Preparing for deep-ocean testing of benthic array, pictured aboard R/P ORB, is William A. Prothero, Jr., of Advanced Ocean Engineering Laboratory.

Advanced Ocean Engineering Laboratory

In 1974, an international Conference on the Law of the Sea is scheduled to open in Santiago, Chile. Called by the United Nations General Assembly, it will attempt to rewrite and add to much of the present law. A number of important and difficult issues are to be dealt with, including scientific research. Developing countries, which by their numbers will be the dominant influence at the Conference, seem determined to have a greater share of the benefits, including knowledge, to be derived from the oceans. It may well be that the price of access to foreign waters in coming years will be a more active role in aiding local development.

The second Center study began in early 1972 and was concerned with communication, or lack thereof, between scientists and policy makers in the area of marine pollution. An anthropologist surveyed the values and attitudes of members of both categories, and political scientists examined cases of science and public policy, such as the United Nations Conference on Human Environment, considering alternative scenarios for the future ocean regime. These studies are currently being prepared for publication.

At the end of its second year, CMA was transferred to the administration of the University's Institute of Marine Resources, directed by Professor John D. Isaacs. CMA's current director is Dr. Gerald L. Wick. The plans are to continue studies in social, legal, economic, and political implications of marine pollution and marine resource management, with special emphasis on problems arising from environmental modification.

A mid-January, 1972, discussion at Center for Marine Affairs included, left to right, Judith Teller-Kildow; Jacqueline A. Weyers, secretary; Francis Latapie, science attaché in the French consulate, San Francisco; Michael L. Redfield; Dr. Michael J. Brenner; Dr. Herman T. Franssen; Dr. Warren S. Wooster, director; and Dr. Michael D. Bradley.

Deep Sea Drilling Project

The Deep Sea Drilling Project has successfully completed four years of drilling and coring operations in the deep ocean basins. During the Fiscal Year 1972, all contractual matters were taken care of for an extension of the Project for an additional three years. The Project is now scheduled for operating until August, 1975, a total of seven years.

The Deep Sea Drilling Project has as its primary scientific objective the investigation of the age and history of development of the ocean basins. Much of the Project's emphasis has been placed on investigation of the processes of sea-floor spreading and continental drift. The floor of the ocean spreads from more or less centrally located rise-rift systems, found in each of the major oceans and connecting together to form a globe-girdling system. New oceanic crust forms at these loci and spreads slowly aside, to be consumed as it plunges back into the upper mantle of the Earth along the deep-sea trench systems that largely outline the very active perimeter of the Pacific Ocean. This is an idea which has developed rapidly from its first mention in the early 1960s, to its serious consideration, based on paleomagnetic studies, in the mid-1960s, to the position it now holds as the comprehensive model for the behavior of the outer part of the Earth and the cornerstone of modern geological thinking, based on direct testing, by sampling, from the Deep Sea Drilling Project in the late 1960s.

The early work by the Project was originally focused on the Atlantic Ocean; since that time it has been extended to include the Pacific and Indian Oceans; the Mediterranean, Red, and Caribbean Seas; and the Gulf of Mexico.

In addition to studies of major structural elements of the oceanic areas, investigations of recovered core material are yielding exceedingly important knowledge and interpretation in many related fields, such as geophysics, organic and inorganic geochemistry, paleo-oceanography, paleoclimatology, glacial geology, biological evolution, sedimentology, biostratigraphy, volcanology, and mineralogy.

The samples are recovered by means of a specially designed drilling vessel named the D/V *Glomar Challenger,* after the famous HMS *Challenger* which sailed on the first major oceanographic expedition, out of Portsmouth, England, in 1872. D/V *Glomar Challenger* is 122 m long, has a one-million-pound capacity drilling derrick amidship, and can position in water depths of 6,098 m without anchors.

From 249 sites at the end of Leg 25, 375 drilled holes had recovered a total of 22,848 m of core. Average recovery was 58 percent of the distance cored. The maximum depth of water in which operations were accomplished was 6,245 m and the maximum penetration was 1,300 m; both records were set during the past year.

Scripps Institution manages the Deep Sea Drilling Project under contract to the National Science Foundation. The Project is a part of the Foundation's National Ocean Sediment Coring Program. Scripps, in turn, subcontracts to Global Marine Inc., Los Angeles, for use of the *Glomar Challenger.* Global Marine provides the drilling crew and the ship's crew, as well as technical support from its engineering staff.

Scientific guidance is provided to the Project through panels 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 School of Marine and Atmospheric Science, University of Miami, Florida; the University of Washington, Seattle, Washington; Woods Hole Oceanographic Institution, Woods Hole, Massachusetts; and Scripps Institution.

During the past year, the Project and the JOIDES Executive Committee have taken actions that pave the way for JOIDES membership for the Institute of Oceanology, USSR Academy of Sciences, Moscow, pending the development of a suitable intergovernmental business relationship regarding the Project. Similar discussions have also been held with institutions from several other countries.

Dr. William A. Nierenberg, director of Scripps, and Dr. Melvin N. A. Peterson, of Scripps, are co-principal investigators for the Project. Dr. Peterson also serves as Project manager. Dr. N. Terence Edgar is Project chief scientist. Oscar E. Weser is senior staff scientist and Dr. Peter R. Supko is chief scientific editor. Other staff scientists are Drs. Anthony C. Pimm, Ansis G. Kaneps, Tracy L. Vallier, Thomas A. Davies, Peter H. Roth, Miss Paula J. Worstell, Miss Lillian F. Musich, and Arthur D. Raff.

Frank C. MacTernan joined the Project as deputy project manager during the year, and Valdemar F. Larson acted as head of operations and engineering during the year. Norman J. Sattler is head of contract administration and William T. Soderstrom is head of finance administration.

Cores taken from the Atlantic Ocean are kept in the repository at Lamont-Doherty Geological Observatory, and those recovered from the Pacific and Indian Oceans are stored at Scripps in the DSPD facility. William R. Riedel, of Scripps, is curator of all DSDP cores.

During the year, the sample distribution policy was changed to allow distribution of DSDP core material to all qualified scientists throughout the world one year following completion of each cruise. Samples from the first three years' operations are available for immediate distribution.

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

The technical accomplishments of the Project are reported in a series of "Technical Reports of the Deep Sea Drilling Project." Five such reports have been produced and are available from the National Technical Information Service of the U.S. Department of Commerce.

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

During visit of 81 Russian scientists and technicians to campus, Dr. Melvin N. A. Peterson, right, presents set of Initial Reports of Deep Sea Drilling Project *to Dr. Alexander Lisitzin, second from left. A geochemist with Institute of Oceanology, USSR Academy of Sciences, Dr. Lisitzin was chief scientist aboard R/V* Mendeleev *during Russian ship's Pacific Ocean expedition. Vessel berthed at San Pedro and group came to Scripps by bus. At far left is Dr. E. M. Suzymumov, deputy chief, Department of Marine Expeditions, USSR Academy of Sciences; at center, Dr. Y. A. Bogdanov, deputy chief scientist for the expedition; and, second from right, ship's Capt. Anatoly S. Svitaylo.*

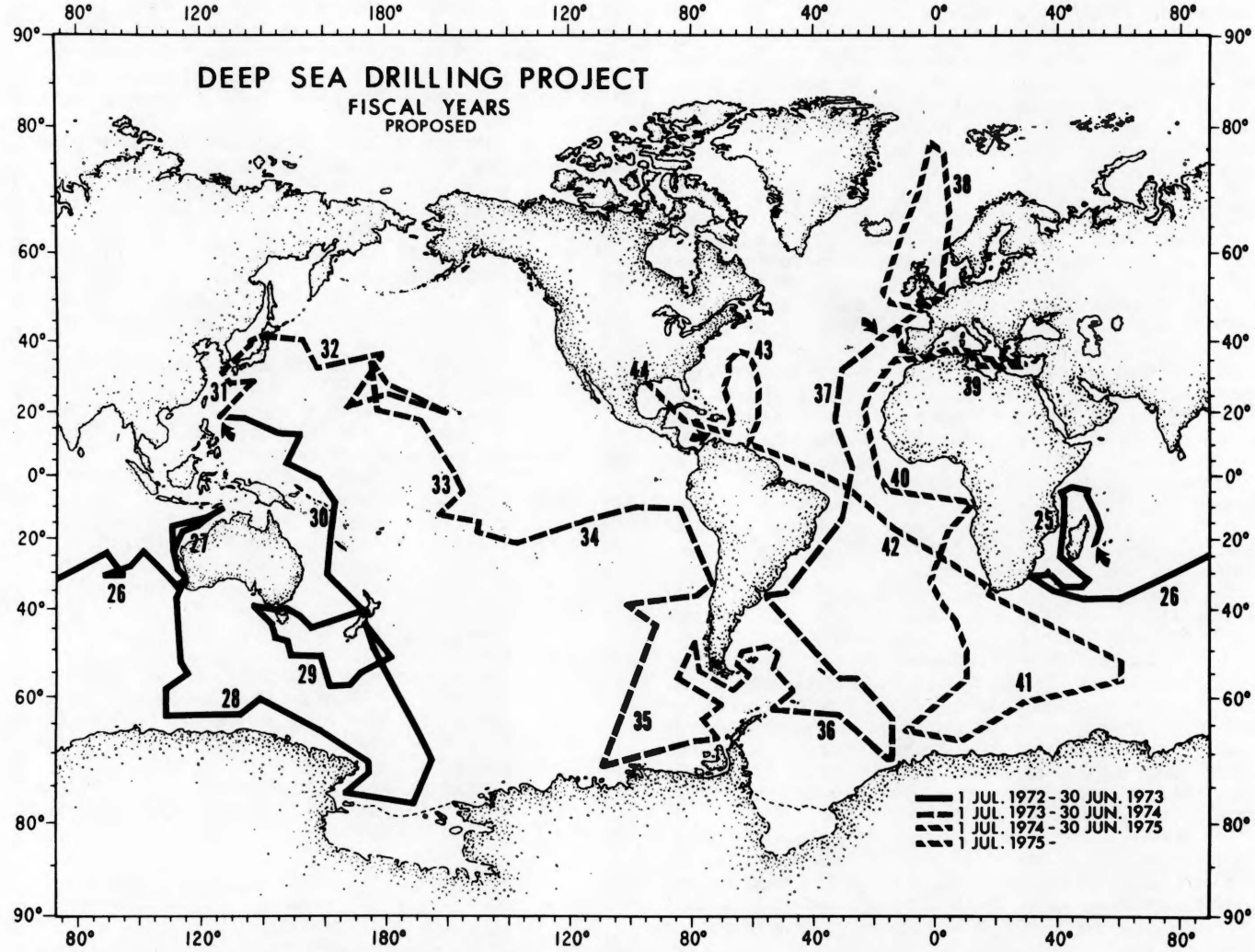


Diagram shows planned track of Phase III of Deep Sea Drilling Project that extends program from August, 1972, until August, 1975. Note proposed track for three seasons of Antarctic work and continued world-wide exploration of remaining ocean basins.
Deep Sea Drilling Project

Scripps scientists who participated in the various cruises of *Glomar Challenger* during Legs 18-24, were Oscar E. Weser and Miss Lillian F. Musich (Leg 18); Dr. Peter R. Supko, Robert E. Boyce, and John A. Grow (Leg 19); Dr. Ansis G. Kaneps (Leg 20); Dr. Thomas A. Davies (Leg 21); Drs. John G. Sclater and Anthony C. Pimm (Leg 22); Oscar E. Weser and Dr. Peter R. Supko (Leg 23); Drs. Robert L. Fisher, and Peter H. Roth (Leg 24).

During the year major contributions to the understanding of Earth processes and events were forthcoming from work largely in the northwest perimeter of the Pacific Ocean, the Indian Ocean, and the Red Sea. Legs 18-24 of D/V *Glomar Challenger* comprised the year's activities. A few of the scientific highlights can be mentioned.

The Project has obtained proof of major subsidence, or sinking, of large structural elements in the Indian Ocean. The Ninety East Ridge is a large submarine feature which is now about 2,000 m below sea level. This feature, which extends through much of the north-south dimension of the Indian Ocean was once above sea level, as shown by the presence of coal and lagoonal deposits. This Ridge was involved during the rapid migration of India and the old Indian crustal plate as it moved rapidly north in the Late Cretaceous.

The complex movements of crustal plates in the area of the Indian Ocean were traced, and some ambiguities in crustal motion models were resolved. The central portion of the Wharton Basin, west of Australia, is probably no older than Cretaceous, as opposed to a model in which it might have been very old. The Arabian and Indian Plates underwent separate movements from Late Cenozoic to Early Eocene, with active sea-floor spreading from a center north of Australia during this time. The two plates became coupled during later times, and moved as a generally single unit, as shown by the similarity of latitudinal indicators on either side of the ridge in sediments younger than Late Eocene.

Sediment carried to the ocean from major rivers of Asia can be traced to have been carried far into the Indian Ocean by turbid, or muddy, flows along the bottom; these distances are as much as 3,500 km.

Major gaps in the sedimentary record, particularly around Australia, can be interpreted to have resulted from various diversions of currents as Australia migrated and Antarctica assumed its polar position.

In general, sedimentation patterns are more complex in the Indian Ocean than is general for the Atlantic and Pacific Oceans. These complications arise because of the presence of a major land mass to the north, and because of the rapid passage of India through the region.

Drill sites in the North and Northwest Pacific give evidence of as much as 1,800 km of northward component of motion of the floor of the Pacific, since Eocene time. Similarly, drilling on the Emperor Seamounts, in the far Northwest Pacific, recovered

tropical fossil assemblages that were formed 70-80 million years ago. These recoveries indicate that there has been a marked latitudinal component of crustal movement that is superimposed on a dominant meridional movement associated with spreading from the East Pacific Rise.

Most of the geological activity in the western marginal province of the Pacific Basin took place in Early Cenozoic time, followed by later Cenozoic relative stability. The western margin of the Pacific Basin has had a very complex history of basin and topographic ridge formation. Shedding of sediment and volcanic debris provides information in the surrounding sedimentary layers of the times of greater and lesser activity in this marginal area.

Drilling in the Red Sea demonstrated that spreading of this notch in the continents has not been continuous. The Red Sea represents the best present-day example of what the ancient rifts in continents must have looked like during the initial opening of the oceanic spaces between the continents, such as that which has grown into the Atlantic Ocean. Spreading in the Red Sea appears to have taken place during a pre-Pliocene period when there was also extensive evaporite deposition. Spreading then ceased, to start again in the Late Pliocene or Early Pleistocene, when the present deep axial trough developed.

Samples have also been recovered that will permit high latitude sequences of microfossils to be established. Drilling in the North Pacific has also shown that Arctic glaciation started about three million years ago; this corresponds to the identical conclusion from North Atlantic drilling.

Another major activity of the past year has been the preparation of *Glomar Challenger* for her first season of Antarctic drilling, scheduled for the Austral Summer 1972-73. Two additional seasons of Antarctic drilling are planned for the following two years.

The drilling around this southernmost continent is intended to elucidate the role of Antarctica in the continental drift system, to establish when it assumed its present polar position and when the Circumpolar West Wind Drift became one of the major oceanic currents of the world, and to determine the glacial history of the high latitude, southern regions of the Earth.

The deep-water circulation of the ocean basins has as its greatest source the area surrounding Antractica. Scientists anticipate that knowledge of the history of circulation surrounding Antarctica will help in understanding sediment characteristics in much of the world's oceans, and may even relate to the distribution of source sediments of hydrocarbons.

Plans also call for substantial attempts to drill into Layer 2 of the oceanic crust, to determine its structure and composition, to ascertain the amount of sediment contained in what is presumed to be a largely volcanic layer of material, and to establish its characteristics for purposes of more extensive drilling attempts in the future. Plans also call for drilling as far north as Spitzbergen, in the North Atlantic.

Aboard D/V Glomar Challenger, *Dr. Robert L. Fisher holds section of fresh basalt breccia, a volcanic rock cored from 80.5 m into the igneous basement that underlies more than 500 m of deep-sea sediment in central Indian Ocean. His co-chief scientist on Leg 24 of Deep Sea Drilling Project, Miss Elizabeth T. Bunce, Woods Hole Oceanographic Institution, stands behind tungsten carbide insert roller cone bit that made the record hard-rock penetration.*

Deep Sea Drilling Project

Geological Research Division

Dr. Harmon Craig's group continued to be occupied with the Geochemical Ocean Sections Study (GEOSECS) Program of the International Decade of Oceanography. During the year they studied the oceanography of the southwest Pacific on Leg 15 of Antipode Expedition, and conducted sea trials of new equipment on Gogo I and II Expeditions, off Baja California, all on R/V *Melville*. On Antipode Expedition, they made 16 deep STD lowerings to depths of 4,800 m in sections across the Tonga Trench, using the new GEOSECS STD developed by Neil Brown, of Woods Hole Oceanographic Institution, and the GEOSECS Operations Group headed by Arnold E. Bainbridge, at Scripps. Close-spaced hydrographic casts and detailed geochemical studies with new sampling equipment were also carried out.

The Antipode work resulted in the discovery of a major deep-ocean feature, a 10^7 km^2, triangular-shaped, density discontinuity surface in the deep water which separates South Pacific deep and bottom water. The discontinuity—a hydrographic frontal surface named the "benthic front"—is characterized by discontinuities in temperature, salinity, and density profiles, and by a sharp maximum in dissolved silicate. Silica was shown to be conservative in this region, and the silicate maximum is an "induced maximum" resulting from the juxtaposition of low-silicate Antarctic bottom water below the deep-water mass. The frontal surface is also marked by a sharp radium maximum and by abrupt changes in the dissolved oxygen, phosphate, and nitrate profiles. The STD records show abrupt and irregular decreases in temperature and increases in salinity at the discontinuity surface with temperature inversions and small-scale layering.

The benthic front begins east of New Zealand and the Chatham Rise at a depth of 2 km, and slopes downward to the north and east, reaching depths of 3.5 to 4 km along the northeast edge which runs from 6°S, 180° to 43°S, 128°W. The front is bounded on the west by the abyssal western boundary current flowing north into the Pacific, and on the southern edge by the eastward flowing Circumpolar Current. The northeast edge is pinned to the northwest-trending 5 km bathymetric contour marking the eastern edge of the abyssal plain by topographic control of the flow of bottom water. Studies of temperature-salinity-silicate measurements from Antipode, Scorpio, and Southern Cross Expeditions indicate that conservative properties along the frontal surface are maintained by strong horizontal diffusion with a minimum scale length of 10^4 km. Below the surface the properties are controlled by horizontal advection along the northwest-southeast strike of the discontinuity surface, while above the benthic front the profiles are consistent with vertical diffusion-vertical advection processes between the frontal surface and the overlying intermediate water. Manuel Fiadeiro and Dr. Yu-chia Chung collaborated with Dr. Craig in this work.

In June, 1972, Dr. Craig and several of his group moved to Woods Hole to begin final sea trials on R/V *Knorr*, in preparation for the start of the Atlantic GEOSECS expedition early in July. Other work carried out during the year included measurements of excess He^3 in the Atlantic Ocean and studies of dissolved gas variations, excess-radon and deep temperature profiles, and oxygen consumption in deep water.

The initial phase of a study of the provenance of classical Greek marbles was completed and published by Dr. Craig and his wife, Valerie. Attempts to determine the ancient quarries, from which marbles used for sculpture and architecture were obtained, date back a hundred years, and include such methods as petrography, structural petrology, and major and trace element analysis, all of which have been generally unsuccessful. The Craigs used the isotopic ratios C^{13}/C^{12} and O^{18}/O^{16}, measured by the mass spectrometer, as a two-parameter "signature" for a marble specimen. They made detailed collections in the four major quarrying areas used by the Greeks from the archaic

period to Roman times: the islands of Naxos and Paros in the Aegean, and Mts. Pentilikon and Hymettus on the mainland near Athens. The results showed that marbles from these areas could be distinguished by the isotopic analysis and that the individual quarrying localities generally have uniform and unique ranges of isotopic composition. The famous Parian "Lychnites" marble, from which most of the great statues of the classical age were carved, was found to be very different from all other marbles which have been analyzed, so that the isotopic method can be applied to many problems such as the current controversy over the possible existence of the missing head of the Knidian Aphrodite in the basement of the British Museum. Since the major quarries were exploited at different times, the method provides a means of dating marble sculptures, as well as matching pieces and distinguishing copies and forgeries. This work is continuing and is being extended to other ancient quarrying areas in Asia Minor, India, and elsewhere.

Dr. Yu-chia Chung has been working on radium distribution in the world oceans. During the year measurements were made of three radium profiles from the Antarctic circumpolar water south of Australia (Aries Expedition), two profiles from the first GEOSECS intercalibration station (28° 29′N, 121° 38′W), and one profile from the southwest Pacific near Tonga-Kermadec trench (Antipode Expedition). These results were presented at the 1972 American Geophysical Union annual meeting. The Aries profiles show that the radium concentrations are constant at 9 rmu (1 RMU $= 10^{-14}$ g/kg) below 2.5 km depth. Above this depth, the concentrations vary with latitude. The surface water samples confirm this variation and show a large radium concentration gradient across the Antarctic Convergence. The two GEOSECS profiles, which were measured for further intercalibration on radium show good reproducibility with a precision better than ±5%. The South Pacific Antipode profile shows a sharp discontinuity in radium concentration at the benthic front.

Drs. Chung and Craig studied the radium profiles from Scan Expedition and found that the *in situ* production rate for radium by particulate matter is generally insignificant, based on a diffusion-advection model. By the use of a "variance map," they determined the values of maximum *in situ* production rate for radium and minimum upwelling velocity in the deep water. Detailed discussion of this subject is in a paper "Radium-26 in the Eastern Equatorial Pacific" which will appear in "Earth and Planetary Science Letters" (EPSL).

They also studied the mixing processes in the bottom water region of the same area, based on excess-radon data and continuous thermistor temperature profiles obtained during heat-flow measurements. These results were published in EPSL. Dr. Chung also studied the mixing and transient characteristics of the Santa Barbara Basin off California. A paper on this subject is in press.

Dr. Ray F. Weiss has continued his studies of dissolved gases in sea water. Gas chromatographs which presently are being used to measure the distributions of dissolved argon, nitrogen, and total carbon dioxide in the GEOSECS program were constructed and were tested at sea. During this time, Dr. Weiss participated in three GEOSECS test cruises: Antipode, Leg 15, in the southwest Pacific, and Gogo I and II, off the Baja California coast. Shipboard intercalibrations between the chromatograph and manual and automatic potentiometric titrations for total carbon dioxide showed good agreement and confirmed the accuracy of earlier chromatographic measurements of this important parameter.

Dr. Weiss's work with the Environmental Protection Agency (EPA) on gas super-saturation in the Columbia River and on the occurrence of gas-bubble disease in fishes has led to his invention of the "gas saturometer" now being patented by the Office of Naval Research. This inexpensive instrument, which accurately measures total dissolved gas pressure by means of a diffusion membrane and a manometer or pressure gauge, has become the EPA standard in a large-scale study of gas supersaturation in rivers and lakes, at dam sites, and in fish hatcheries throughout the Pacific Northwest.

Dr. Wolfgang H. Berger studied Cenozoic and Cretaceous sediment from the Atlantic Ocean off Africa (Deep Sea Drilling Project, Leg 14). The sediments indicate pronounced variations in oceanographic conditions caused by changing topography (continental drift, sea-floor spreading, sea-floor subsidence, compressional buckling at the Gibraltar Fracture Zone during Alpine orogensis), variations in deep-sea circulation (carbonate under-saturation, oxygenation, nutrient concentration, bottom current strength), upper water circulation (from transatlantic to intra-atlantic currents, fluctuations in upwelling and fertility), and redeposition processes throughout the last 100 million years.

Calcite compensation depths (CCD) were reconstructed for the Atlantic and Pacific Oceans using DSDP data and paleobathymetry derived from the sea-floor subsidence. CCD fluctuations of the Atlantic and of the Pacific differ, but may nevertheless be related through global controlling factors and through oceanic fractionation processes.

Dr. Joseph R. Curray spent the early part of 1972 on sabbatical leave at the Geological Institute, Swiss Federal Technical Institute, Zurich, Switzerland. During his leave, he studied Alpine geology, particularly flysch deposits, for purposes of comparison with deep-sea fan and continental rise sediments of the modern oceans. He continued work on the Bengal Deep-Sea Fan and the underlying geosynclinal accumulation of sediments in the Bay of Bengal, Indian Ocean, in collaboration with Dr. Russell W. Raitt of Scripps and Dr. David G. Moore, of the Naval Undersea Center, San Diego. Their interpretation of the results of Leg 22 of the Deep Sea Drilling Project in the southern part of the Bay of Bengal gives some age control to the longitudinal geophysical section published in last year's *Annual Report*. The upper unit of the Bay is Holocene to Upper Miocene, the middle unit Miocene to Eocene, and the lower sedimentary unit Paleocene and Late Cretaceous. Drs. Curray and Moore are currently working on an hypothesized reconstruction of the Indian Ocean, relating the breakup of Gondwanaland and the formation of the sea floor of the Bay of Bengal underlying this thick section of sediment. Later history of the geosyncline relates collision of the Indian lithospheric plate with the Eurasian lithospheric plate, resulting in subduction of some of the sediments, but with uplift and folding of the remainder of the sediments into the Indo-Burman Ranges and the Andaman and Nicobar Islands.

According to this working hypothesis, first collision between India and Asia occurred at the end of the Paleocene; major uplift of the Himalayas did not occur until continental underthrusting in middle Miocene time.

Dr. Robert L. Fisher and collaborators continued the analysis and field relation interpretation of igneous rock samples, bottom photographs, topographic-magnetic and sediment thickness data collected by him from the transform fault — active mid-ocean ridge region of the western Indian Ocean — and from very deep trench walls in the Southwest Pacific.

The aim is to establish, from numerous areas of precisely located and fresh, dredged, rock samples: (1) a definitive igneous rock distribution along and across the ridge segments, as well as the relative and perhaps absolute ages of the extensive rocks and their ages vis-á-vis the magnetic stripe time scales; (2) possible changes in initial composition of these basalts through time or in terms of distance from presently active zones; and (3) the vertical and horizontal extent of fresh to serpentinized coarser-grained mafic and ultramafic rocks bared in deep fractures. Such fractures provide windows opening on the deep layers, exposing Layer 2 and locally Layer 3 in the western Indian Ocean. Layer 2 in the eastern equatorial Pacific, and probably Layer 3 far down the west wall of Tonga Trench. Not only the attitude of ancient sediments present on the offshore margin or on the trench floor but also the species of hard rock really present in quantity on either side of a deep trench not subject to deposition of ice-rafted material, bears critically on the subduction hypothesis. Work to date, begun with Dr. Celeste G. Engel and now with Dr. James W. Hawkins, indicates the deep nearshore flank to be composed of layered intrusives (perhaps refractory residua or cumulates formed by extreme liquid-crystal fractionation deep in the crust) and some diabase and dense basalts, rather than contorted and plastered sediments, metamorphics, or melted sediments.

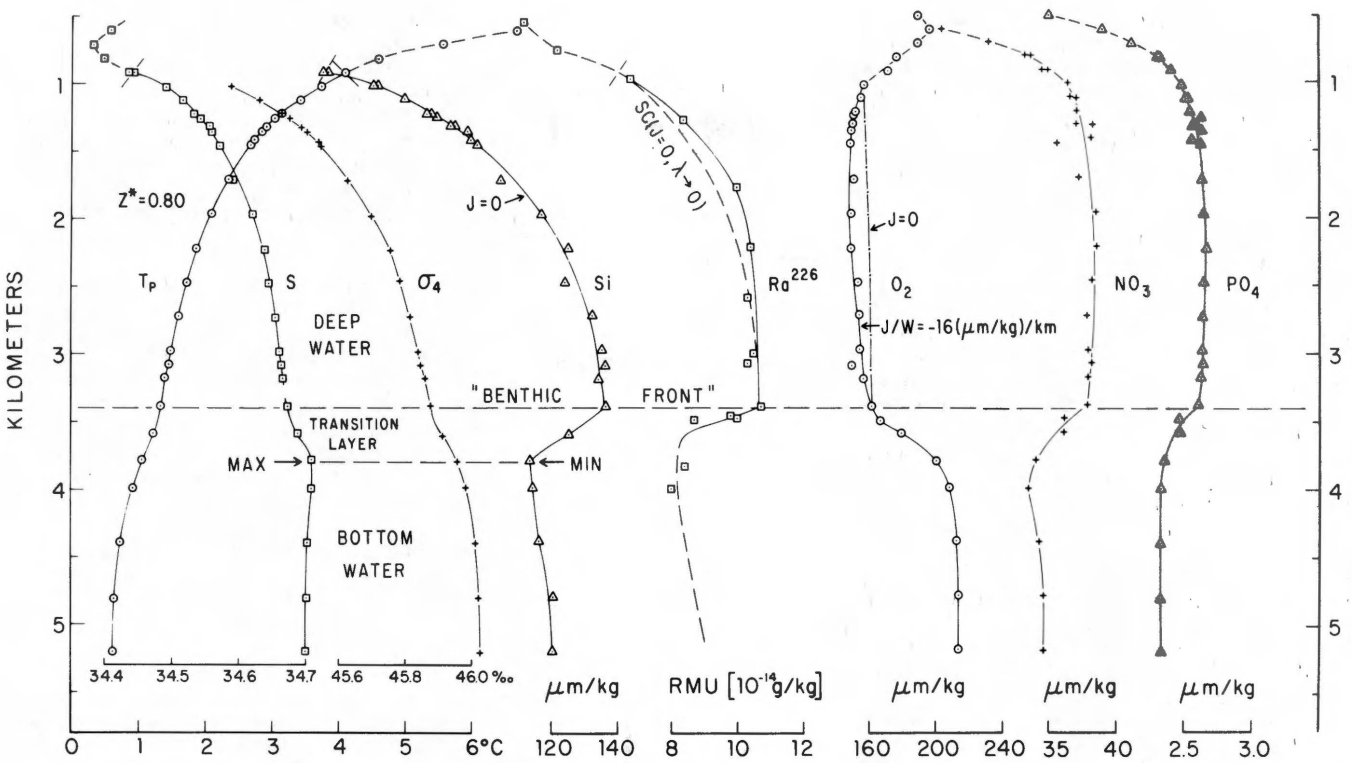


Chart shows potential temperature, salinity, "density" (O_4), silicon, radium, dissolved O_2, nitrate, and phosphate profiles across the benthic front. Readings are from Station 10, Leg 15, of Antipode Expedition, at 18°S, 172°W.

Geological Research Division

Dr. Fisher participated as co-chief scientist of Leg 24 of the Deep Sea Drilling Project in the Gulf of Aden and western Indian Ocean. Emphasis was on obtaining complete sections of sediment, expectably latest Cretaceous through Cenozoic, to establish standard micro-fossil zonations for the tropical western Indian Ocean; on recovering sediment-igneous contact zones; and on penetrating as deeply as possible into any igneous rock encountered to establish whether it was basement and therefore would provide acceptable evidence on refining the magnetic time scale or on changes in initial mineralogical composition of Indian Ocean Ridge basalts through Cenozoic time. (A preliminary account of this work, by the shipboard party, appeared in *Geotimes*, September, 1972.) A continued project with the collaboration of Robert M. Beer and H. Paul Savage is the preparation of a 45-minute film on the 1970-71 Antipode Expedition to the western Pacific Ocean and Indian Ocean.

Research programs of Dr. Edward D. Goldberg and his associates, Drs. Rudolf H. Bieri, Kathe K. Bertine, and Dwight Smith, and 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.

With Griffin and Dr. Smith, elemental carbon (Microcrystalline graphite) produced in forest fires has been detected in marine sediments with concentrations varying between 0.00X and O.X percent by weight. Higher values are found in deposits from the higher latitudes, corresponding qualitatively to the greater extents of non-tropical forests. The records of forest fire residues in deep-sea sediments can offer an entry to mapping of such forests in past geological periods. Scanning electron micrographs of carbon separates have similar morphologies to those from atmospheric particulates collected from modern forest fires and there are retained remnants of the cellular wood structure. The possibility of identifying the type of tree from such records can extend the prehistorical records of our knowledge of forests.

With Koide and graduate student Ken Bruland, two new dating techniques, applicable to coastal marine and lacustrine sediments over periods ranging from years to a century, have been developed from the naturally occurring uranium and thorium series: the Th-228/Th-232 method from the Th-232 series and the Pb-210 method from the U-238 series. Deposits off the coast of California, Mexico, Chile, and Peru have given accumulation rates of the order of millimeters per year. Now for the first time there is available a radiometric technique for these inshore and relatively rapid depositing marine sediments.

With Bertine, the compositional changes in the trace metal contents of shells of mussels and clams, that might be related to man's influence on the composition of inshore marine waters (North Sea and Mediterranean Sea) over the past 100 years, were sought but not found. During this work, it was found that the proteinaceous molts of shrimp contain extremely high concentrations of trace metals. With 20-25 molts per shrimp per year, the molting of a shrimp can cause a redistribution of such elements as cobalt, scandium, silver, zinc, and mercury within the marine environment.

Graduate student Ross Barnes developed an *in situ* interstitial water sampler to be used in helium diffusion studies in the marine sedimentary column. The instrument has been used to filter and encapsulate 20 ml water samples from sediments at depths of 5,000 m.

Dr. Bieri developed features of the Pacific Equatorial Undercurrent as a consequence of noble gas profiles to depths of 356 m on Expedition Aries. The injection of North Pacific water into the equatorial regions was revealed by very high concentrations of the noble gases. Also, upwelling was evident through supersaturation of Ar and Kr and it appears more at the equator than to the north or south of the equator.

One of the main research activities of Dr. James Hawkins has been a continuation of studies of the Lau Basin-Tonga Trench area. Data collected on Seven-Tow, Antipode, and South-Tow Expeditions have helped develop a model for explaining the origin of the Lau Basin. The basin is situated behind the Tonga Arc, a zone of crustal compression, but it ap-

pears to have formed by crustal dilation. This model is supported by an extensive study of the bathymetry, crustal structure, and magnetic patterns in the basin. Rocks dredged from the basin are basalts, and they show a remarkable similarity to basalts from oceanic ridges in their mineralogy and geochemistry. The dilation of the basin has been accompanied by the extrusion of basalts similar to those under spreading oceanic ridges. This suggests that the tectonic and magma-generation processes operating in the Lau Basin may be the same as those under oceanic spreading centers. Counterflow in the mantle, above the descending Pacific lithosphere plate, is implied by the large volume of basalt which floors the basin.

In a closely related study, mafic and ultramafic rocks from the Tonga Trench have been studied in collaboration with Drs. Celeste E. Engel and Robert L. Fisher. (This work is described elsewhere in the Geologic Research Division section of this *Annual Report.*) Other research activities have included tectonic and petrologic studies of volcanic rocks from the East Pacific Rise crest and the Gulf of California. Samples collected on Hypogene Expedition include the first basalt samples recovered from the Gulf. They are petrologically and geochemically identical with East Pacific Rise basalts. Their location on presumed fracture zone trends, and their similarity to East Pacific Rise rocks, offer strong support for the plate tectonics model for the rift origin of the Gulf of California. The petrologic studies indicate that the crust under the central and southern parts of the gulf have an oceanic geochemical character.

During 1969, work was begun on diverse problems in earth and space sciences, based on the study of charged particle tracks which are fossilized in materials during their existence as solids. The charged particle tracks studied are primarily of two origins, spontaneous fission and cosmic rays.

For the year under discussion, fission tracks were studied by Douglas Macdougall in volcanic glass shards in sediments and in glassy chill margins in Atlantic basalts. The track method was established to be reliable in the former case but marked annealing; *i. e.*, track-erasure effects, were found in the case of some basalts. Laboratory studies were carried out to understand track annealing as a function of temperature.

Cosmic ray tracks were studied in samples from the lunar regolith. Particular emphasis was laid on understanding the dynamics of transport, deposition. and mixing of lunar top soil up to depths of the order of 1 m, based on analysis of cosmic ray track densities in Apollo 11, 12, and 14 cores. These studies, which were carried out by Dr. Gustaf Arrhenius, Macdougall, and Dr. Devendra Lal, of the Tata Institute, Bombay, in collaboration with N. Bhandari and others of Tata Institute, have led to rather significant conclusions: (1) The individual core layers were found to have irradiation histories similar to those sampled at random from the surface; (2) the track density and angle distributions suggest a "throw-out" model in which the regolith is layered with ejecta blankets from cratering events; (3) the individual layers typically remain on the surface for periods on the order of 1-100 m.y. before burial by deposition.

Observations of cosmic ray track densities in gas rich meteorites and in lunar fines and fragmental rocks were critically analyzed to study irradiation and consolidation conditions for the lunar regolith and meteorite sample by Drs. Arrhenius and Lal and Macdougall. One of the experimental discoveries made during the course of this work, in collaboration with graduate student Barbara Martinek, was that in the Fayetteville meteorite, most of the "irradiated" samples are in fact grain aggregates (lithic fragments), in contrast to Kapoeta, where earlier work by Drs. Lal and Paul Pellas, from France, and their groups showed primarily an irradiation of individual grains. In Kapoeta, also, examples of "irradiated" lithic fragments were discovered. These observations have shed new light on the history of accretion/compaction of meteorites and have now become all the more important because samples from the lunar regolith which contains material irradiated in free space, is available for a direct comparison.

Study on the composition and radioactivity of particulate matter in the oceans is continued. Realizing the importance of this work, the scientists fabricated a new sampling device that involved the use of 30-cm diameter TAMIL-cotton-filters (made by TATA Mills, Bombay) and pressure-activated switches to turn on the filtration at the required depths. By using this device, about 5,000 to 15,000 1 of sea water were filtered at depths ranging from 50 to 2,000 m in the South Pacific. Surface filtration of waters up to 30,000 1 is being carried out in the GEOSECS expeditions to the Atlantic. All these samples are being analyzed for various radioactive and stable trace elements of both natural and man-made origins. Dr. Lal, graduate student Sharon Stonecipher and Drs. Harmon Craig, Bhamidipati L. Somayajulu, and S. Krishnaswami are associated with these studies.

Using the *in situ* extraction technique with ferric-hydoxide-loaded synthetic fibers developed by the groups of Drs. Lal and Craig, several vertical profile extractions are being made in the GEOSECS expeditions to the Atlantic for studying Si^{32} and Ra isotopes. These studies are made to understand the deep and near-bottom mixing in the ocean. Drs. Craig, Krishnaswami, Lal, and Somayajulu are involved in this program.

Dr. Jacqueline Mammerickx continued work on a ten-sheet bathymetric chart of the South Pacific. Two new sheets are close to completion: (1) the area extending from the Manihiki Plateau to the Tuamotus and (2) the area south of New Zealand. The analysis of bathymetric and magnetic data has led to the mapping of segments of three large fracture zones in the south Central Pacific, and to the identification of a series of north-south trending magnetic anomalies east of Tahiti, varying in age from 27 m.y. to 47 m.y.

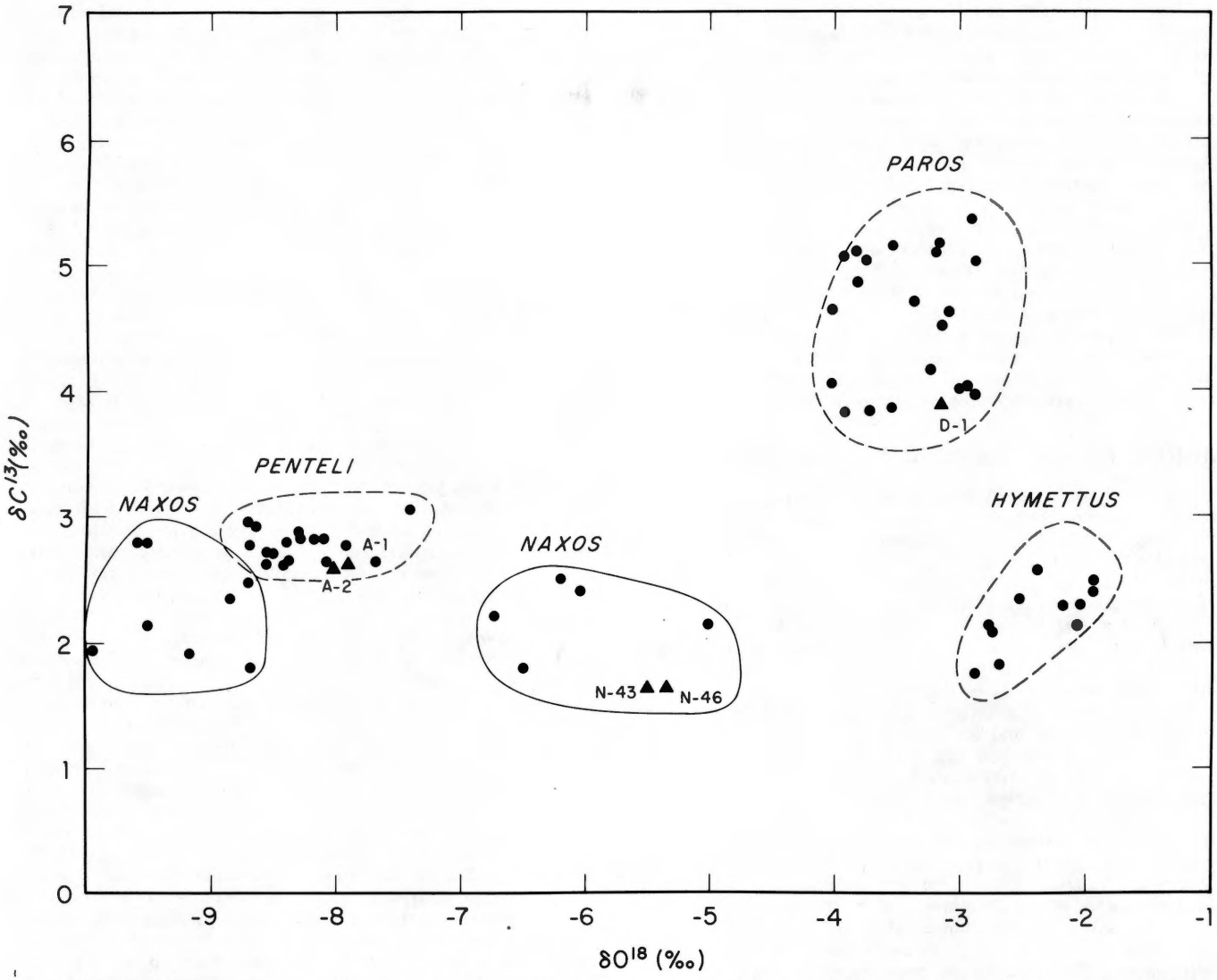
Dr. H. W. Menard published *Science: Growth and Change* (Harvard University Press), a sociological analysis. In collaboration with Dr. James Brune and other colleagues, he coordinated the Hypogene Expedition to the Gulf of California. A satellite-controlled geophysical survey of the opening plate boundary in the gulf is being analyzed by George Sharman. It appears that the small spreading centers between plates have been slightly reoriented several times. Thus the relative motion between the American and Pacific plates has varied.

Ocean basin volcanoes and the moats and arches around them are being re-examined in the light of the hot-spot hypothesis. Localized vertical motions of a few hundred meters can be correlated with the growth of linear island groups.

Dr. William A. Newman, in collaboration with Dr. Harry S. Ladd, of the U.S. Geological Survey, Washington, completed a study of the first Miocene coral-inhabiting barnacles to be encountered in the Caribbean Sea. The exceptionally well-preserved material came from elevated reefs of several islands, where calcitic remains had been leached from aragonitic coral debris by subaerial erosion. The number of species identified exceeds that known for Recent species from the Caribbean, indicating a richer fauna during the Miocene than at present. Other workers have noted that Caribbean molluscs were also more diverse in the past than they are today. The material included an extremely generalized or primitive representative that provided new insights into the origin of the tropical Atlantic coral barnacles. The evolution of comparable forms in the Indo-Pacific apparently occurred independently at essentially the same time.

Other work on coral barnacles includes a revision of the entire group in collaboration with Arnold Ross, of the San Diego Museum of Natural History, San Diego, an analysis of Miocene samples collected by Dr. Ladd from the Bikini and Eniwetok drillings, and a sample dredged from Capricorn Guyot by Dr. Fisher. Dr. Fisher's sample contains hermatypic coral and coral barnacle remains, a fact that proves that Capricorn spent at least one period of time at the sea surface since the lower Miocene.

Frances L. Parker completed work on the Upper Cenozoic planktonic foraminifera of the deep-sea tropical Atlantic in Deep Sea Drilling Project Legs 1, 2 and 4, and deep-sea cores. A comparison with the tropical Pacific section shows that for the most part the species ranges are the same. Certain differences in faunal makeup are apparent for the faunas on the two sides of the Panama isthmus starting in latest Miocene time, well ahead of the completion of the land bridge, presumably resulting from the disruption of the pattern of oceanic circulation between the Atlantic and Pacific. A study of living planktonic foraminifera in the Gulf of California was com-



Investigations by Dr. Harmon and Valerie Craig show carbon-13 and oxygen-18 variations in marble samples from ancient Greek quarries of Naxos, Paros, Mt. Hymettus, and Mt. Pentelikon. The C-13 and O-18 variations are relative to the PDB isotopic standard.

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pleted. The faunas of the southern half are tropical in character, whereas those of the northern half are relatively sparse and more temperate in nature. Preliminary work on the distribution and solution patterns of the planktonic foraminifera in the surface sediments of the North Pacific was completed and a similar study of the Indian Ocean continued.

The research of Dr. Fred B Phleger is concerned with the ecology of foraminifera and applications to various aspects of oceanography. The ecology and processes in a coastal lagoon and estuary in Natal, South Africa, was studied in cooperation with the Natal Parks Board. This area extends about 65 km along the coast and consists of a large basin connected with the open ocean by an inlet approximately 24 km in length. A large river, the Mkuzi, also enters the basin. During low runoff the basin water becomes hypersaline because of a net inward flow of seawater, and endangers the large endemic population of crocodiles, hippopotami, and birds. The formaninfera indicate that the lagoon has the ecology of a marsh, probably caused by a filtering effect by the long inlet, and a high organic production with low faunal diversity. Invasion of salt water up the Mkuzi River, not previously recognized, is shown by the benthic foraminifera.

Very large standing stocks of benthic foraminifera have been found in three areas of intense oxygen minimum (0.1 ml 0^2/L) in the eastern Pacific. These large populations appear to result from abundant food because of high organic production and absence of benthic predators due to low oxygen. Oxygen is not a limiting ecological factor for foraminifera in these low oxygen environments.

William R. Riedel and Annika Sanfilippo continued their investigations of the biostratigraphy, evolution, and taxonomy of Tertiary radiolarians, studies that resulted in increased usefulness of these microfossils in determining the age and environment of deposition of sedimentary rocks. These studies are now being extended to Cretaceous and Jurassic assemblages, on the basic of samples obtained by the Deep Sea Drilling Project, and on supplementary field work in California and Europe. In connection with the preparation of a catalog of radiolarians, an attempt is being made to develop a system of objective descriptors for these microfossils in order to avoid some of the difficulties involved in transmitting micropaleontological information by means of Linnean binomens.

The third edition of Dr. Francis P. Shepard's *Submarine Geology* (Harper & Row), is to be released in October, 1972. Dr. Shepard has a paper to be published on "Currents Along the Floors of Submarine Canyons," with Neil F. Marshall, and one on "Sea Floor off Magdalena Delta and Santa Marta Area, Colombia." Continued work on the bottom currents in sub-

marine canyons now includes ten canyons off California and Baja California and one record from Congo Canyon, off west Africa. With the exception of the Congo Canyon, the currents are predominantly downcanyon, with highest velocities and longest periods of flow in the downcanyon direction. Most of the periods of reversal from downcanyon to upcanyon direction are of irregular length and have little relation to the tides. Again, the Congo Canyon is an exception, and upcanyon flows are mostly during rising tides and downcanyon flows mostly during falling tides.

A survey of the Congo Canyon was made by Dr. Shepard cooperatively with Dr. K. O. Emery on the Woods Hole Oceanographic Institution ship *Atlantis II*. The seismic profiles showed that the canyon has been cut in part into diapirs, presumably salt domes. The profiles showed a distinct change in character of this marine valley at a depth of about 2,744 m from a steep-walled deeply incised canyon on the landward portion to a leveed valley of small wall height, with distributaries as the outer valley winds across the great fan of the lower slope.

Marine Biology Research Division

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

The beginnings of embryonic life are being actively studied by Dr. David Epel and his colleagues. Their research on the easily studied sea urchin egg provides basic information applicable to the embryonic development of all organisms. Recent research has centered on the description and quantitation of the sequence of sperm attachment and detachment which occurs during fertilization. Ms. Mia Tegner described this sequence by means of the scanning electron microscope, and Dr. Victor D. Vacquier quantitated this phenomenon with regard to the presence of a finite number of sperm binding sites. Their work shows that the detachment of sperm results from the action of a protease which is released from the egg following fertilization. This detachment prevents extra sperm from entering the egg, and is thus an important part of the mechanism which blocks polyspermy.

Following sperm entry, the egg is "activated" to begin embryonic development. The mechanism of this activation is being studied by Dr. Epel in collaboration with Dr. Daniel Mazia and Richard A. Steinhardt of the University of California, Berkeley. Their research is especially aimed at understanding the linkage between changes in the plasma membrane and the activation of metabolism.

Research by Dr. Nicholas D. Holland is concerned with an electron microscopic study of the formation of the fertilization membrane by inseminated eggs of *Comanthus japonica*, the Japanese feather star (Echinodermata: Crinoidea). Material was collected and fixed at the Misaki Marine Biological Laboratory in Japan in September and October, 1972. The definitive fertilization membrane, which was found to enclose the zygote 20 minutes after insemination, is actually a composite of the vitelline membrane as well as two distinct types of cortical granule material. At this time, the definitive fertilization membrane is separated from the plasma membrane of the zygote by a perivitelline space about 10 microns wide. Unfertilized eggs and earlier zygotes are now under study to elucidate the sequence of events leading up to the formation of the definitive fertilization membrane of crinoids.

Dr. Denis L. Fox, professor of marine biochemistry emeritus, has continued his researches and writing relating to the comparative metabolism of carotenoid pigments in marine animals. His studies of the nature of chemical binding of carotenoids in the calcareous skeletons of hydrocorals have been expanded. He has discovered carotenoids firmly bonded chemically to the calcareous skeletal material of additional hydrocoral species. While the preponderant carotenoid so involved is the tautomeric, acidogenic compound astaxanthin, there have now appeared two instances; *viz, Stylaster elegans* (orange-pink skeleton) and *S. sanguineus* (pale pink skeleton), wherein not only astaxanthin but a neutral, presumed di-hydroxy-carotene (resembling zeaxanthin) exists in a chemically bonded condition. Since the calcium carbonate was able to chemically bind both acidogenic and neutral carotenoids, it was anticipated that sterols and long-chained fatty acids would likewise be bound to skeletal material. This was found to be the case for the purple hydrocoral *Allopora california*, the colorless skeletal fatty acids being preponderantly palmitic, stearic, and oleic. A plausible mechanism for the chemical binding of carotenoids and fatty acids to $CaCO_3$ of the coral skeleton has also been proposed.

Another new development has been the discovery of chiton-conjugated ketonic carotenoids: *i.e.*, echinenone, canthaxanthin, phoenicoxanthin, and astaxanthin, in the exoskeleton of crustaceans. There is reason to believe that chemical linkage involved here resembles that likely operative in carotenoid-protein conjugation; *i.e.*, between ketone groups and terminal or other free amino radicals.

Of Dr. Fox's articles currently in press, one deals with calcareous xanthophyll esters in skeletons of several hydrocoral species; another discusses the chitin-conjugated keto-carotenoids of crustacean carapace, and a third is a comprehensive entry on biological pigments for *Encyclopaedia Britannica*. Other activities involved the preparation of a chapter for a forthcoming volume on *Biochemical and Biophysical Perspectives in Marine Biology*, to be published by Academic Press. Finally, the University of California Press plans to reprint the volume *Animal Biochromes*, first published by Dr. Fox in 1953 by Cambridge University Press, and a supplement with separate bibliographic listing is being prepared for inclusion.

The central role of wax in marine nutrition has become increasingly apparent. The fats of algae (phytoplankton) are converted to liquid wax ester by tiny copepods which are small enough to graze these microscopic plants. The total mass of wax so produced probably equals the production of all terrestrial plants and animals. The group of biochemists working with Dr. Andrew A. Benson has studied the metabolism of copepod species ranging from those under Ice Island T-3, near the North Pole, to those in Antarctic seas. Invariably, animals threatened with starvation in the deep sea or those forced to survive the dark polar winters accumulate the most wax, up to 70 percent of their body weight. By regulating their consumption of wax, they survive months of starvation and darkness.

While wax is not a normal human food, it is a potential source of energy. Its utilization by animals other than fishes is being studied. Metabolic studies on flea-sized copepods and on small fishes have revealed the biochemical processes for synthesis and breakdown of wax ester. Electron microscopic studies of copepods and isolated membrane fractions relate the anatomy of the animal and its metabolic functions. The transfer of lipids for dispersion in the sea and to cells or to marine sediments is a process basic to cell nutrition, geology, and control of environmental pollution. The methods used in all three studies have much in common and are basic to the projects of the laboratory.

The biology of halophilic bacteria, algae, and plants is being investigated from the point of view that knowledge of their adaptations could be useful in adapting agricultural plants to more saline waters.

Attention is also being given in Dr. Benson's laboratory to marine diatoms which produce hydrocarbons to the extent of 15 percent of their lipids. The metabolism of these and of the related petroleum hydrocarbons by members of the marine food chain has revealed utilization of some components and toxicity of others.

In the brown-colored phytoplankton of the sea, diatoms, dinoflagellates, and coccolithophorids, a significant portion of the radiant energy used in photosynthesis is harvested by the accessory carotenoid pigments fucoxanthin and peridinin. How these pigments are bound in the chloroplast and the mechanism by which they participate in the reactions of photosynthesis are subjects of current investigation by Dr. Francis T. Haxo and colleagues. In some but not all dinoflagellates examined, the

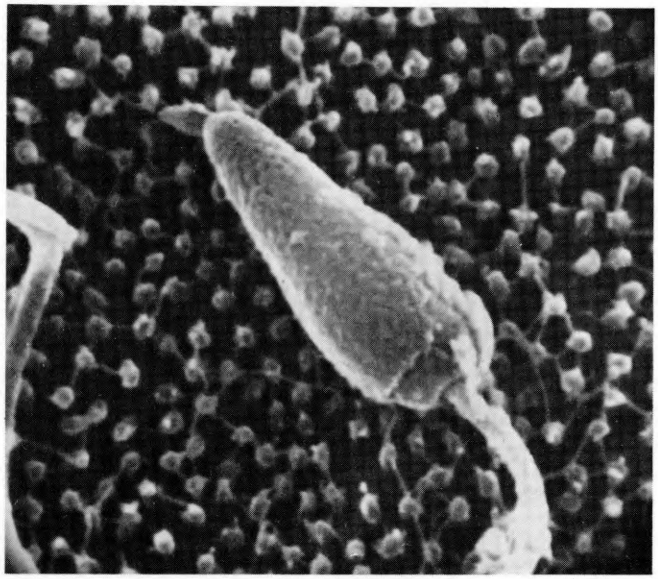
accessory carotenoid was found to occur as water-soluble peridinin-chlorophyll, a protein complex; attempts to isolate comparable fucoxanthin proteins have so far been unsuccessful. A detailed characterization of the peridinin protein complex has been continued in collaboration with colleagues at the Brookhaven National Laboratory, Long Island, New York; Barbara Prezelin, a graduate student, has found *Glenodinium* sp. to be a good source of this complex. It has been partially characterized and attempts are now being made to obtain information on its photoreactive function in relation to the two photosystems of photosynthesis.

Other studies in Dr. Haxo's laboratory have been concerned with the yellow-to-red-colored inclusions which lie outside of the chloroplast in many dinoflagellates. In some cases these may represent lipid storage bodies, in others, eyespots, part of the light-sensitive system involved in phototactic responses. Spectral examination of these inclusions *in situ* has suggested that their coloration is due to the accumulation of different but specific carotenoids. These bodies are liberated upon rupture of the cell and may be partially purified by fractional centrifugation. The opportunity is thus provided for a closer examination of their chemical composition and relationship to other constituents of the cell. In the case of *Peridinium foleacium,* isolated eyespot preparations are being examined by Nancy Withers, a graduate student; it is hoped such studies will contribute to the understanding of the functional and structural basis for photoreception in dinoflagellates.

The research in Dr. Benjamin E. Volcani's laboratory continues to be centered on the biochemistry of silicon, using diatoms as experimental materials. In one line of inquiry the mechanism of silica shell formation in diatoms is being investigated as a model system for biological mineralization. This work includes the isolation and identification of possible organo-silicon compounds, studies of silicic acid transport, and examination of silicic acid polymerization within the silicalemma (site of silica deposition).

A second line of investigation concerns the effects of silicic acid on the general metabolism of the cell. Detailed studies are being carried out with light-dark-synchronized cells to determine the *in vivo* and *in vitro* effects of silicic acid on DNA replication and on specific enzyme systems. The uptake and incorporation of ^{31}Si and ^{68}Ge by subcellular organelles of diatoms and rat liver cells as well as the effect of silicic acid on isolated mitochondria from these cells are being studied. Collaborators in various aspects of this research program are Drs. Cornelius W. Sullivan, Charles W. Mehard, Jacob Yasphe, and Farooq Azam and John S. Paul, a graduate student.

A sperm of the sea urchin Strongylocentrotus *has just undergone the awesome reaction attaching it to the egg, the first step in fertilization. This scanning electron micrograph was taken by Mia Tegner.*



Dr. Claude E. ZoBell has continued to investigate the microbial degradation of oil polluting the sea and the effects of deep-sea pressures on biochemical reaction rates of bacteria. In studies reported at an international symposium on the effects of hydrostatic pressure on organisms, it was found that denaturation of vital enzymes by deep-sea pressures helps to account for the failure of certain organisms to survive at great depths in the sea.

Virtually all kinds of crude oil and many refined petroleum products have been shown to be vulnerable to microbial degradation under favorable environmental conditions in the sea. Dr. ZoBell and associates have been studying the rate of such degradations under various conditions. The observations of most investigators have been made in laboratories at temperatures extending from 15° to 35°C. But the oil pollution problem is often more severe at lower temperatures such as in deep water, during the winter season, or at high latitudes; *e.g.*, the North Sea and the North Alaska Slope. With the assistance of Ms. Jan Agosti, a visiting scientist from Alaska, Dr. ZoBell demonstrated the bacterial degradation of oil at 4°C in 16 samples of oil-polluted soil, water, and tundra muck collected in the vicinity of Prudhoe Bay, Alaska. Some of the bacteria found in these samples grew in aqueous oil media at temperatures as low as −1.5°C. Indeed, some of these psychrophilic (cold-loving) bacteria oxidized oil more rapidly at −1.1°C than at 4°C. Slush ice provided solid surfaces which account for better bacterial growth at the lower temperature.

Of the three main lines of research carried out during the past 12 months in the laboratories of Dr. Ralph A. Lewin, two have been of some practical application, while the third is of more theoretical interest. The main effort has centered on studies of the possible biological effects of lead on marine phytoplankton. Five representative types of plankton have been selected for study in the laboratory, and for each, studies are being made of the effects of various concentrations of dissolved lead ions—on growth, respiration, and photosynthesis, at various temperatures, and in various intensities of light. Short-term effects seem to be minimal, but there is reason to be less sanguine about long-term effects.

The effluent from a glutamate factory in Singapore, pouring organic waste into the sea, is being studied as a possible nutrient supply for algae which could, in turn, serve to feed fish in impounded lagoons. A few grams of selected blue-green algae have been grown on this substrate, in pilot studies carried out at Scripps, and are being tested as fish-food by colleagues in Southeast Asia.

The third series of experiments centers around an unusual colorless, filamentous marine microbe. The filaments, which are capable of gliding at speeds up to 8 μm/sec, can take a variety of forms. Ranging in length from less than 20 μm to more than 200 μm, they may be helical or not, and they occasionally branch (a feature hitherto unknown among flexibacteria). The cells may be cylindrical, barrel-shaped, or spindle-shaped, according to the medium in which they have been grown. A further feature of interest is the tendency of the filaments to autolyse, liberating not only rhapidosomes but also submicroscopic goblet-shaped particles which may constitute essential structural components of the cell membrane. These strange bodies are being studied by Harry Ridgway, a graduate student. This microbe was provisionally identified as *Beggiatoa,* a genus of sulphur bacteria. However, attempts to grow it autotrophically, using H_2S and O_2 as a source of energy and CO_2 as a sole source of carbon, have been unsuccessful and it now seems that the intracellular granules which initially had been taken to be amorphous sulphur are, in fact, of an organic nature. The chemical nature of these lipid inclusions was investigated in collaboration with Dr. Basil Johns, on sabbatical leave at Scripps. These studies showed that they consist largely of hydrocarbons, without trace of elemental sulphur.

A visitor from abroad this past year was Miss Moenti Soesarsi, lecturer in plant taxonomy, Faculty of Biology, Gadjah Mada University, Jogjakarta, Indonesia, who has returned to her teaching duties in Java.

Studies on marine insects by Dr. Lanna Cheng are proving to have all kinds of interesting ramifications. A short-term study of the biting midges that abound in mangrove swamps along the coast of Baja California has revealed that even the predominant species, *Culicoides furens,* has not been hitherto identified from this area. The females, the blood-sucking sex, are attracted to red or yellow surfaces, but not to green, black, or white—a useful point to remember, according to Dr. Cheng, when choosing shirts for fishing trips in such areas. Adult hatching densities as high as $40/m^2/day$ have been recorded in certain intertidal areas around the lagoons. The larvae seem to be restricted to certain narrowly defined zones, indicating possiblities for ultimately controlling these troublesome insects. Dr. Cheng is currently trying to find out how they sense their victims (she has shown that warm bodies attract them) and is therefore studying surface structures with the scanning electron microscope in the hope of identifying some of their special sense organs.

The most marine of all insects are the ocean-striders, *Halobates* spp. How these insects stay unwet, despite surface turbulence in stormy weather, and how they find one another across considerable distances of the undulant sea surface, are other subjects for which scanning-electronmicroscopy is proving especially useful.

Dr. Elizabeth Kampa Boden is continuing investigations of the effects of photoenvironment on the behavior of mesopelagic animals that undertake extensive diurnal vertical migrations and on the evolution of vision in these animals.

During 1972 two "standard" light stations were again occupied at three-month intervals in an effort to determine the validity of interpreting vertical distributions of animals in terms of light transmission measurements taken in a particular area at a remote time, or in a nearby area at somewhat the same time. The objective of this study was to establish whether or not simple measurements of incoming radiation at the sea surface can be used for estimates of photoenvironment at depth when no immediate *in situ* measurements are available.

The results obtained at the more landward station in the San Diego Trough north of the Coronados Islands showed the greater variation, and hence, the lesser reliability for biological work. In the period 1955-1958, Dr. Boden had recorded a set of attenuation curves for the San Diego Trough which indicated a relatively murky surface layer overlying a surprisingly clear upper mesopelagic environment. A different situation was observed in the same area in measurements made in 1971 through February, 1972, suggesting that some effluent from the land was responsible for the much greater attenuation of the deeper layers. However, in April, 1972, the entire pattern at the San Diego Trough station changed, and the attenuation of sunlight at depths greater than 150 m was as low as it had been in the 1950s. The June, 1972, observations showed that the deep waters of the Coronados Islands had again become turbid. The aberrance in April at the San Diego Trough station is apparently real, but the basis for this situation is as yet not evident in terms of San Diego area outfall or in current structure.

Observations at the station in the San Clemente Basin have remained reassuringly stable. The water in the mesopelagic zone is clearer than that off the Coronados, and little seasonal change has been observed during 1971-1972 cruises. In the San Clemente Basin, then, it would seem that the deep photoenvironment may be calculated from surface light measurements.

During August-September, Dr. Boden participated in C-Bog I Expedition to the area north of the Hawaiian Islands and on the outward voyage monitored sonic scattering layers on the precision depth recorder and incoming solar, stellar, and lunar radiation with the surface photometer. One complete set of ocean spectra (to a depth of 150 m) was obtained under lunar illumination with the bathyphotometer north of Oahu on the 2nd day of the full moon. On the homeward voyage a nine-position series of midday light measurements were carried out at seven wavelengths at regular depth intervals from the lower limits of the bathyphotometer to the sea surface. The data are being processed and will present the most complete record of photoenvironment in the mesopelagic-to-surface depth range ever obtained along an oceanic transect.

Studies of the biochemical mechanisms of temperature adaptation in marine organisms continued in the laboratory of Dr. George N. Somero. Particular emphasis during the past year was given to the effects of temperature on rates of protein degradation in fish tissues. It was found that thermal effects on this process are sharply differential in various tissues, and that the energy requirements for replacing degraded proteins may differ markedly at different temperatures.

In studies of enzymic adaptations to temperature, major differences between warm-blooded and cold-blooded organisms were discovered in the thermodynamic characteristics associated with the activation of the enzyme-substrate complex. Enzymes of cold-blooded organisms; *e.g.,* fishes and marine invertebrates, are more efficient catalysts and apparently are capable of utilizing the relatively low entrophy of their cellular environment as a mechanism for supplying the energy required for catalysis.

Comparisons of enzymes from different seasonal populations of a number of marine and freshwater fishes were performed using electrophoretic procedures. The seasonal thermal acclimation process in all organisms studied does not appear to entail the production of different enzyme variants (isozymes), unlike the situation which occurs in certain Salmonid species.

Studies of evolutionary differences among closely related fishes of a single genus were initiated to determine whether species adapted to different thermal regimes have evolved enzymes with different, and adaptive, thermal characteristics.

A joint project with Dr. C. Ladd Prosser and Ray Wilson of the University of Illinois was conducted during the summer. Work focused on differences in enzymic activity between two local marine fishes, one of which inhabits relatively warm shallow waters, and a second member of the same genus which lives largely below the thermocline in cooler waters.

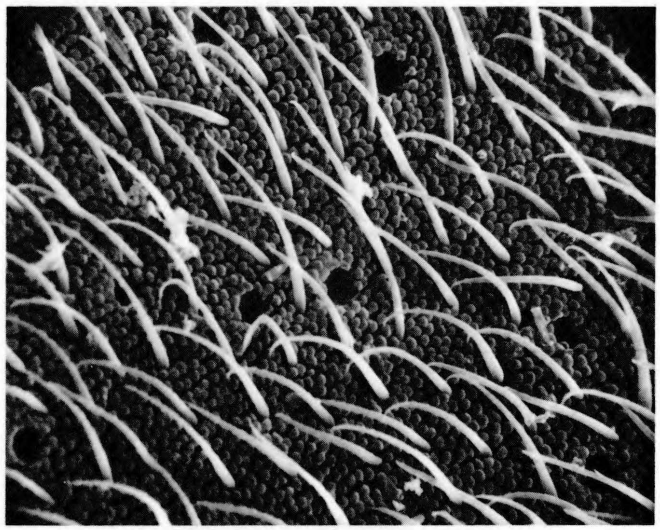
Gary H. Dobbs, III, is studying kidney function of Antarctic fish under the guidance of Drs. Arthur L. DeVries, George N. Somero, and Theodore Enns. He had accompanied Dr. DeVries on an extensive expedition to McMurdo Sound on the Antarctic continent.

In the laboratory of Dr. Enns, studies were continued on transport mechanisms of water, electrolytes, and respiratory gases in intact animals and tissue preparations. Rosemary A. Thompson has completed her doctoral thesis on electrolyte transport regulation in euryhaline fish, demonstrating in particular the importance of potassium in the control of active salt transport. In other studies the action of the enzyme carbonic anhydrase in the photosynthetic production of marine plants, the first step in the support of all ocean life, is under investigation. In all species of marine algae tested, inhibition of the enzyme produced a severe retardation of growth. Similar studies are planned on the effect of DDT, which at very low concentrations has been demonstrated to inhibit carbonic anhydrase derived from animal sources.

Activities of Dr. Carl L. Hubbs and associates continued in part along the following lines. A long-term project, dealing with the paleohydrography and the remnant fishes of the Great Basin, in collaboration with Dr. Robert Rush Miller, culminated in a manuscript to be published as a *Memoir* of the California Academy of Sciences, dealing with 21 of the basins in the northcentral Great Basin. This research is continuing, with emphasis on the basin of pluvial Lake Alvord in Oregon and Nevada.

Particular attention was accorded studies on the distribution, systematics, and phylogeny of the marsipobranchs (the most primitive of the vertebrates) of the world. The general treatment of the lampreys was published in *The Biology of Lampreys,* and the revision of the hagfish was expanded, with international cooperation, to the point of approaching a doubling of the known world fauna. New material was studied from Scripps expeditions to the west coasts of North and South America, from and at the U. S. Natural History Museum in Washington, at collections in Australia and South Africa, from Chinese zoologists in Taiwan, and from other sources. Charmion B. McMillan has been collaborating these studies.

In other activities, a classified and annotated list of the hundreds of fish species in California, with W. I. Follett, was brought closer to completion, with publication anticipated early



Scanning electron micrograph showing surface fine structure of the ocean-skater Halobates.

in 1973. A revision of the Pacific species of the gerreid genus *Eucionostomus* was expanded, particularly by examining the collections in Mexico City. In the area of marine mammals, the revision of the southern fur seals (with C. A. Repenning and R. S. Peterson) and the dramatic account of the primeval abundance, supposed extinction, but survival of the Juan Fernández species was published, in the Antarctic Research series. Collaborative studies on the marine mammals of the West Coast were continued.

Robert L. Wisner has remained active during the year in systematic studies of lanternfishes (Myctophidae), and he served as chief scientist on two legs of the South-Tow Expedition, off Chile. Final revisions have been made on his key and synopsis of the eastern Pacific lanternfishes.

Dr. William A. Newman has been continuing studies on the Mid-Pacific Mountains, a chain of seamounts extending some 1,500 km west from the southern half of the Hawaiian Archipelago to Wake Island. The chain includes numerous guyots whose nearly flat tops lie approximately 1,700 m below the sea surface. In a recent paper with Peter Lonsdale and Dr. William Normark, formerly of Scripps and now with the University of Minnesota, Dr. Newman presented data showing the environment of the top to be one of accumulating and shifting pelagic sediments with periods of erosion where hard surfaces are swept free, especially around the margin of the summit. An account of the cirripeds (barnacles) of some of these guyots, done in collaboration with Lakshmana Rao, indicates that these organisms occur primarily on soft sediments. Hard surfaces, generally coated with ferro-manganese oxides, appear unfavorable for attached benthic invertebrates, but the reason for this has not been determined.

Work has also continued on the causes underlying the *Acanthaster* outbreaks on Pacific reefs. The consensus of current workers in the field is that aggregations are for the most part natural and have occurred numerous times in the past. Data indicating a direct correlation between typhoon activity and the major outbreaks on the Great Barrier Reef and Guam are presented in a recent paper by Thomas F. Dana and Drs. Newman and E. W. Fager, who suggest that the aggregations of starfish represent redistributions of existing populations after a disturbance, rather than "population explosions."

The activities of Dr. Robert R. Hessler are divided between two general topics. His 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.

Investigations on the systematics and distribution of fishes continue in the laboratory of Dr. Richard H. Rosenblatt. An analysis of the distributional significance of the fishes of the Gulf of Chiriqui, Panama, was published, along with the description of the first heterenchelyid eel from the Pacific Ocean. Studies were initiated on the Anomalopidae, a family of shallow-water beryciform fishes of interest because of their unique possession of a large subocular light organ containing symbiotic luminescent bacteria. The study was the result of the capture of an undescribed species of the group, otherwise known from the western Pacific and the Caribbean. One of the outcomes of this research has been an assessment of the relationships of the group and a reconstruction of their evolutionary history.

Other studies completed by students are a revision of the primitive shark family Heterodontidae, a revisionary and distributional study of the mesopelagic fish family Scopelarchidae, and a biochemical-genetic study of the yellowfin tuna.

Marine Life Research Group

The Marine Life Research (MLR) program, in existence for nearly 25 years, is the University of California's component of the California Cooperative Oceanic Fisheries Investigation (CalCOFI). CalCOFI is a multi-agency study of the California Current system, involving studies also by the California Academy of Sciences, the Hopkins Marine Station of Stanford University, the National Marine Fisheries Service, and the California Department of Fish and Game.

One of Scripps's continuing contributions to these studies is the conduct and analysis of periodic oceanographic and marine biological surveys of the California Current system. These are now carried out every three years. Data and results of the analyses are contained in the CalCOFI Atlas series now encompassing 17 volumes.

Originally called the California Cooperative Sardine Research Program, CalCOFI (and MLR) was conceived as an inquiry to explain the decrease or disappearance of the sardine, which had previously supported an immense fishery. It soon became apparent that the answer to this question would not ensue from a hopeful poking about into the sardine, but, rather, from a large-scale study of the major pelagic inhabitants of the California Current system and the changes in their environment.

From the record of varved sediments of Southern California and southern Baja California, the sardine question has been substantially penetrated by the discovery that the sardine apparently has only occasionally been a conspicuous component of the pelagic population. Rather, for the last several thousand years the pelagic fish have been dominated by the hake and northern anchovy, species presently in great abundance.

The conditions responsible for such fluctuations are not yet clear, but it is clear that changing oceanographic and marine biological conditions are initiated by events far from the California coast, probably by those in the western North Pacific and possibly by events in the equatorial Pacific. This realization has stimulated inquiries into large-scale air-sea interaction in the North Pacific, some of which is discussed below.

In addition to its periodic surveys and studies of the organisms and conditions of the California Current, the MLR program has extended its inquiries in time—the varved sediments; in depth—the benthic work; and in space—the North Pacific Study. Some components of these are described below. The biological findings, particularly those of Drs. Edward Brinton, Lanna Cheng, Abraham Fleminger, John McGowan, and Elizabeth Venrick, will be emphasized in next year's report.

VARVED SEDIMENTS

Anaerobic and varved sediments accumulating under productive coastal waters preserve information in considerable detail on the ocean and terrestrial environment.

Investigation of this type of sediment in the Santa Barbara Basin, California, and the Soledad Basin, Baja California, continues to support the original conjecture that herein lay serial pages of climatologic, oceanographic, and marine biological history, recording critical events and trends in post-Pleistocene and contemporary times. Particularly important to the further development of this record into the past have been pertinent scientific observations on those portions of the sediments deposited in the last century-and-a-half.

The continued investigations by Andrew Soutar, John D. Isaacs, and others, have revealed that such sediments constitute a unique framework for the critical evaluation of geochronological methods and geochemical sequences (including man's effects). These sediments display a response related to records of seasonal rainfall that can characterize fluctuations and trends of precipitation in recent millenia. There are also indications of interrelationships between pelagic fish and records of fluctuations in their abundance over past centuries which are supported by recent studies of these fish.

It appears that the studies of varved sediments will continue to yield an increasing inventory of integrated understanding of past events, and that this understanding will be of growing importance in the broad guidance of man's activities, in recognition of the range of natural changes to which he must accommodate, and in the secular effects of his activities.

DEEP BENTHIC INVESTIGATIONS

Under the direction of John D. Isaacs and Richard Schwartzlose, the development of the deep-ocean, autonomous, still and motion picture camera by Meredith Sessions and Richard Shutts has made it possible to photograph and observe the nature and behavior of the active populations of the deep ocean floor. A stereo mode of operation has provided photographs of spectacular realism and greatly added to the veracity of measurements of size and distribution of subjects.

A new "drifting camera" is being developed which will provide a tool whereby the population densities and their variations of many benthic species can be quantitatively approached.

An understanding of the benthic populations is most pertinent to a number of important long-term problems. These creatures are subject to the "fallout" of terminal material entering the sea from all terrestrial and atmospheric sources and from processes within the oceanic surface and midwaters.

Thus the degree to which inputs of many trace substances, metals, long-lived radioisotopes, and pollutants are brought into balance by removal in the sediment is strongly influenced by the degree of uptake of these terminal materials by benthic organisms on the sea floor. These activities must then constitute a final, vital term in the expression for the ultimate equilibrium value of trace materials introduced into the sea.

It appears that the populations of large, active, deep-sea creatures are often dense extensions of commercially valuable species, caught in higher latitudes at shallower depths. Thus the extent of resources, known and unknown, may be much greater than previously estimated. In addition, depending on rates of migration, these populations constitute vectors by which terminal trace debris can be returned directly to the nearshore environment and to the food of man.

Such creatures, organized to discover and exploit large falls of food, can be unusually and extensively vulnerable to ill-advised acts of man. Thus the organisms killed in relatively small lethal areas created by disposal could selectively attract the active creatures from great areas in a sort of deep, undersea, La Brea charnel pit, with an attendant persistent wide-scale disruption of benthic life.

There is a great need for further work to understand with some thoroughness the nature, behavior, and possible vulnerability of the life on the deep sea floor.

During the past year, MLR's primary effort centered around the cruise on the R/V *Thomas Washington* to the Chile-Peru Trench.

The cruise covered a latitudinal range of 21° between 35°S to 14°S. Photographs were taken both in shallow depths on the continental shelf and in the bottom of the Chile-Peru Trench where the deepest pictures are from 7.864 m. Data were collected on the bottom of the trench, at the upper edge, and on ledges noted on the precision depth recorder. Most of the pictures were taken near free-vehicle set lines and traps. Films show species of fish not taken by hook or trap.

Examination of the black and white film was started on board the vessel soon after cameras, fish traps, and baited set lines were recovered. These revealed no fish at the bottom of the trench—only amphipods, a few tube worms, and holothurians. The deepest fish were taken at 4,937 m on a bench on the eastern slope of the trench off Taltal, Chile. One large five-rayed starfish was also seen at this depth. At a similar depth (4,956 m) on the abyssal plain westward of this latter site, only amphipods and shrimp-like forms were captured by film and in the traps.

One film sequence shows the amphipods arriving at the bait within 15 minutes after the camera reached the bottom. In one hour there were great numbers in all sizes. Within about 12 hours, the flesh on the fish bait was consumed and only the bones were left; the amphipods had disappeared almost entirely. In one of the photographs, there are ten holothurians slowly creeping toward the bait at the time the camera released from the bottom.

Unlike the deep fish concentrations that have been observed at other locations, the amphipods are able to devour the bait very quickly because of their ability to remove small pieces of flesh. Since each of the camera stations in the bottom of the trench shows large numbers of amphipods arriving in a very short time after the camera reached the bottom, the biomass appears to be very large. A high biomass could be accounted for by the very large production of anchovettas near the surface that caused a continual rain of detrital and fish remains to the bottom. The biomass on the floor of the Chile-Peru Trench probably is not representative of other trench areas that do not lie under areas of high productivity.

During the expedition, five current records were recovered. Two of these were in the trench bottom five and ten meters off the ocean floor. A preview of the data indicates that the direction was between 020°-340° at a speed of four or five cm/sec. One record is eight days long, the other is one-and-a-half days. The eight-day record at the lip of the trench was quite variable in direction, probably due to large influence by the tide.

The drifting camera has had several successful trials at sea. The results from this system clearly show the advantage of an unbaited instrument drifting across the bottom with the current, taking pictures at preset distances, thus making it possible to assess the density of benthic fish and invertebrate populations more accurately and also to provide a known photographic transect of the ocean bottom. With the present arrangement, close estimates can be made of the speed of the current and the direction and dimensions of the track covered by the camera.

In other deep benthic research, a number of physical oceanographic studies have been in progress. Joseph L. Reid has completed an initial study of the contribution of the Norwegian-Greenland and Weddell Seas to the bottom waters of the Indian and Pacific Oceans. These bottom waters have temperatures, salinity, and density characteristics that suggest origins from the extreme waters of the Norwegian-Greenland and Weddell Seas. With R. J. Lynn, Reid has attempted to trace these waters along a stratum defined by a density parameter. From the Norwegian-Greenland Sea, the cold and saline water is traced southward through the Denmark Strait, where vertical mixing raises both temperature and salinity to their maximum values in the central North Atlantic. From there the temperature and salinity decrease monotonically southward toward the Weddell Sea, partly by lateral mixing with the cold, low-salinity waters on this stratum where it lies near the sea surface in the Weddell Sea, and partly by vertical mixing with the underlying Antarctic bottom water. From the southern South Atlantic, the high values of temperature and salinity (the stratum now lies close to a vertical maximum in salinity) extend eastward with the Antarctic Circumpolar Current into the Indian and Pacific Oceans, with monotonically decreasing temperature and salinity as further vertical mixing erodes the maximum in salinity, until the salinity maximum is found at the bottom in the North Pacific Ocean.

The stratum thus defined terminates at abyssal depths in the northern Indian and Pacific Oceans; since water must rise somewhere to balance the sinking in regions of bottom-water formation, there must be upward flow across the stratum elsewhere. The tremendous areal extent of the salinity maximum, however, suggests that the upward flow through the stratum must be minimal except in the North Indian and North Pacific Oceans, where stability is shown to be very low at the depth of the stratum.

NORTH PACIFIC STUDY

Study was continued on large-scale, air-sea inetractions over the North Pacific Ocean. Two research projects were completed by Dr. Tim P. Barnett in collaboration with Dr. Warren B. White. One offered a rudimentary theory of ocean-atmosphere coupling and indicated that the spatial distribution of heat flux off the east coast of Asia exerted a strong control over the weather of the North Pacific Ocean. The other project offered a qualitative explanation of the coupling mechanisms and interactions between the major ocean-atmosphere fields in the North Pacific Basin. Dr. Barnett completed, in collaboration with numerous other authors, an extensive monograph on the Joint North Sea Wave Project (JONSWAP). The principal result indicated that nonlinear wave-wave interactions are responsible for a major portion of wave growth.

Dr. White has completed work on a seasonal thermocline model, wherein the depth of the mixed layer and the interfacial mixing is specified from surface observations of wind stress and vertical heat flux.

Dr. Jerome Namias has continued his research relating to large-scale and long term interactions between atmosphere and ocean. Among other things it was determined that a major change in winter wind, weather, and ocean-surface temperature patterns took place between the roughly decadal periods 1948-57 and 1958-70. Clear evidence of the change shows up in temperature anomalies over the United States where in the earlier decade it was unseasonably cold in the west and warm in the east, but the reverse in the latter decade. It was demonstrated that there changes were associated with equally remarkable changes in North Pacific sea-surface temperatures and upper air wind patterns. The evidence suggests that the anomalous weather pattern over the United States was generated by air-sea interactions over the North Pacific involving complex feed-back systems whose understanding should ultimately make possible forecasting of climatic regimes.

In other studies by Dr. Namias, the time and space scales of atmospheric and surface temperature anomalies were investigated. When treated as statistical aggregates over a month or more, strong spatial coherence was found indicating (1) the large-scale coupling of atmospheric and sea-surface systems; (2) the dimensions of anomalies in either medium are of the order of one-third of the North Pacific Basin. Study was begun involving empirical techniques to specify and forecast air-sea changes of the order of a month or season. Preliminary results suggest that, because of differences in the time constants between air and sea, it may be possible to throw light on pertinent physical processes to be further explored and at the same time to develop some interim prediction methods.

The research of Dr. Joseph C. K. Huang has concentrated on a numerical dynamic model in simulation of the North Pacific Ocean. This model was developed for the study of air-sea interacting mechanisms in order to understand the physical nature of large-scale normal characteristics and anomalous changes in the North Pacific Ocean in response to the various seasonal meteorological conditions. The model is based on the governing hydrodynamic equations for fluid contained in a basin. The lateral configuration and bottom topography of the North Pacific Ocean are built into the model. Real oceanic and atmospheric field data are used as input constraints to the hydrodynamic system. The model provides insight into transient phenomena of the responding ocean when the boundary conditions are changed from one state to another. Different hypotheses concerning the large-scale, ocean-atmosphere interacting processes will be tested in the model as a first step toward the understanding of the coupling phenomena. In addition, an atmospheric model is being developed. Ocean-atmospheric systems for the North Pacific Experiment will be coupled in the near future. More model study concerning ocean-atmosphere coupled processes responsible for large-scale oceanic and atmospheric fluctuations and teleconnections will be carried out next year.

Other research work by Dr. Huang, based on field data, includes a mesoscale pilot study for the heat budget in the atmosphere-ocean system within an area of 200 km in diameter at the central portion of the North Pacific Ocean. Based on long-time series of atmospheric and oceanic field data monitored by a cluster of buoys moored in the mid-latitude, detailed subsurface heat content analyses on local heat conduction, horizontal and vertical heat advection, and diffusion are carried out. Results confirm that the net heat transformation in the naviface is mainly responsible for the local temperature change in the upper ocean but that the horizontal advection of heat is not negligibly small.

Twenty years of subsurface data in the eastern North Pacific Ocean have also been analyzed by Dr. Huang. From the long-term mean thermohaline structure in the California Current system, decadal oceanic patterns were identified, thus verifying the recent decadal climatic regions observed by meteorologists. Detailed analysis based on the temperature and salinity data confirms the decadal variations of sea-level along the California coast.

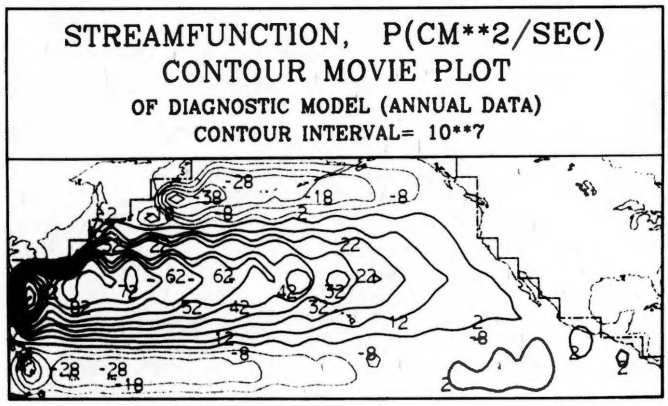
In the past year Dr. Ronald K. Lam has been examining existing data and gathering additional data in order to better understand the California Current. His major effort has been directed toward developing a taut-wire, subsurface mooring capable of placing near surface current meters with an accuracy of ± ten meters in four km of water. To this end the existing Scripps current meters were modified to withstand the strain of a taut-wire mooring. The timing devices used with Scripps free-vehicle systems were adapted to two different releases. The first system utilizes the conventional release and squib linked to a mechanical-advantage mechanism, while a later model uses release electronics and an explosive bolt.

Test moorings were placed near San Diego and off California's Pt. Conception. The first test mooring verified the ability of the design to withstand launching stresses. Two free-vehicle, near-bottom, current meter records, totaling about three months' duration, have been obtained off of Pt. Conception in four km water depth.

Dr. Lam has developed computer programs to calculate dynamic height and to plot any combination of temperature, depth, and salinity in order to assist in examining existing and incoming data. This has been applied to some interesting hydrographic data series obtained in years past and also to the pertinent data being obtained in the 1972 CalCOFI Cruises.

Diagram shows stream function pattern in simulated model of North Pacific Ocean. Maximum transport along the Kuroshio region is about 52 Sverdrups, which agrees quantitatively with observed mean transport. All large-scale features in model match with observed current patterns in North Pacific.

Marine Life Research Group



Free-vehicle camera developed by Marine Life Research Group took these photographs off Chile during South-Tow Expedition. Upper left: Amphipods completely cover bait within an hour after camera reached bottom at 3,700 fathoms in Chile Trench on April 9, 1972. at 27°04.9'S and 71°44.0'W. Photo below shows that less than 12 hours later, most of amphipods have left, and bait is almost entirely consumed. Upper right: First picture taken after camera reached bottom at 3,935 fathoms in Tal Tal Trench, off Chile, on April 14, 1972, at 25°11'S and 71°29.5'W. Photo below, taken just two hours later in same location, shows amphipods swarming over bait.

Marine Life Research Group

MARINE PHYSICAL LABORATORY

Programs in basic and applied research at the Marine Physical Laboratory (MPL) continue to range over wide areas of marine science. Some 100 reports issued from the Laboratory in the past year have summarized work in such diverse fields as geomagnetism, bottom topography, physical acoustics, acoustic propagation, sonar signal processing, hydrodynamics, heat transfer, and benthic biology.

Three legs of Expedition South-Tow were completed this year, all three employing the R/V *Thomas Washington*. Leg 2, under the direction of Dr. John Mudie, originated at Papeete, Tahiti, on February 15 and terminated at Valparaiso, Chile, on March 20. Extensive near-bottom geophysical data over the Pacific-Antarctic Rise at 51°S were obtained in order to study the detailed structure of the magnetic time scale between magnetic Anomaly 3 on both sides of the Rise crest. An excellent surface magnetic profile on the west flank of the Rise showed anomalies 1-20 clearly with an abrupt increase in the spreading half-rate from 2.3 cm/yr for anomalies older than Anomaly 5 to 4.8 cm/yr for the younger anomalies. A surprisingly fast spreading half-rate of 4.1 cm/yr was clearly observed on the east flank of the Chile Rise between Anomalies 1 and 5.

Dr. Fred N. Spiess served as chief scientist on Leg 5 of Expedition South-Tow, which commenced at Callao, Peru, on May 22 and ended at Guayaquil, Ecuador, on June 12. Of primary interest on this leg were two areas near the crest of the Carnegie Ridge where erosion transportation and redeposition of sediments have extensively altered the bottom topography. Surveys made with a deeply-towed instrumentation system developed at MPL revealed that the terrace on the south flank of the Carnegie Ridge is barren with the exception of the few piles of sediment that were noted on air-gun records. Towing operations over other sediment sequences on the terrace revealed some rippling and dune formations indicative of present sediment transport. Current meters deployed in the channels and on the exposed terrace recorded currents as high as 15-20 cm/sec. A survey in the channel on the north flank of the ridge revealed trains of sinuous, transverse sand waves at a water depth of 2.7 km. Dunes having an average wavelength of 20 m and amplitude of 0.75 m appear on well-sorted foraminiferal sand and are completely covered with asymmetric ripples having an average wavelength of 20 cm. These dunes are similar in size and shape—and perhaps origin—to the "sand waves" of tidal estuaries and shallow seas.

With Dr. Mudie as chief scientist, Leg 6 of the expedition ranged from Guayaquil to Balboa, Panama Canal Zone, in the period June 19-July 12. On this leg, interest was centered on marine geophysical investigation of the Galápagos spreading center in the Panama Basin.

Deep-tow studies were divided among three areas. The first was centered around 00°40'N. 86°10'W covering the Rise crest and a 25-km-wide rectangle extending 60 km south of the crest. Five passes over the crest revealed a pattern of lineated fault scarps facing the crest extending from the crest itself to the southernmost point of the survey. With rare exception the relief of the region was dominated by these steep, inward facing scarps and gentle backslopes. The uniform sediment cover of the gently sloping regions suggest that block faulting is a dominant phenomenon in this area. Anomalies exceeding 10,000 nT

(one nanoTesla = one γ) in amplitude were observed with the main field of 36,500 nT.

A second area of interest was a 20 km square centered at 02°N, 86°W wherein a long profile connecting with the first area was obtained. The area, being just north of a large trough, was one of low heat flow and low amplitude, surface magnetic anomalies. Near-bottom anomalies also showed a more subdued character. The bathymetric relief was again fault-scarp controlled, with steep scarp faces pointing toward the axis of the trough.

Finally, a long profile was obtained on the Costa Rica Rift approximately along 83°30′W from 03°20′N to 01°30′N. This section of the Galápagos spreading center also shows scarp-controlled relief, with the scarps facing the Rise crest. The magnetic anomalies are more subdued than those observed in the first area, but they appear to be as explicable by sea-floor spreading and bathymetric relief as those in the other two areas.

MPL has enlarged its continuing study of internal wave motions in the upper layers of the deep sea. The objective is to better measure the distribution of internal wave energy with respect to horizontal wavelength, vertical wavelength, and frequency. The approach taken by the MPL group, headed by Dr. Spiess, is to detect vertical wave displacements in the upper 300 m of the sea by monitoring time fluctuations in the temperature/depth profile in this region. Repeated temperature profiles are sampled at four horizontal locations surrounding the R/P FLIP. From a comparison of the observed signal phase across this array, horizontal wavelength and directional information can be deduced. Analysis of the variation of wave amplitude with depth yields knowledge of the vertical wavelength. The electronics and mechanical apparatus required for these measurements has been tested and will be used for an extensive measurement effort in November (1972) off the California coast. A future operation in the Mid-Pacific north of Hawaii is in the planning stage.

Drs. George G. Shor, Jr., and Russell W. Raitt continued seismic refraction observations devoted primarily to a study of the anisotropy of the horizontal velocity of compressional elastic waves in the uppermost mantle immediately below the Mohorovicic discontinuity. Previous expeditions in the Pacific and Indian Oceans made use of moored sonobuoys using balloon-supported radio transmitters to gain the radio range needed to conduct mantle refraction studies with a single ship. In the spring of 1972, with the help of the Hawaiian Institute of Geophysics (HIG), a two-ship, seismic refraction operation was conducted in the eastern equatorial Pacific by R/V *Ellen B. Scripps* and HIG's *Kana Keoki*. This expedition, called Iguana, was carried out to study the geological structure and the mantle anisotropy of the area between the East Pacific Rise, the Carnegie Ridge, and the coast of Central America. Preliminary results indicate anisotropy with maximum velocity directed northeasterly. From best available opinion about the geomagnetic lineation, this result appears to support previous conclusions that the direction of maximum velocity is normal to the magnetic lineations and in the direction of sea-floor spreading at the time of formation.

Studies of oceanic convection by Dr. Theodore D. Foster have been extended to the polar regions and theoretical studies of haline convention induced by sea ice formation and the cabbeling instability induced by the nonlinearity of the equation of state of sea water at low temperatures have been carried out. Laboratory experiments on thermohaline convection induced by the evaporation of sea water were performed. Work at sea was mainly aimed at studying convection induced by geothermal heating at the sea floor. Measurements were made in several deep ocean basins on Antipode Expedition and in several shallow basins during local cruises of the *Ellen B. Scripps*.

A completely redesigned two-wavelength radiometer system has been developed under the supervision of Dr. Stephen Rearwin. The radiometer now includes the capability of processing data on-line by means of a mini-computer. It is currently being used to investigate the thermal interaction between the ocean and the atmosphere.

Dr. John G. Sclater and Roger N. Anderson made detailed heat-flow measurements on the crests of the East Pacific Rise and of the Galápagos Rift, some of which were carried out in conjunction with deep-tow surveys and acoustical transponders for navigation. They confirmed the existence of a low-heat-flow zone at the ridge crest predicted by Lister which can be caused only by deep penetration of water into the cracks of the hot rock as it is being extruded at the crest. Fresh serpentinite was brought up in two dredges from a fossil ridge parallel to the East Pacific Rise, proving that hydrothermal alteration of peridotite had taken place. The suggestion of Anderson that the heat flow low on the flanks of spreading ridges is attributable to the dehydration of minerals hydrated at the crest now rests on firmer ground. In another paper, Anderson showed that in a region of sea-floor spreading which cannot be dated by magnetic anomalies, the age of the ocean floor can be found from bathymetric profiles normal to the ridge axis. A statistical study of the anomalies in the satellite gravity field of the earth as related to the age of the ocean floor (and therefore to its depth) by Anderson, D. P. Mackenzie, and Dr. Sclater, has yielded for the first time gravitational evidence that spreading ridges are held up by rising plumes of subcrustal material. Details of terrestrial heat flow were brought out by additional stations in the Gulf of California.

Professor Victor Vacquier and Richard E. Whiteman reported on measuring fault displacement by optical parallax between Ángel de la Guarda Island and the Baja California peninsula in the Gulf. Over a period of two years, the fault moved less than 4mm, whereas 120 mm was expected from average plate motion. In the north central and northwestern Pacific, Professor Vacquier, in collaboration with Dr. C. G. A. Harrison of the University of Miami, surveyed seamounts which confirmed the 30° northward drift of the Pacific plate since the Cretaceous found previously.

Dr. Frederick H. Fisher has initiated studies of the relation of the scale of bottom topography variations to effects on fluctuations in acoustic propagation. Two sea trips with FLIP in a 3-point moor have been made in which hydrophones on FLIP were used to record acoustic signals from shallow shots and pulsed CW sources. Variations in bottom topography measured from FLIP have been confirmed by deep-tow profiling over the same area. In a joint project with Professor Yeager at Case Western Reserve University, of Cleveland, Dr. Fisher has investigated the origin of the low frequency (1 kHz) acoustic relaxation effect in the ocean by making temperature jump measurements on real and artificial sea water. It was found that the boric acid-borate system is responsible for a chemical relaxation in the same time domain as observed acoustically in the ocean. His studies of the chemical equilibria responsible for the

Astrometric project installation on Baja California as shown during studies by Prof. Victor Vacquier of the Marine Physical Laboratory.

Marine Physical Laboratory

high frequency (~100 kHz) acoustic relaxation in the ocean, $MgSO_4$, continued with measurements of electrical conductance as a function of pressure, temperature, and dielectric constant. Work has also been initiated on the equilibria of $CaSO_4$ and boric acid. In the acoustic absorption phenomena, several chemical equilibria are coupled to each other and it is necessary to understand these in order to explain the observed acoustic effects. Work is continuing to explain the large pressure dependence of acoustic absorption in the 100 kHz region observed by Dr. Hugo Bezdek.

A Deep Acoustic Reverberation Studies System operated by graduate researcher Robert K. Johnson has confirmed the existence of a scattering layer extending from 1,100 to 1,500 m depth. Observations over a frequency range of 3 to 30 kHz indicate a scatterer length of 1 to 10 cm and a population density of 1 per 10^5 cubic meters. This layer has been observed in two locations, one lying 129 km southwest of San Diego in a water depth of 2,000 m and the other lying 323 km west of San Diego in water of depth exceeding 4,000 m. Additional investigations in the San Diego Trough indicate that the water column can be divided into three vertical regions. Strong incoherent scattering varying diurnally with layer migration characterizes the upper 350 m. Individual targets are resolvable at low frequencies against lower reverberation levels present between 400 and 550 m. Below 600 m, coherent scatterers are observed at high frequencies with a typical density of four per million cubic meters.

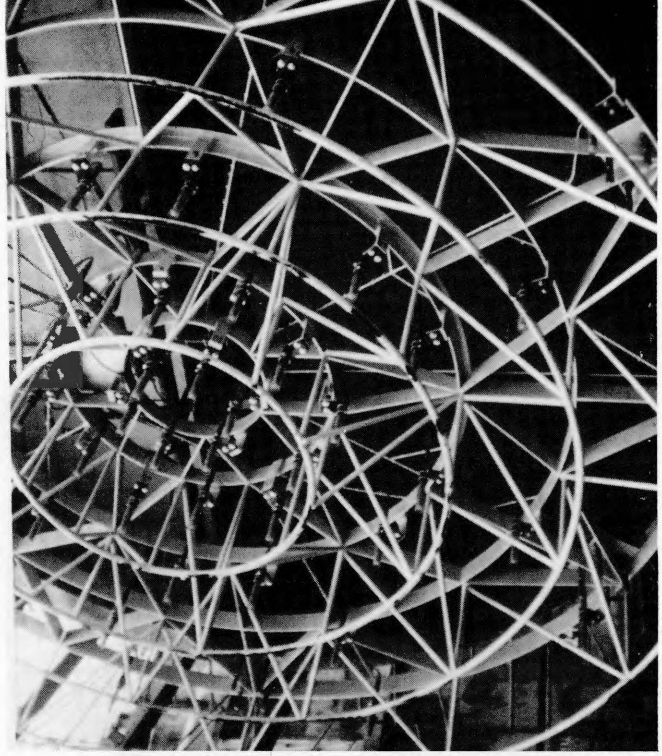
Current work on the DICANNE II acoustic signal processor system has been expanded to provide an on-site convertible processor capable of performing either the beam cancellation or the beamforming technique. Developed for the Long Range Acoustic Propagation Project (LRAPP), the beamformer conversion is an analog adaptive beamformer designed around a 48-element hydrophone array. The system operates in the frequency band of 10 Hz to 1000 Hz and can be programmed to form up to 512 beams. Element-to-element time delays are calculated by a minicomputer and can be adapted to various array configurations by software manipulation. The data obtained are displayed as a detected beam scan on a time-bearing recorder and are being recorded and processed with an FFT computer program. The equipment, principally the LRAPP beamformer, is scheduled for extensive use in 1973 on board the R/P FLIP.

The existing 31-element FLIP planar hydrophone array was expanded to 48 elements, with an increase in diameter from 3 to 6 m. FLIP was drydocked briefly, and the stern modified in order to accommodate the larger array. Construction of a 48-hydrophone, 256-beam DIMUS (Digital Multibeam Steering) beamformer was completed, and the array and beamformer were used to collect data for Dr. Victor C. Anderson's continuing investigation of the azimuthal characteristics of ambient sea noise fluctuations. With this array it has been possible to observe the noise generated by individual waves and follow the build-up and decay of these noise sources as they are driven over the surface of the ocean by the wind stress.

Ambient sea-noise studies were conducted by William Whitney and Dr. Gerald B. Morris using FLIP stationed in a 3-point moor in 4,100-m water. The observations demonstrated the unique capability of studying ocean background noise simultaneously at four points spaced over the entire water depth in the deep ocean.

The MPL DIMUS beamformer, serving as a fundamental passive sonar system aboard the U. S. Navy research submarine *Dolphin,* has undergone extensive at-sea tests and evaluation in the Gulf of Alaska. One of the unique features of this sonar system is the packaging of a sizable portion of its electronics exterior to the hull where it is exposed to the ambient sea pressure. Little difficulty was experienced with this package during the Alaskan operations, permitting the conclusion that this technique is feasible. Serving in its primary capacity as a fundamental sonar system, the DIMUS was instrumental in the gathering and evaluation of ocean acoustic data. Still on board the *Dolphin,* the DIMUS is scheduled for additional service in the forthcoming year.

Studies of target perception in visual sonar displays are continuing under the direction of Dr. Robert A. Rasmussen. The fundamental problem is the presentation of data to the human observer in a manner which, at worst, will not detract from the spatial and spectral processing gains achieved in other parts of the sonar system. Two series of studies have been completed. The first was undertaken to measure effects of target area on perception in a homogeneous noise background. Contrary to findings of other investigators, no uniform relationship between threshold level and target area was observed. Rather, a correlation between threshold level and the angular distribution of cones in the retina was indicated. In the second series of studies, effects of data quantization on target perception in intensity modulated displays were investigated. The method of partitioning the data samples was held constant in 16-, 8-, and 4-level presentations while the gray shades were altered simply by attenuating the amplitudes of all quantized data samples transmitted to the CRT. Essentially, effects of the number of quantized brightness levels and their relative contrast on target perception were measured. Little variation in perceptual performance for the several displays was found. Differences between the target brightness and the mean background brightness for the several displays were measured and it was found that the coarser backgrounds yielded higher contrasts. The rms fluctuations for each background and the ratios of target contrast to the rms fluctuations for each display were then calculated. These ratios were nearly constant. It was concluded, tentatively, that a measure of display merit is this ratio.



FLIP's planar hydrophone array was expanded during the year from 31 elements to 48 and with an increase in diameter from ten to 20 feet.

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The ORB-RUM Remotely Manned Sea Floor Work System has further proven its usefulness and versatility during six extensive operations totaling 71 days at sea off the Southern California coast. A variety of sea-floor work at 17 sites ranging in depth from 45 to 1,900 m has been carried out under the direction of Dan K. Gibson. The RUM vehicle has logged over 280 hours of actual operating experience upon the sea floor. Fifty-one sediment core samples have been collected. Sixty-seven cone penetrometer profiles and 36 vane shear measurements, to a depth of .07 km below the sea floor, have been made *in situ* to determine sediment strength. Fifty-nine profiles of vehicle track depressions, made with the vehicle operating at various track pressures, have been recorded. Problems with a winch-tensiometer system, developed for making vehicle drawbar pull measurements, have dictated a redesign. Only two satisfactory drawbar pull measurements were obtained this year.

A pair of camera systems, using 35 mm and Super 8 mm

color film, have been added to the instrument suit for documentation of the sea-floor work performed and some excellent pictures were obtained. A high resolution search sonar having a 200 m range has also been added.

During a cooperative experiment with the Naval Civil Engineering Laboratory and the Pacific Missile Range, an ocean weather station mooring clump and the remains of a sea-floor construction experiment, each weighing more than 1,361 kg were searched out, picked up, and returned to the surface by RUM from depths of 900 and 1,260 m, respectively. A recovery line was fastened to an 8,165-kg foundation at 185-m depth and tied off to a subsurface buoy for later recovery. Several long-term, sea-floor, construction experiments were searched out, observed, and photographed to obtain settling, loss of buoyancy, and marine growth information.

Benthic biological studies have been conducted at two sites near 1,150-m depth in the lee of San Clemente Island. In this work, a graduate biologist used the TV and movie cameras on RUM to observe and document behavioral activities of visible benthic creatures, within well-defined areas of the bottom, for periods of several hours per area.

Six near-shore work sites, at depths of 45 to 180 m, were selected on the basis of interest expressed by the U. S. Bureau of Reclamation in data from *in situ* soil mechanics measurements and core samplings which may be of value in their reconnaissance survey for an off-shore California aqueduct.

Studies have also been initiated in connection with this project which should contribute to the development of a methodology for the economic analysis and prediction of work performance for future sea-floor work systems.

Neurobiology Unit

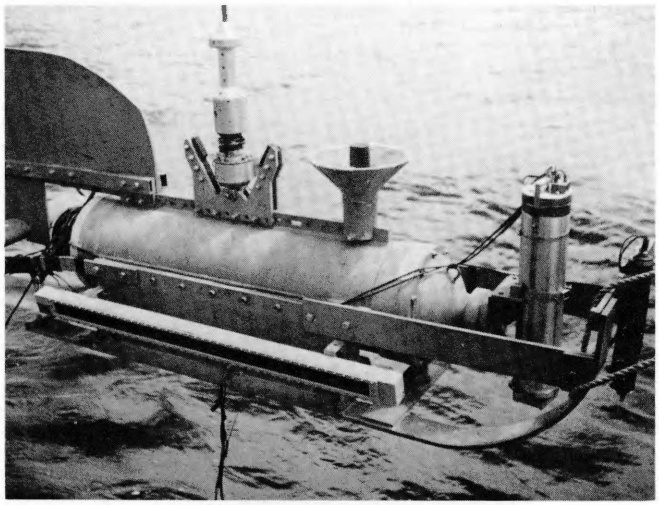
Dr. Theodore H. Bullock of Scripps Institution and Dr. Sam Ridgway of the Naval Undersea Center in San Diego published the results of their electrophysiological studies of the brain, during echolocation studies in porpoises and a companion study of sea lions.

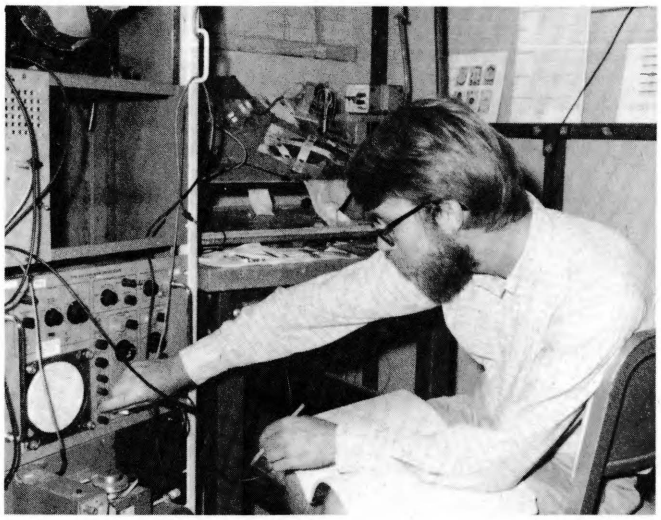
Together with Dr. Henning Scheich and Robert H. Hamstra, Jr., Dr. Bullock completed a study of the behavioral response by which high-frequency electric fish avoid being jammed by others of their own kind. This involved experiments on freely behaving fish and microelectrode recording from single cells in the brain of anesthetized fish.

Dr. Scheich made the first measurements on the detection by electric fish of objects in the water on the basis of their electrical capacitance.

Developed by the Marine Physical Laboratory, Deep Tow vehicle, with side-looking sonar visible in foreground, is lowered over side of research vessel.

Marine Physical Laboratory





In a Neurobiology Unit laboratory, Christopher Platt conducts electrophysiological and behavioral experiments to demonstrate that change in posture of adult flatfish is caused by changes in the central, rather than the peripheral, nervous system.

Neurobiology Unit

Dr. Adrianus J. Kalmijn successfully completed his investigations on the biological significance of the passive and active electric sense in weakly electric and non-electric teleosts. The biophysics of electroreceptor systems and their relations to naturally occurring electric fields and impedance distributions are under study. Good progress has been made in building new shark facilities especially designed for electronavigation experiments.

Dr. Joseph A. Bastian inaugurated an investigation of the cerebellum, especially of electric fish in relation to object detection, by microphysiological recording from the cortex. Drs. Harvey J. Karten and Leonard Maler and Thomas Finger conducted experimental histological studies to trace the pathways of electrical reception in the brain of such fish. Dr. Carl D. Hopkins brought to the group field and ethological experience and began to recognize and catalog the social signals used by high-frequency electric fish.

Christopher Platt continued his thesis research on central control of postural orientation in flatfish. Anatomy of the otolith organs and physiological activity of the primary vestibular afferent neurons suggest that the alteration to the side-lying adult normal position is not a result of peripheral changes, but central ones. The demonstration that gravistatic responses can be affected in specific ways by stimulation of visual centers suggests an optic-vestibular efferent pathway may allow direct central control over gravistatic function.

Dr. John E. Byrne is studying behavioral and physiological aspects of locomotor activity rhythms in teleosts. One subject, the senorita *(Oxyjulius californica),* becomes immobile during darkness by burrowing into the sand. This behavior results in very precise locomotor activity records, and both burrowing and emergence from the sand are responses to decreasing light intensity. Phenomena associated with burrowing are a reduced opercular rhythm and the formation of a mucoid cocoon. The mucoid cocoon originates from a glandular structure located in the opercular cavity, and is similar to a mucous envelope producing gland of the parrot fish family (Scaridae). Current experiments include Thin Layer Chromatography assays of tryptophan, particularly in reference to metabolites such as 5-HT and melatonin, in regional and whole-brain areas.

The laboratory of David Lange, Peter Hartline, and Ann Hartline has been pursuing various approaches to the understanding of sensory information processing. Most emphasis has been on the visual system of *Octopus bimaculoides* and *Loligo opalescens.* One three-week trip on the R/V *Alpha Helix* and

several shorter trips on the R/V *Ellen B. Scripps* and R/V *Alexander Agassiz* have contributed heavily to this work. A complete transfer function for the transduction from light stimulus to the electroretinogram activity is now at hand. Characterization of the response of many optic nerve units has been accomplished. Work is beginning on the further stages of visual processing in the optic lobes.

Since the unit is primarily interested in physiological explanations for aspects of visual behavior, Stanley St. John is continuing visual discrimination training experiments on octopus. A new line of investigation is Ann Hartline's study of the schooling behavior of Loligo. Efforts are being made to examine the development of schooling in squid of different ages. Experiments are being conducted to determine what stimuli are important in controlling the organization of schools.

In marine environments, non-visual systems such as fish lateral line, electric sense, and cetacean sonar have evolved to tell animals about objects distant from themselves. Such systems can be studied in land animals and the principles which are learned may be applicable to marine animals as well. Peter Hartline is studying the infrared sensory system in rattlesnakes by recording from midbrain neurons. The goal is to learn what kind of "image" the brain forms from its infrared organ input, and how this image is formed.

Ocean Research Division

Research conducted by the staff of the Ocean Research Division includes investigations in biological oceanography, in marine chemistry and geochemistry, and in physical oceanography and geophysics.

Several projects concerned with the ecology of the kelp community are being carried out by Dr. Paul K. Dayton. This community is a complex association of species which in the past ten to 15 years has disappeared from certain areas of the California coastline, and has been drastically reduced in other areas. The harvest of the kelp, large abalone and lobster fisheries, and extensive recreational usages, such as sportfishing and skindiving, are dependent upon the maintenance of the kelp community. Proposed research is directed toward an evaluation of natural variation in time and space of selected populations in the kelp community and an evaluation of effects of man-caused disturbance to the kelp community.

A monitoring of permanent quadrats in the kelp bed off Del Mar, begun in July, 1967, continues. The adult *Macrocystis pyrifora* population in these quadrats slowly declined until June, 1970, when some slight recruitment occurred. None of these young plants survived, however, and the first adult plants recorded reaching the surface were seen in June, 1971. Since that time the population has again declined. Observations in February, 1972, have shown another major *Macrocystis* recruitment. Although this recruitment appears to be successful, it is too early to evaluate the survival of these juvenile plants. It can be concluded that five years is not sufficient time to evaluate natural fluxes in the *Macrocystis* population. Another interesting observation in the Del Mar kelp bed is that there was a very large "explosion" of *Diopatra ornata* in 1971. *Diopatra* is sometimes considered a "pollution indicator" species; the outbreak at Del Mar, in the complete absence of known pollution, throws doubt on the use of *Diopatra* as such an indicator species.

In addition to the Del Mar study, permanent base-line quadrats were begun in June, 1971, at Pt. Loma, and in March, 1972, at Catalina Island. It is too early for meaningful analysis, but the following comparative statements can be made regarding survivorship of adult (plants with fronds on the sea surface) *Macrocystis*. The Del Mar bed, which is considered unstable in the literature, had a 78 percent survival for one year (July, 1971, to June, 1972), while the reputed stable Pt. Loma bed had only 53 percent survival of such plants over the same time period. The *Macrocystis* population at Fisherman's Cove, Catalina Island, would seem to be in an ideal habitat, since it is protected from storms which caused most of the mainland *Macrocystis* mortality, and has extremely clear water; nevertheless, this population had by far the highest mortality, as there was observed a survivorship of only 50 percent in five months. For comparative purposes, this would extrapolate to 100 percent mortality within one year. These results are unexpected and emphasize the need for careful long-term monitoring programs of permanent quadrats.

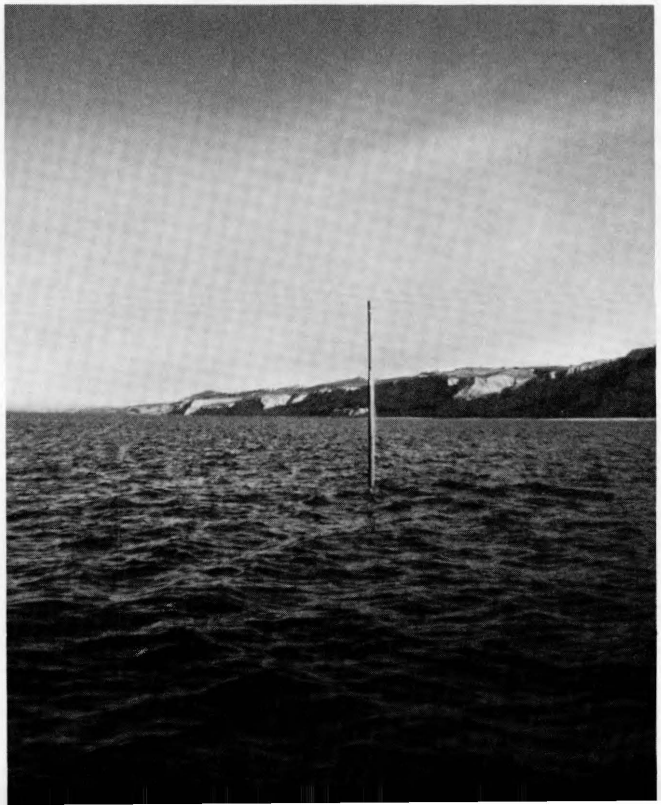
Study of the patterns of distribution and abundance of the starfish *Patiria miniata* is in progress. It has been hypothesized that eutrophication is a major factor in increasing the successful recruitment and survival of urchins; in the same sense it is possible that moderate levels of organic enrichment also selectively increase the population of *Patiria*, a predator with a very generalized diet which includes urchins, larval invertebrates, and detritus. Preliminary sampling has shown that the *Patiria* population may be enhanced by organic effluents from the San Diego sewer outfall, as there appears to be a higher density ($0.65/m^2$) in the vicinity of the sewer outfall than one-half mile north ($0.005/m^2$) and two-thirds of a mile north ($0.0025/m^2$) of the sewer outfall.

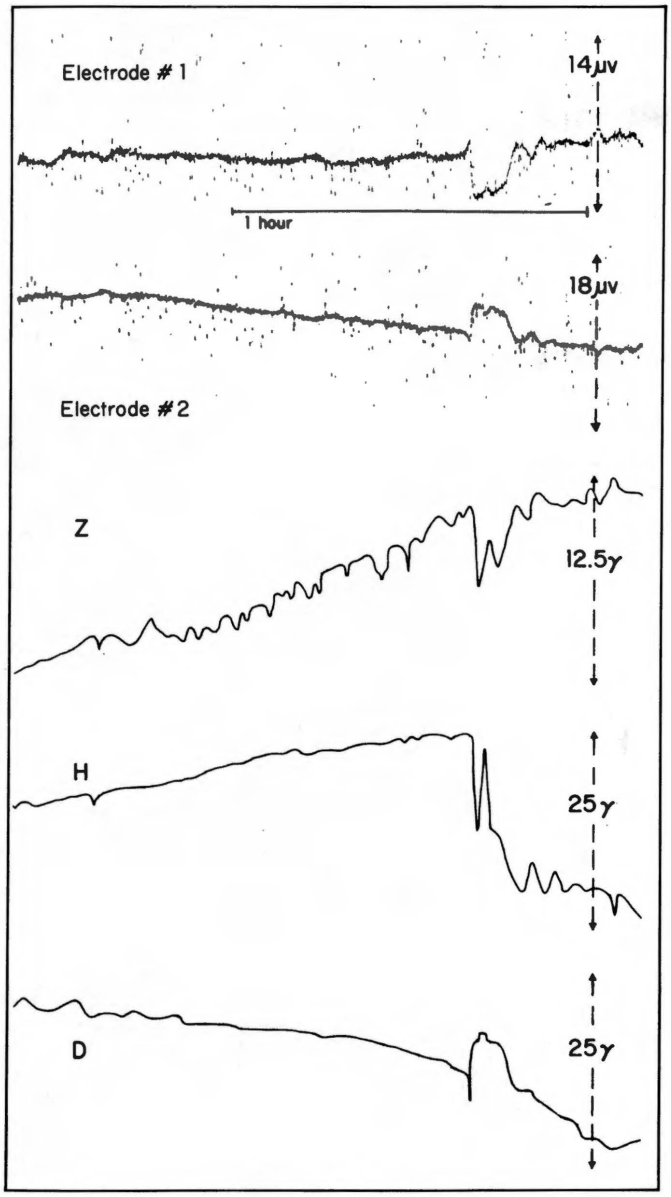
Dr. James T. Enright has continued his studies of "biological clocks," and has completed a study of vertical migration. The laboratory studies of animal timing processes have focused upon the tidal and lunar rhythms of an intertidal isopod. These animals, when placed under constant conditions, show peaks of swimming activity at times of high tide, swimming which is most intense on days of highest spring tides. Several kinds of manipulation of this timing capacity have been undertaken in an attempt to elucidate the synchronization of the "clock" under field conditions as well as to explore the chemical processes underlying the "clocks." Investigations of vertical migration of offshore zooplankton have demonstrated that the time of upward migration of herbivorous copepods is not determined directly by light intensity. Instead, the animals often move up to the surface an hour or two before sunset. The observed timing conforms with predictions based upon the hypothesis that the primary selective advantage of the migrations is to optimize feeding efficiency by taking advantage of the higher standing crop of algae in the late afternoon.

The effects of placing solid substrates in open sandy areas has been a continuing subject of study for over four years by Dr. E. W. Fager and his students. The most immediate result is the concentration of fish, such as sandbass, *Paralabrax* spp., that are normally scattered widely over the sand. These fish

This instrumented station, installed on the continental shelf off La Jolla by the Shore Processes Study Group, monitors environmental paramaters on the shelf and transmits data to a recording station on shore.

Ocean Research Division





Electrode noise test near the sea floor at 1,000 m is illustrated here. Upper two traces show the electric potential between points separated by 2.5 m (in two opposite directions). Lower three traces indicate magnetic pulsations: Z downward, H northward, and D eastward.

Ocean Research Division

do not depend on the solid substrate for food, but they do seem to use it for orientation and, perhaps, shelter. As the substrate ages in place, a covering of encrusting organisms develops, mostly bryozoa, colonial anemones, barnacles, and rock oysters. The difference in species composition of the cover on different sides of the same piece of substrate is usually greater than the difference between sides with the same orientation on separated pieces. Interspersed among the encrusters, and feeding on some of them, are such motile animals as starfish, large crabs, octopi, and spiny lobsters. Though these do use the community on the substrate as food, they also utilize material brought in by water movement, especially on drifting algae. The starfish, themselves, probably arrive mostly by being carried on such detritus that is slowly moved across the bottom by a complex of currents.

In addition to the animals, various algae become established, especially a few species of small red algae and, occasionally, some of the larger brown algae that are important in the kelp beds. There have been *Macrocystis* plants more than nine m long and full-sized *Laminaria, Pterygophora,* and *Egregia*. The latter seems to be the most often successful, both in establishment and persistence, but individuals of all species decline within a year or so for various reasons that do not include predation by urchins. Identical substrates placed at the same depth and within a few hundred kilometers of each other on the sand plain show marked differences in the flora that establishes; one will have a thriving colony of *Pterygophora* and few other species; another will develop a patch of *Laminaria* on one side only; and another may not develop any brown algal community during a period of years.

There has been a continuation of long-term manipulation of the environments that are in place on the sand, such as scraping to bare substrate and the removal of major predators. The latter has not had the striking results expected on the basis of similar studies done in the intertidal zone. The composition of the subtidal community seems far less dependent on predation as a mechanism for maintaining diversity.

Long-term studies have already paid off in terms of greater understanding of the dynamics and stability of communities on solid substrate in shallow water. The communities that have been followed by weekly dives seem to be long-persistent, slow to change in composition and though, in many ways, they are very similar from example to example, in other aspects, they are very different. This is particularly striking in the case of the larger brown algae. Some species have been present as small plants on all the structures, but some have grown to large size and persisted on only a few. Other species have appeared and persisted on only one or two of the structures, despite the uniformity of materials, construction, and environment. It is not now known whether all the "rocks" will eventually come to be alike or not, but present evidence suggests that the early history of a community continues to influence its pattern for a long time.

During the past year a sampling study of diversity indexes was published. This showed clearly the virtues and the limitations of these indexes that are so widely used to judge the state of a community. The response to this paper indicates that a large number of people want guidance on which index to use and how to interpret it.

Dr. Jeffrey L. Bada's laboratory has carried out extensive investigations of the potential uses of the racemization reaction of amino acids in dating various fossil materials. The amino acids commonly found in the proteins of living organisms are almost entirely of the L-configuration. However, amino acids have been found to undergo a racemization reaction producing the non-protein D-amino acids. The rate of this reaction is slow enough to be useful in geochronology.

The racemization reaction of various amino acids has been studied in detail in calcareous marine sediments, in bones, and in aqueous solution. The results of these investigations have indicated that the racemization reaction of amino acids provides an important tool for dating Pleistocene (and possibly older) sediments. The method is now being used to date several deep-sea cores collected during Scripps expeditions. Preliminary data have also shown that the racemization reaction of the amino acid isoleucine can be used to estimated the age of fossil bones, especially those found in caves. The amount of racemization of the amino acid isoleucine has been used to estimate the age of two fossil bones, one from a cave on the Island of Mallorca (Spain) and the other from the core of a deep-sea manganese nodule. The calculated ages were in close agreement with the ages determined using radiochemical methods. These results suggest that the amino acid racemization reaction can be used to date fossil bones which are too old to be dateable by radiocarbon. The major limitation of the reaction in dating bones is that some estimate of the temperature history of the fossil must be available.

Work continues on the application of the amino acid method to the dating of ancient hominoid remains, including those from the Olduvai Gorge area of east Africa and several from South Africa. One of the South African bones is of particular interest, since it is believed to be one of the oldest remains found of modern man. An age determination on this bone would, there-

fore, be an estimate of when modern man originated in Africa. The sample is too old to be dated by radiocarbon. It can be dated by the amino acid method, however, and preliminary results suggest an age of 55,000 to 60,000 years.

Dr. Tsaihwa J. Chow's research interest has been the geochemistry of lead isotopes. His recent work dealt with the lead baseline concentrations of the ocean and of the continental atmosphere.

He participated in the marine baseline study program of the International Decade of Ocean Exploration (IDOE). The purpose of this program was to establish a background concentration level of various man-made pollutants in the marine environment. The tuna family was chosen as the representative of pelagic marine life because its habitat includes both the North and South Pacific. Also, it is at the end of a food chain and a favorite edible seafood. It was found that lead concentrations in the outermost layer of the skin of tuna fish are much higher than within the muscle. Lead concentrations in skeletal bone, spleen (blood), and stomach contents are twice those in the muscle. Lead is not stored in fish bone to the same extent it is stored in mammal bone. Skipjack and yellowfin showed higher lead body burdens than albacore, whose muscle contained an average of 0.02 ppm of lead (wet basis).

For evaluating the extent of lead aerosol contamination, it is desirable to know the continental lead aerosol baseline concentration. The seasonal trend of lead aerosol concentrations at two remote mountainous locations has been established.

The White Mountain sampling site is located at the University's Barcroft Laboratory (near Bishop, California) at an elevation of 3,800 m, the highest-altitude, continuous, year-around sampling station in existence. The Southern California Laguna Mountain site is at the astronomical observatory of California State University, San Diego, on the crest of the Peninsular Range at an elevation of 1,850 m.

For 1971 the lead aerosol concentration at White Mountain ranged from 0.0012 to 0.029 microgram per cubic meter ($\mu g/M^3$) of air, and the annual average was 0.0080 $\mu g/M^3$. The lead areosol concentration at Laguna Mountain ranged from 0.0040 to 0.141 $\mu g/M^3$ for 1969, 1970, and 1971, and the annual averages were 0.048, 0.070, and 0.068 $\mu g/M^3$, respectively. The lead aerosol concentration at White Mountain was lower than that at Laguna Mountain because the former location is at a higher altitude and farther away from sources of pollution than the latter. However, both mountain sites showed the same seasonal trend (a minimum lead concentration in the winter months, a gradual increase in the spring, and a maximum during the summer and early autumn), because both mountain sites are well above the temperature inversion which normally occurs in the winter and traps pollutants below the inversion boundary.

The annual average lead aerosol concentration at the White Mountain station, which is 0.0080 $\mu g/M^3$, may be considered as the present baseline concentration of atmospheric lead for the continental United States.

Coal burning, which contributes annually some 907,194 kg of lead aerosols, constitutes the second largest emission source. In regions where coal burning prevails, high lead concentrations in soot near power plants were observed. Dr. Chow and his associates have developed procedures to trace various leads in the environment by examining the characteristic isotopic composition of lead.

Coal samples were obtained from various North American coal provinces. Coals of the eastern and the interior provinces were deposited during the Pennsylvanian age; those of the Rocky Mountain province during the Mesozoic age; and those of the northern Great Plains and the Pacific Coast provinces during the Tertiary age. The isotopic compositions showed that coal leads are equal to or much more radiogenic than the average lead in the present continental crust. The isotopic composition of lead in these coal samples showed no correlation with the age of plant accumulation or coalification. However, the radiogeneity of the lead in the coal is inversely proportional to the lead concentration. This can be explained by the gradual accumulation of common lead by the coal from its matrix after deposition of the original plant material. The common lead diluted the radiogenic lead components produced by radioactive decays of uranium and thorium.

A comparison of the isotopic compositions of the lead in North American coals with those in gasoline additives which were manufactured with lead ores of "older ages," shows a distinct difference between these two sources of lead pollutants. Therefore, it is feasible to distinguish between gasoline and coal lead by examining their isotopic compositions.

The sea hare, *Aplysia californica,* is a large shell-less mollusc found intertidally at La Jolla. The major foodstuffs of the sea-hare are the red algae, particularly species of *Laurencia.* In Dr. D. John Faulkner's laboratory, it has been shown that bromine-containing compounds from algae are concentrated in the digestive gland of the sea hare. Studies are being made of the relationship between bromine-containing chemicals in the algae and in the sea hare.

As part of a program to study potential pharmaceuticals from marine sources, isolation of a number of antibiotics from marine organisms has been accomplished. The structure of one antibiotic from a sponge of the genus *Verongia* was of interest, since it indicated that the antibiotic had arisen during extraction of the sponge. This has led to the suggestion that the sponge contains a rare arene oxide, from which antibiotics are formed by hydrolysis.

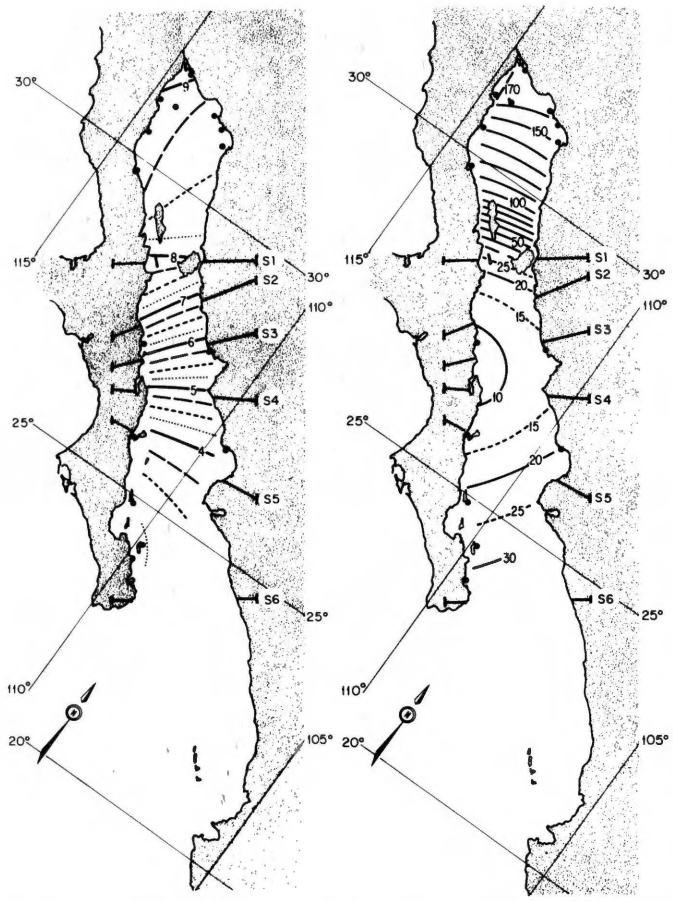
Two potential insect control agents were tested on the cyprid stage of an acorn barnacle, *Balanus galactus.* It was found that the barnacle developed into an adult before settling on its substrate. This is the first report of accelerated metamorphosis in crustaceans. The environmental impact of these chemicals is of great importance.

Dr. Theodore R. Folsom continued a study of distribution of natural cesium that, although present in the ocean in only very small amounts, is spread so uniformly that specialized analytical techniques are required before anomalies can be demonstrated and followed. Highly purified reagents and special high resolution 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 (^{137}Cs) 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 North 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.

Other studies are continuing concerning the character and distribution of natural radioactive burdens experienced by marine organisms, and determinations are being made as to the degree to which certain artificial radioactivities recently may have added to the natural burdens. Last year some startling confirmation was made of evidence that ^{210}Po, a natural alpha-emitting radioactive decay product of radium, contributes the major fraction of the total natural radioactive background in many marine organs. It was shown that the levels of natural radioactivities in marine fish frequently far exceed natural burdens typical of terrestrial animals, including man. In fact, the highest concentration of any natural radioactivity ever reported, in terms of radiation dose delivered to local tissues, was discovered at the Institution's Soledad Mountain Laboratory through inspection of certain tissues of the "caecal mass" of a tuna (*Thunnus alalunga*). Because of the high concentration of ^{210}Po, the total natural radiation energy delivered to these tissues may reach intensities about 1,000 times higher than what is typically expected in human liver tissues, for example.

Dr. Vernon F. Hodge, in collaboration with Dr. Folsom, Dr. David Young and Kai Wong, has been studying the long-term biological availability and distribution of several radioactive and stable elements that enter the oceans as atmospheric fallout or as reactor wastes. Fallout radioactivity found in livers of albacore, caught off San Diego during the last eight summers, suggests that cobalt, silver, and plutonium introduced into surface waters of the North Pacific will remain available to this tuna



Representation of Gulf of California tidal topography is shown, the lefthand figure being a cotidal map for an M_2 tide. Number refers to time lag in hours with respect to high equilibrium tide on Greenwich time. At right is corange map for M_2. Elevation is in centimeters.

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for a decade or more. Zinc-65 concentrations in these livers provide evidence for large new inputs of this nuclide to the oceans in 1968. Concentrations of cobalt and silver nuclides attributable to the first power reactor in Southern California were found to have decreased in molluscs and algae this past year.

The alpha emitters ^{239}Pu and ^{210}Po were shown to accumulate preferentially on the surfaces of several kelp. For example, 2,000 times more ^{210}Po is typically found on the outside surface of the kelp bladder than is in the innermost tissues. Lead-210 and ^{239}Pu show the same inside-outside trend.

Special seagoing cesium collection and processing procedures were developed to meet requirements stipulated in the initial GEOSECS program.

In collaboration with 44 other laboratories, intercomparisons of trace level radioactivity standards were carried out under sponsorship of the International Atomic Energy Agency. In addition, several intercomparisons were made with eight laboratories in this country that are interested in radioactivity and trace elements in the Great Lakes. These intercomparisons clearly demonstrated that serious discrepancies can appear in environmental reports from different laboratories because of inadequate methods or standards.

Dr. Joris T. M. Gieskes and graduate student Carl Rogers investigated the accuracy of the closed vessel titration method for alkalinity and total carbon dioxide. In addition to improvements in the mathematical evaluation, a more appropriate pH range was established for this method. Dr. Gieskes also participated in Leg 25 of the D/V *Glomar Challenger* to collect more information and data on the geochemistry of Deep Sea Drilling Project cores. Rogers sampled some cores on the East Pacific Rise for similar investigations.

Edward Sholkovitz finished his PhD thesis with a detailed study of the early diagenesis of organic matter in anoxic marine sediments. Graduate student Peter Christenson further investigated the thermodynamics of mixed electrolyte solutions, with particular emphasis on a study of the application of free energy relationships to more complex mixtures of electrolytes.

Dr. Charles D. Keeling, assisted by Drs. Robert Bacastow and Carl Ekdahl, continues his investigation of the geochemistry of carbon dioxide. Fourteen years of measurements of atmospheric CO_2 at the South Pole and at Mauna Loa Observatory, Hawaii, have been used to determine how the CO_2 from the burning of fossil fuel redistributes between the air and sea. The airborne fraction has varied synchronously in both hemispheres with low values in the middle 1960s and high values recently. The variability reflects short-term global changes in CO_2 uptake by land plants and ocean water. Dr. Keeling and his associates have shown that, if the present trend in the consumption of fossil fuel continues, the capacity of the oceans to absorb new increments of industrial CO_2 will diminish drastically in the next century because of increased acidity of surface ocean water. Since the growth of land plants can probably not be greatly accelerated, most of the industrial CO_2 will remain airborne from about 2040 A.D. until the end of the fossil fuel era. The concentration of atmospheric CO_2 may rise to several times the present value and significantly alter the radiation balance of the earth's atmosphere.

During 1971-1972, the Geochemical Ocean Sections Study (GEOSECS) Operations Group, under the direction of Arnold E. Bainbridge, continued to develop, construct, and test analytical systems with associated computer interfaces for the shipboard analysis of various physical and geochemical components of seawater.

These physical and chemical measurements were made on samples taken in the Atlantic Ocean beginning in July, 1972, and will be made in the Pacific beginning in June, 1973. All measurements made at sea will be directly coupled with the shipboard computer. Data will be logged from principal and auxiliary sources and brought together in a real time system to compute final values of the parameters for immediate evaluation before moving off station.

The basic purpose to be achieved by GEOSECS is the detailed measurement of some 40 constituents along arctic and antarctic sections at all depths to provide a set of physical and chemical data measured on the same water samples, in both Atlantic and Pacific Oceans. These data will permit quantitative studies of oceanic mixing and organic productivity and, at the same time, serve as a base line for levels of pollutants, fission, and waste products being added to the sea. Continuous profiling of salinity, temperature, oxygen, and particulate concentration will provide the details of ocean structure (micro and macro) which are basic to the understanding of transportation of chemicals within the ocean system.

Shakedown and inter-calibration cruises were accomplished during November and December, 1971, and March, April, and May, 1972. Beginning mid-May through mid-June, 1972, more than 32 tons of winches, cable, and portable laboratories and 25 tons of analytical equipment, computers with associated peripheral equipment, testing and calibration instrumentation, spares, and supplies were shipped from the GEOSECS Operations Group headquarters in Sorrento Valley, La Jolla, by truck and air for the expedition staging point in Woods Hole, Massachusetts. These items were installed on R/V *Knorr,* of the Woods Hole Oceanographic Institution, and a final shakedown was undertaken and completed. The expedition departed from Woods Hole on July 18, 1972.

A data processing computer facility is planned for shore processing of the large volume of data anticipated.

Research goals of the Shore Processes Study Group under Dr. Douglas Inman include: 1) field and laboratory measurements of waves, winds, currents, and sediment transport; 2) identification and understanding of physical processes operative in the nearshore zone; 3) application of these processes to the dispersion of pollutants and the development of improved coastal engineering techniques; and, 4) formulation of criteria for long-

range planning of the coastal zones.

Research by this group includes study of the interaction between incident waves and edge waves in the nearshore zone. Initial results of these efforts led to an understanding of the mechanism for the generation of rip currents and formation of nearshore circulation cells. The circulation cells were shown to be primary mechanisms for mixing and dispersing of nearshore waters. Recently this study has been extended to include the effects of standing edge waves that are trapped by irregularities in coastal topography. It is now realized that standing edge waves are an important factor in the formation of crescentic longshore bars, and in the generation of strong currents in submarine canyons.

The instrumentation capability of the group has been expanded to include meaningful measurements of waves and currents over large areas of the continental shelf by use of a sophisticated data acquisition system. Robert Lowe, senior development engineer for the group, has developed a shelf-and-shore (SAS) simultaneous data system. This system consists of several shelf stations that are bottom referencing spars containing oceanographic sensors and a telemetry transmitter; and a mobile shore station that receives the telemetry signals from up to six shelf stations and records the data for analysis. Each shelf station can accommodate digital wave staffs, pressure sensors, current meters, and/or other sensors that are used individually or as group arrays to monitor the environment at the installation site.

One shelf station is presently deployed off Torrey Pines Beach, three km north of Scripps, to make measurements of waves incident to the beach. The waves are measured using a line array of pressure sensors mounted on the ocean floor; the data are transmitted directly to Scripps for recording. The line array provides both energy and directional spectrum of the wave field, which is being studied by graduate student Steve Pawka. These daily measurements will be compiled over a period of two years to determine a wave climate for this area.

Beach profiles are measured along three rangelines established on Torrey Pines Beach in the vicinity of the shelf station. Charles Nordstrom, staff research associate, is responsible for making the profile measurements. In addition, offshore sand level changes are measured using reference rods placed in the bottom at various depths out to the 20-meter-depth contour. Measurements of the exposed reference rods give an accurate measure of the change in sand level at specific points which are used to correct the less accurate depths obtained by fathometer. The beach profiles are used to determine the changes in sand level along each rangeline in relation to waves incident to the beach. It is hoped these data will provide additional insight into the mechanics of the equilibrium profile of natural beaches.

Rolland Harris, dredging consultant, and Burton Adams, associate development engineer, are working on several studies aimed at improved technology for moving and transferring sand. One study, the crater-sink sand transfer system, consists of a hydraulic jet pumping sand from the bottom of a crater. The crater acts as a gravity-fed sink for sand and other material. The crater-sink sand transfer system shows promise of becoming an effective method of bypassing sand around coastal structures, for moving sand from offshore deposits to feeder beaches, and for recycling sand along beaches subject to erosion. Initial testing is being carried out under controlled conditions in the test basin at Scripps's Hydraulics Laboratory. The system will be field tested in the ocean for evaluation of its performance under different wave conditions.

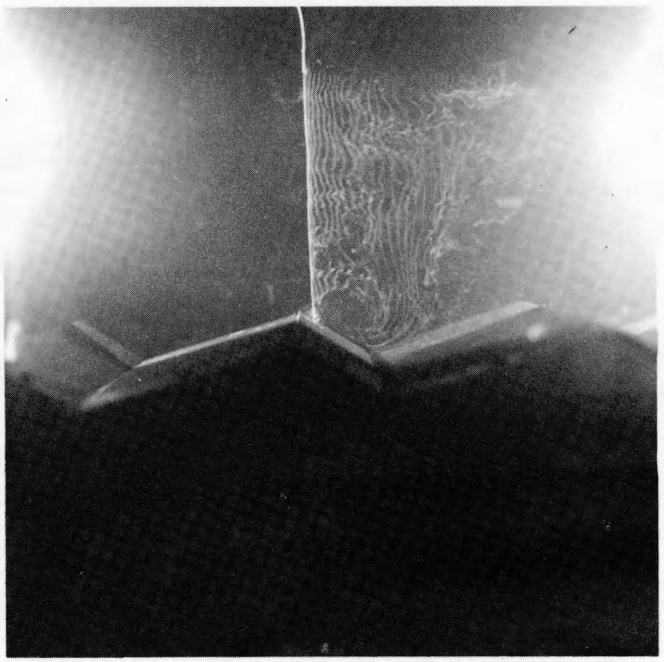
Another procedure under study by graduate student Edward Tunstall utilizes "phase-dependent" roughness elements for controlling the direction of sand transport by waves. These roughness elements resemble natural asymmetrical sand ripples and influence the sand transport because an intense vortex forms 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.

Dr. Inman is also studying ancient harbors in an effort to learn what the people of earlier civilizations knew about controlling the siltation of harbors. Since early ship builders and harbor engineers did not have access to powered machinery, they worked more closely with the natural effects of waves and currents; it is hoped that study of ancient harbors will reveal methods of controlling sand transport not passed on to modern technology.

Dr. Robert S. Arthur has made preliminary studies of the dynamics of the wind-induced circulation and upwelling in the Gulf of Tehuantepec. In collaboration, Dr. William Holland, of the Geophysical Fluid Dynamics Laboratory, Princeton University, and Dr. Warren White have initiated experimental numerical modelings of this wind-driven current system. In another collaborative study with Joseph L. Reid, consideration has been given to a qualitative explanation of the shift of the centers of high-pressure ocean gyres and ridges toward the poles as attention is directed to deeper and deeper levels. The observed shift is found to be consistent with the interaction of a Sverdrup transport produced by the wind and a stable density distribution satisfying an upper boundary condition (density increasing from equator to pole in and somewhat below the mixed surface layer) and a bottom boundary condition (meridional density gradient small or zero at the bottom).

Drs. Charles S. Cox and Michael Gregg and others are continuing use of their "free-falling microstructure recorders" to identify the mechanisms of mixing within the deep oceans, to find the locations where mixing occurs, and to measure the intensity of mixing.

Mixing is responsible for transporting momentum, heat, and chemical substances within the oceans. Some indications of these processes have been discovered as a by-product of ocean circulation studies which utilize conventional oceanic instrumentation, but more quantitative measurements are needed. This requires specialized apparatus capable of registering the structure of velocity, temperature, or chemical composition in sufficiently fine detail to measure the ultimate diffusion by molecular processes.



Shore Processes Study Group photo shows wave motion producing a vortex over the steep face of a phase-dependent roughness form. Intensity of vortex formation controls the direction of sand transport over the form. The flow pattern is delineated by hydrogen bubbles from an electrically pulsed platinum wire.
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Mixing is an episodic phenomenon, sharply limited vertically by the stability of the water column and occurring infrequently. As part of his thesis work, Peter Hacker has found that the intensity of mixing may vary over a factor of 500 from one 10-m section to another. The accumulation of statistically valid averages is accordingly quite difficult. Studies within the centers of the North and South Pacific Gyres indicate an order of magnitude differences, but whether this represents a difference caused by season, weather, or position remains to be determined.

Dr. Russ E. Davis has been examining theoretical descriptions of weak motions in a turbulent flow. The objective of this study is to determine the form of the relationship between mean motions and Reynolds stresses in turbulent flow. It has for years been common to assume, in the absence of satisfactory theory or measurement to the contrary, that the turbulent stresses could be related to the mean flow using an eddy viscosity. This phenomenological concept has never found any theoretical basis but it has proved reasonably successful in predicting mean flows. Dr. Davis' theory, which involves severe mathematical approximations but no phenomenological hypotheses, suggests that the eddy viscosity concept has a dynamical basis and is appropriate to a certain class of mean motions; in general, the stress is given by a visco-elastic relation.

Dr. Davis has also been active in the planning stages of MODE (Mid-Ocean Dynamics Experiment). The primary concern has been with determining the optimal placement of various current meters which will be deployed in the MODE array. The limited amount of data available from the area were analyzed to determine the characteristic scales of the dominant motions (which turned out to be roughly two months and 100 km). These data were used in conjunction with a Weiner filter technique for mapping random functions to determine the current meter placement that maximizes the area over which accurate maps of velocity can be drawn. The mapping technique appears to hold great promise for treatment of a large class of oceanographic data, since it allows direct determination of the expected errors in the map. Historically, mapping has relied on subjective judgment and no quantitative error estimates were possible.

Dr. Jean H. Filloux has processed tide data from the Gulf of California obtained during 1970 and 1971. From the resulting diurnal and semidiurnal transfer functions between gravitational forces and recorded elevations, a clear representation of the Gulf of California tidal topography has become possible. The accompanying photograph illustrates an example given in terms of cotidal and corange maps for the semidiurnal lunar constituent M_2.

Development of a short-span, two-component, free-fall and buoyant recovery electric field recorder intended to estimate barotropic motion at three MODE sites in the Atlantic during 1973 is in progress. It has been demonstrated that electrode noise on the vicinity of the sea floor is not a limiting factor. This conclusion is best illustrated by the photograph in which the upper two electric field traces are shown to be very well correlated with the magnetic pulsations of the sudden commencement of a magnetic storm shown on the lower three traces. The experiment was carried out at a depth of 1,000 m, using a salt bridge type of electrode connection. Resolution is estimated to be .1 μ Volt/m.

A low-drain automatic electrode reversal system is being tested with a view to eliminate long-term electrode drift.

Drs. Carl Gibson and Carl Friehe and their associates have made a series of boundary layer observations from the research platform FLIP. Fine-scale velocity, temperature, and humidity fluctuations were made over the open sea, and determinations of the fluxes of momentum and sensible and latent heat were obtained. Corrections for the motion of FLIP, which is a relatively stable platform, turned out to be important. Five-scale measurements of velocity and temperature in the mixed layer of the ocean were used to deduce viscous and temperature dissipation rates. In another program from the R/V *Thomas Washington*, measurements of small-scale fluctuations were made at a depth of about 100 m in the Pacific Equatorial Undercurrent. The velocity and temperature spectra implied large viscous and temperature dissipation rates corresponding to rather strong turbulence. An interesting further implication of the rates is that the vertical diffusivity of momentum is much larger than the diffusivity of heat.

Dr. Myrl Hendershott, along with several other Scripps staff members, was active in the planning of MODE, for which the most intensive part of the field work is to begin in late winter of 1973. Dr. Hendershott and graduate student David Behringer developed a numerical model for barotropic flow over the actual relief of proposed MODE sites, and studied the way in which eddies and low-frequency motion are influenced by bottom roughness.

Drs. Hendershott and Paolo Rizzoli, the latter of Laboratorio Dinamica delle Grandi Masse, Venice, Italy, developed a theoretical model of flow in the northern Adriatic Sea during winter months. The model is able to predict the winter field of temperature and hence density, and makes a number of predictions about the winter flow which is susceptible to direct observational test.

Dr. Hendershott continued his study of global ocean tides. He found that the deformation of the solid earth by the weight of the oceanic tidal column, an effect heretofore neglected in models of ocean tides, must be included in models aspiring to better than qualitative accuracy in their prediction.

Dr. Peter D. Killworth has investigated the problem of the meander of the Kuroshio Current between its two stable positions. It has long been known that during the meander, a mass of cold water rises between the Kuroshio and the coast of Japan. The objective of the study was to determine whether the appearance of the cold water is cause or effect, and to this end a two-layer numerical model of the region has been created. A variety of incoming flows can be simulated, and thus allow analysis of the meander under many conditions.

A second problem concerned the properties of the so-called "thermocline equations"; *i.e.*, the equations of an ideal, geostrophic and hydrostatic fluid. It has been found that, in contradiction to the expressed hopes of previous workers, in general the equations do not possess solutions, and the physical consequences of this were studied.

In contrast to the above, Dr. Killworth and Dr. H. Russell Bernard, an anthropologist in the Center for Marine Affairs, cooperated on a truly interdisciplinary study of the social structure on board an ocean-going research vessel. This was studied ethnographically and numerically, and involved the development of a completely new sociological tool. The importance of the smooth day-to-day existence of the technicians on board, and the relations between captain and senior scientists were stressed. This study is hoped to be the beginning of a complete survey of research vessels, to be undertaken in spare time over the next few years.

Dr. Robert L. Parker has been working on two problems connecting the ocean with the Earth's magnetic field. In many places small magnetic fields are observed that are caused by permanent magnetization of the oceanic crust at the time of its formation; analysis of such measurements has been significant in understanding the recent geology of the ocean basins through the theories of sea-floor spreading and continental drift. To deduce the actual magnetization of the crust, geophysicists generally construct plausible models, calculate their behavior, and compare it with what is observed in practice. When large quantities of measurements are available (especially when a small area is intensively surveyed), the calculation phase of this procedure can be very time-consuming and expensive, even with modern computers. Using a Fourier transform approach, Dr. Parker has developed a theory that allows these calculations to be performed very rapidly. With programs developed by Steve Huestis, work is under way to interpret a detailed magnetic survey in the North Atlantic. The same method can also be applied to gravity measurements; it is expected that it will receive wide application in marine geophysical interpretation.

The second geomagnetic problem under consideration last year has been that of interpreting observations of the short-period fluctuations measured on the sea floor. These variations (in the period range 10 min. to a day) originate in the ionosphere, but are of interest to the geophysicist because they enable him to

deduce the electrical conductivity within the Earth, down to the depths of hundreds of kilometers. Working with Anthony White and John Greenhouse, Dr. Parker has developed a method that includes a realistic representation of the ocean's conductivity while allowing the deep conductivity to vary laterally. This situation is particularly important when measurements are made near to shore, because it is suspected that the conductivity rises sharply under the ocean-continent boundary. Drs. White and Greenhouse are applying the interpretation technique to data obtained off California and in the Gulf of California with the instruments of Professor Victor Vacquier.

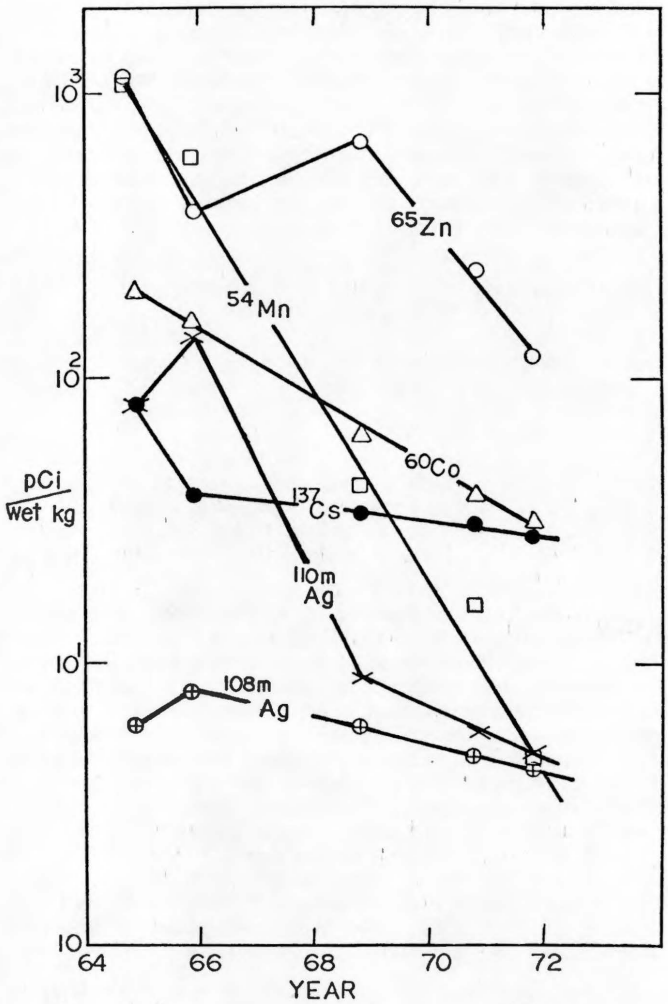
During the past year, Margaret K. Robinson's Bathythermograph (BT) Analysis and Processing Group has been editing the final results of the computer analysis of temperature data in the Pacific Ocean, and drafting of the horizontal contour charts for publication is under way. The title of this atlas, to be published in color by the Naval Oceanographic Office, will be "Atlas of Monthly Mean Sea Surface and Subsurface Temperature and Depth of the Top of the Thermocline, North Pacific Ocean."

A large-scale version of the temperature fields in the Gulf of California and Pacific Ocean adjacent to Baja California, extracted from the Pacific atlas, has been prepared for separate publication in early 1973 by the San Diego Museum of Natural History. A similar large-scale version of the temperature fields in the Red Sea was prepared for presentation at a special symposium on the Red Sea, in Paris, in October, 1972, sponsored by the International Association of Physical Oceanographers. This atlas, too, will be published in 1973. A large-scale version of the temperature fields in the Gulf of Mexico, Caribbean Sea, and adjacent Atlantic Ocean, bounded by 35°N and 60°W, extracted from the temperature atlas of the North Atlantic Ocean, is being prepared for publication in January, 1973. The enlarged charts in these separate atlases describe in greater detail the sharp horizontal and vertical temperature gradients found in these areas.

The atlases are based on digitized BT temperature data collected since 1941, supplemented by available reversing thermometer temperature data. The analysis is being done by computer, using programs that are operational at Scripps and at the Fleet Numerical Weather Central (FNWC), Monterey, California. These computer programs, which produce complete fields from existing data by interpolation, also have been used to derive annual temperature distribution from 125 m 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 CalComp 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.

Since January, 1968, under contract with the National Oceanographic Data Center, the Naval Oceanographic Office, and the National Science Foundation, the Group has digitized 139,000 BT observations, using the BT digitizer designed and developed at Scripps under the sponsorship of the Office of Naval Research. The digitized BT data included observations from Australia, Canada, Chile, Peru, the Netherlands, New Zealand, and Turkey, in addition to those from Duke University, Durham, North Carolina; Oregon State University, Corvallis; University of Miami, Coral Gables, Florida; the University of Washington, Seattle, and the United States Navy, Coast Guard, and National Marine Fisheries Service.

Analysis of current measurements made in 1971 on the equator in the Central Pacific by Dr. Bruce A. Taft has shown that there is a series of reversals of the current direction with depth. In addition to the well-known Equatorial Undercurrent, which flows eastward underneath the usual westward surface current, there is westward flow between 500 m and 1,000 m (Equatorial Intermediate Current) and an eastward flow with a speed of 5 cm sec^{-1} at a depth of 3,000 m. There is evidence that the deep westward and eastward flows are ocean-wide and that each transports rather well-defined water characteristics. The eastward flow at 3,000 m was quite steady; a four-and-one-half month current meter record showed the flow was eastward during the entire period of measurement. There are very few deep-water current measurements in the world ocean which have indicated such consistency in velocity. There may be other reversals in the Equatorial Current profile below 1,000 m; continuous profiles to the bottom have not been made.



Concentrations of Zn-65, Mn-54, Co-60, Ag-110m, Ag-108m, and Cs-137 found in whole livers of adult albacore caught in early summer fishing efforts off Southern California. These are records of extremely small traces of radioactivity that are useful for understanding the open Pacific. These radioactivities are, however, far below the levels that might present any hazard to human beings.

Soledad Mountain Laboratory

During the summer of 1971, Dr. Taft carried out an intensive study of the flow of the Kuroshio Current south of Japan. Determinations of the path of the current showed that the behavior of the current was strikingly different east and west of the island of Shikoku. The position of the current was extremely variable went of Shikoku, but was very steady farther downstream south of Honshu. Deep current measurements under the Kuroshio south of Honshu show that the movements of the current at the surface can be predicted from the bottom current records. The Kuroshio extended to the bottom south of Honshu and the time stability of the path there may have been caused by topographic control of the current path. The deep water current meter records from the region where the path was very variable did not show motion at the bottom which was in the same direction as the surface flow of the Kuroshio. The Kuroshio appears to be a relatively shallow current as it enters the region south of the

main islands of Japan; as the current flows to the east it deepens and reaches to the bottom off Honshu. Estimates of the volume transport of the Kuroshio range between 55 and 65 million m^3 sec^{-1}. This transport is quite similar to the Gulf Stream transport at the same latitude.

Dr. William G. Van Dorn and graduate student Stephen Pazan extended a previous study of shallow water waves breaking to deep water, an area that has received little scientific attention. The objectives of both studies are to conduct careful measurements of all wave parameters important to the breaking process under a variety of controlled conditions, with the hope of arriving at generally applicable breaking predictions. They are presently measuring surface elevation, subsurface pressure, and wave orbital velocities in periodic waves that are gradually steepened to the breaking point in a deep converging channel. The waves are generated by a tape-controlled servomechanism that permits perfect duplication of complicated waveforms.

Dr. Van Dorn has completed the manuscript of his new book, *Oceanography and Seamanship,* to be published soon by Dodd, Mead & Co., New York.

The climatological study of coastal upwelling in the eastern Atlantic has been continued by Dr. Warren S. Wooster in cooperation with Andrew Bakun and Douglas R. McLain of the National Marine Fisheries Service, Monterey, California. In addition to revealing the seasonal migrations of upwelling, it has been possible to identify a major area of chronic upwelling off the northwest coast of Africa (south of Cap Blanc) corresponding to a zone of maximum offshore Ekman transport as indicated by merchant ship wind observations. Strong summer upwelling has also been found off the Portuguese coast, similarly associated with enhanced offshore Ekman transport. Attention is now being directed to the time and space variations in upwelling intensity in the Gulf of Guinea and the southwest African coast.

Physiological Research Laboratory

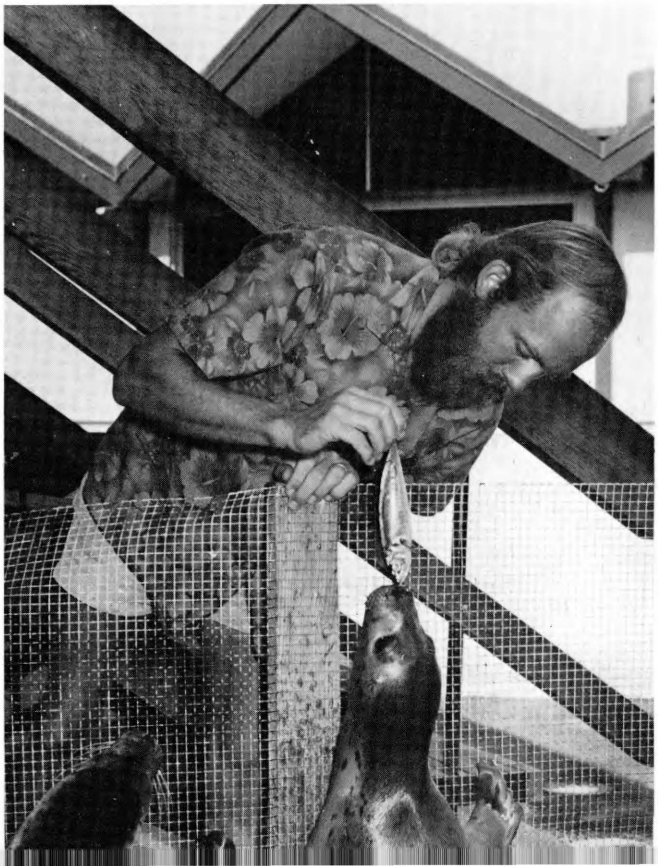
Dr. Robert Elsner is continuing his research in diving physiology. Of special interest is the use of marine mammals in the exploration of those evolutionary adaptations that reveal the general nature of reactions to asphyxia in terrestrial animals and man. These responses have been found to be widespread throughout vertebrate species, and they constitute an asphyxial defense mechanism of fundamental importance. Although the primary adaptive mechanisms appear to be circulatory, they are paraleled by important cellular features. It was demonstrated earlier here that some species of diving seals possess enhanced tolerance to cerebral hypoxemia and that their brain tissue can in severe asphyxial conditions rely on anaerobic glycolysis for metabolic processes. In a recent study, enzymatic properties of representative tissues were examined by a study of activities of two key enzymes. This Laboratory has joined with colleagues at Stanford University Medical Center in the continuing investigation.

Activities of cytochrome oxidase, a rate-governing enzyme in mitochondrial oxygen utilization, and of pyruvate kinase, a key enzyme in the glycolytic pathway, have been determined in tissues from three species of diving mammals. Thus, the importance of both aerobic and anaerobic processes, as indicated by the activities of these key enzymes, could be compared with values for non-divers and could also be related to diving capabilities, which vary among the species studied. Cytochrome oxidase activity of heart, brain, skeletal muscle, liver, and lung differed little from that observed in rabbit tissues, suggesting that oxidative capacity is not markedly enhanced in the divers. Pyruvate kinase activity, however, was found to be higher in marine mammal tissues. This was most notable in heart and brain, the two vital organs through which blood continues to be circulated throughout the dive. Furthermore, the determinations for these tissues correlate well with diving capability among the species studied, pyruvate kinase activity being highest in the longest diver, the Weddell seal. Tissue glycogen storage is also high in this species.

In the spring of 1972, Dr. Elsner was chief scientist of the *Alpha Helix* Bering Sea Expedition. He worked with Drs. H. T. Hammel, of Scripps, and H. Craig Heller, of Stanford University, and preliminary studies were initiated on the effects of combined thermal and diving stresses in the harbor seal. Circulatory responses to diving and thermal load might be expected to be in conflict, since each alone produces opposite reactions. Diving results in intense peripheral vasoconstriction, while the requirement for heat dissipation results in peripheral vasodilation. The consequences of simultaneous exposure to combined stresses are of interest for what may be learned of priorities governing central regulating mechanisms. The harbor seal was used as the experimental animal for this study, because it is known to respond vigorously to diving, with drastic reduction in peripheral blood flow as part of a generalized reduction and redistribution of cardiac output. It shares with other marine mammals a restriction to only vasomotor means for controlling heat dissipation to the environment. The procedures employed involved measurement of superficial and core temperatures during experimental diving in several controlled thermal environments. In some procedures the temperature of the preoptic hypothalamic region was controlled and manipulated in order to vary the temperature of the central thermoregulator as a means of determining threshold and other characteristics of the responses. The hypothalamic tissue was heated, cooled, and left undisturbed during separate experiments. Diving resulted in reduction of core temperatures and a general decline in superficial temperatures and heat loss. Vasodilation induced by hypothalamic heating was promptly inhibited at the onset of the dive and reappeared again after the dive as heating continued. This and other evidence suggest that thermoregulatory thermogenesis was inhibited during diving. It is believed that these results support other evidence for a markedly reduced metabolic rate during diving. They also indicate that the diving response vigorously overrides thermoregulatory stimuli.

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

Harbor seal gets meal of mackerel from James Wright in Physiological Research Laboratory pool area.



While they were aboard *Alpha Helix* in the Bering Sea, Drs. Hammel, Elsner, Heller, and C. Bainton and J. E. Maggert experimentally heated and cooled the preoptic and anterior hypothalamic (POAH) tissue in the harbor seal, and found that physiological responses, such as vasodilation of cutaneous blood vessels and shivering, were easily affected. They also learned that the temperature of the skin had little effect on the threshold hypothalamic temperatures for these responses, whereas the temperature of extrahypothalamic core temperature had a large effect. During a simulated dive, no thermoregulatory responses could be activated by heating and cooling POAH tissue of the seal. Dr. Larry Crawshaw found that heating the forebrain of the Scorpion fish *(Scorpaena guttata)* increased ventilation of its gills, while cooling the same tissue decreased gill ventilation. This suggests that the physiological effects of temperature on ectotherms may, in part, be caused by the temperature of the brainstem. Dr. Frank Sharp found that the hypothalamic temperature threshold for thermoregulatory salivation is greatly diminished in running dogs and is increased in febrile dogs. He also demonstrated that anesthesias obliterate all thermoregulatory responses that are normally activated by changing hypothalamic temperature. Dr. Annette Halpern has been investigating freezing of water in arctic tenebrionid beetles without damage to the insect, and Dr. K. R. Morgareidge has been searching for autonomic thermoregulatory responses in reptiles.

Drs. P. F. Scholander and Hammel have been investigating the basis of osmosis. Using a colloidal suspension of magnetic ferrite particles in water, which can be forced to migrate in a magnetic field gradient, they have been able to demonstrate that the colloidal osmotic pressure (COP) increased as the ferrite particles were forced to migrate away from the semipermeable membrane and toward the unrestrained surface of the solution. The increase in COP was attributable to the tension in the water caused by viscous shear while the particles were migrating through the water and by the pressure of the particles against the free surface in equilibrium. Contrariwise, when the magnetic particles were forced to migrate toward the semipermeable membrane, there could be a very negative COP followed by an equilibrium COP that was nearly zero. The only plausible deduction from these experiments seems to be that osmotic pressure occurs when a hydrostatic tension in the solvent of the solution is caused by the dispersal pressure of the solute.

Dr. Edvard A. Hemmingsen continued to study the respiratory physiology of the antarctic hemoglobin-free fishes and of other fishes. The respiratory and cardiovascular responses to anemia and to stresses imposed by hypoxia and by elevated temperatures were of particular interest. In addition, he studied the changes in concentration and respiratory properties of myoglobin in the tissues of penguins during their development from chick to adult. Studies in progress are concerned with the properties of gases in water at high gas pressures and with the cavitation properties of highly gas-supersaturated liquids.

Research activities of Dr. Gerald Kooyman have dealt with diving behavior of birds and mammals, and modifications of the respiratory system in aquatic reptiles, 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 its re-inflation upon decompression. These studies are expected to be continued in the future as are more general investigations of the morphology and function of the vertebrate lung.

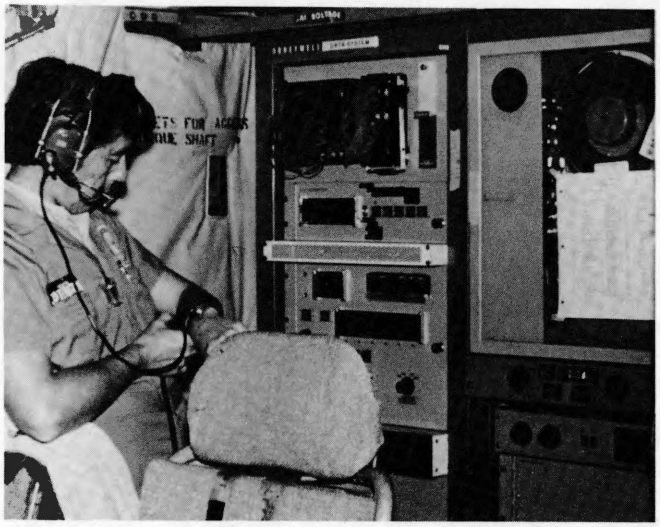
The volume of solutions of amino acids continues to be of interest, and is being measured as a function of temperature from 0°C and of pressure from 0 to 2,000 atm. The value of the partial molal volume, among other quantities, is calculated from these data. Studies by Dr. A. A. Yayanos have concentrated on testing theories that might explain the observed increase in the value of the partial molal volume with increasing pressure. One theory, treating the amino acid as an incompressible entity, describes the interaction between water molecules and the charges on an amino acid molecule, and accounts for only part of the observed pressure-induced increase in the value of the partial molal volume. Another theory treats the amino acid as a compressible entity undergoing a reactive compression when interacting with water molecules. This latter approach gives better agreement with experiments. The overall objective of these studies is to develop rules for predicting the effect of pressure on the volume of a molecule and on the interactions between molecules. Ultimately, such knowledge forms a basis for understanding certain biological and chemical processes at the high pressures in the depths of the oceans.

Drs. Larry Crawshaw and Walter Garey studied the circulatory and ventilatory responses exhibited by scorpion fish to selective heating and cooling of their hypothalamic tissues. Dr. Garey serves as principal investigator and program manager of the R/V *Alpha Helix,* a national facility sponsored by the National Science Foundation and operated by Scripps Institution.

Dr. Arthur L. DeVries, Dr. Yuan Lin DeVries, and John Duman are continuing their research on freezing resistance in polar

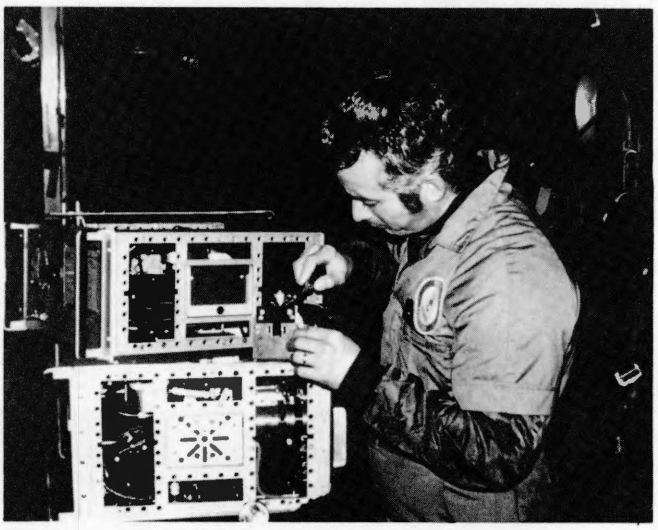
Project engineer Richard Johnson operates automatic airborne data logging system used by Visibility Laboratory to record optical and meteorological data.

Visibility Laboratory



Principal flight technician Len Castro performs inflight repair of a Visibility Laboratory counter for atmospheric particles.

Visibility Laboratory



fishes. The chemical and physical properties of a glycoprotein which acts as an antifreeze agent in these fishes has been the main subject of study. Unlike most antifreeze agents, the glycoproteins produce a freezing point depression in a way that preserves ionic and osmotic balances. A large part of Dr. DeVries' work was carried out at McMurdo Station, Antarctica, with the assistance of David Checkley and James Raymond.

Visibility Laboratory

The Visibility Laboratory conducts a broad spectrum of research related to the propagation of light, both natural and artificial, through the atmosphere or through sea water; the recording of image information by photographic cameras, photoelectric systems, or the human eye; and the fundamentals of the extraction and interpretation of the received image information. The following examples illustrate the diversity of current research activities.

OPTICAL OCEANOGRAPHY

The propagation of light in sea water continues to represent a major research interest of the Visibility Laboratory. Under the direction of Drs. Seibert Q. Duntley and Wayne H. Wilson, experiments were performed to determine the detailed structure of in-water photographs of a laser point source. These experiments were performed in a laboratory tank filled with sea water. Instruments which measure water clarity were operated during the experiments. These fundamental data on the quality of point imagery of objects can be used to predict image quality for any general object.

In another set of tank experiments, Roswell W. Austin explored techniques for obtaining improved image quality over long water paths. In this research conventional light sources for illuminating the object were replaced by a flying spot scanner system which illuminates the object, rapidly, one point at a time in an ordered sequence. Images are then formed by modulating the intensity of a spot on a cathode-ray-tube display in response to the amplitude of the total signal received by a lensless (nonimaging) detector. The position of the spot on the display is synchronized with the position of the illuminating scanner in much the same manner as in conventional television systems. The essential improvement of this system over conventional imaging methods results from the utilization of all the flux reaching the receiver at a given time in the formation of the image. Thus, the presence of scattering particles in the water between the object and the receiver does not degrade the image.

The Laboratory has continued and expanded its interest in the remote sensing of the oceans in the visible spectral region. Using radiative transfer methods, Dr. Duntley and his colleagues have been able to compute the upward directed spectral radiance signature resulting from the interaction of natural daylight with a body of water having an arbitrary vertical distribution of optical properties. Such signatures represent the optical input to the bottom of the atmosphere for remote sensing. For example, the remote spectral signature caused by various vertical distributions of ocean phytoplankton was calculated from the optical properties of laboratory phytoplankton cultures. Studies are being directed toward the converse problem of determining whether the total primary productivity in the water column can be assessed by means of a remotely sensed spectral signature.

Preliminary field studies to assess the potential for optical oceanographic research in the arctic were supported by a grant from the Arctic Institute of North America under contractual arrangement with the Office of Naval Research. Under the direction of Dr. Raymond C. Smith, Visibility Laboratory instruments were tested in the arctic environment and optical properties of the arctic upper water were measured from Fletcher's Ice Island, T-3, in the Arctic Ocean. Optical oceanographic research in the arctic is applicable to the physical problem of the radiative transfer of electromagnetic energy through snow, ice, and water; to engineering problems of underwater visibility; and to the biological problem of mathematically modeling primary productivity under light-limited conditions.

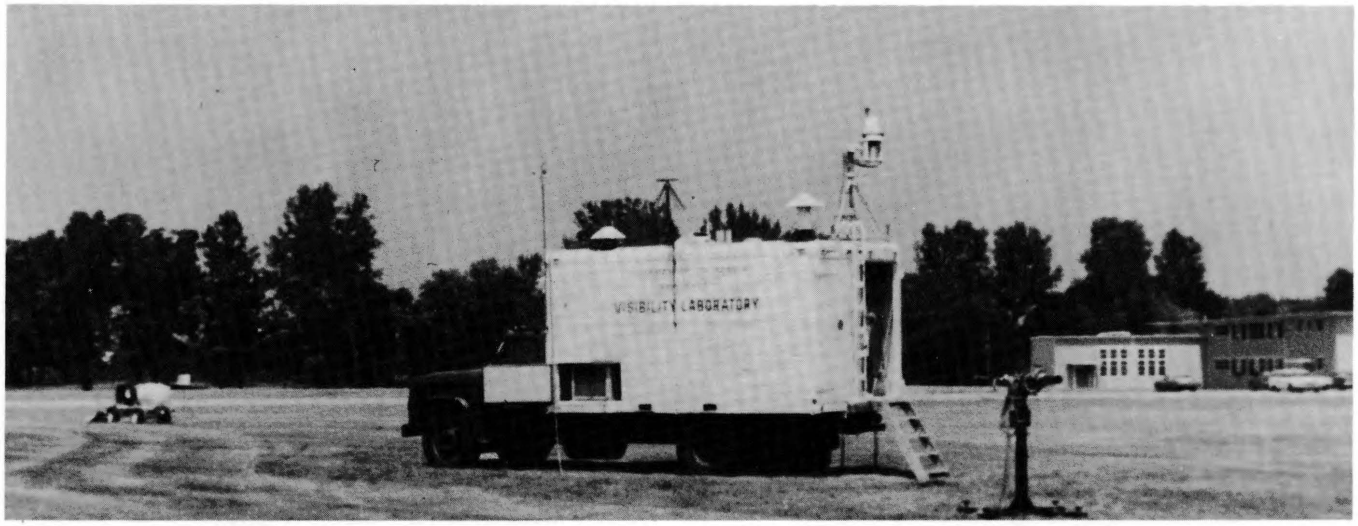
ATMOSPHERIC VISIBILITY

The fundamental studies of the propagation of natural light in the atmosphere have continued; an Air Force C-130 aircraft is assigned to the Laboratory for this purpose. Richard W. Johnson carried out three series of flight programs during the past year to measure optical atmospheric properties. These measurements and the computations related to their use are elements of the Laboratory's continuing development of improved techniques for predicting, by calculation from physical data, the probabilities with which any distant object can be visually detected and recognized.

Sixteen data collection flights were made in a broad variety of geographic locations, including Yuma, Arizona; San Clemente Island, California; and Concord, New Hampshire. During most flights, airborne measurements are coordinated with corresponding observations by a ground-based scientific team

Instrumented ground station used by Visibility Laboratory for acquisition of optical and meteorological data simultaneously with airborne measurements.

Visibility Laboratory



operating an instrument van. The joint operation of these two air/ground instrument systems yields a well-integrated set of optical and meteorological data which contribute an enhanced understanding of vision through the atmosphere.

RESEARCH UTILIZING IMAGE PROCESSING FACILITIES

The computer image processing facilities at the Laboratory consist of an IBM 360/44 computer, a variety of scanning and display equipment, a versatile computer program package, and a number of control units including keyboards, switches, and thumbwheels which allow the investigator to interact with the computer. This facility is being used for a number of different research activities.

Research in image processing continues under the direction of Benjamin L. McGlamery. Elimination of image defects due to defocus, image motion, atmospheric turbulence, or lens aberrations is sought. Concentration during the past year has been centered on studying the manner in which the properties of photographic film and the properties of optical systems combine to form a degraded image. Recent equipment modifications allow larger array sizes to be processed. The system is now capable of scanning, processing, and displaying images with more than one million independent picture elements.

The 1971 *Annual Report* described studies to determine the efficiency with which a human observer is able to perform detection when viewing a cathode-ray tube upon which a visual stimulus is presented. Gerald D. Edwards has extended these studies to include the recognition of such images. He used the image processing computer facility to generate movies which simulate the cathode-ray-tube display. Several images, each of which is familiar to the observer, are presented in random sequence, and the observer is scored on his ability to correctly recognize each image as it is presented. The observer's score is studied as a function of important properties of the cathode-ray-tube display, including resolution and noise level (time and space varying fluctuations in the display brightness). A theoretical limit to observer performance can be calculated and, when compared with observer scores, indicates the efficiency with which observers are able to extract recognition information from such displays.

The use of the image processing facility for studying the visual aspects of aircraft safety has continued under the direction of James L. Harris, Sr. New computer programs make it possible to produce movies which show how an airport runway appears to a pilot during a final approach to landing. The movies are used to determine the precision with which the pilot can judge the quality of his approach as a function of the size and contrast of the runway and the atmospheric visibility.

Another portion of the air-safety studies deals with the ability of a pilot to determine visually the flight path of another aircraft which appears to be a potential collision threat. Central to his judgment is the necessity of sensing apparent rotation of the approaching aircraft. This information is vital to a determination of whether the threat aircraft will tend to pass in front or behind. This dictates, to a large degree, the evasive maneuver which should be performed. The computer image processing facilities are used to generate movies which show aircraft with different rates of apparent rotation. The goal of the experiments is to determine the distance at which each rotation rate is detectable.

Improved microscopy is the goal of another computer-related research activity. A specially designed differential interference microscope has been connected to an existing scanning system so that its images can be recorded directly on punched cards. The data are collected in such a way that the computer can repropagate the image such as, for example, to achieve a new focus. Improved resolution and knowledge of the three-dimensional properties of the specimens are two of the important objectives of these studies.

The image processing facility is also being used to perform fundamental studies of the propagation of light in sea water. Computer simulation of the scattering and absorption in sea water is being used to seek more fundamental understanding of the relationship between these mechanisms and the quality of underwater photography.

Institute of Geophysics 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 and Sir Edward C. Bullard hold Scripps appointments; their offices are located at IGPP. Drs. Ralph H. Lovberg and Barry Block hold joint appointments in IGPP and the Physics Department of UCSD. Drs. Hugh Bradner and John W. Miles hold joint appointments in IGPP and UCSD's Department of Applied Mechanics and Engineering Sciences. Drs. Jonathan Berger, Peter H. Molnar, William A. Prothero, and Frank E. Snodgrass, and Bernard O. Zetler have senior research appointments in the Institute.

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.) He is also working on propagation of elastic waves in anisotropic media, and on probability theorems involved in the construction of Earth models.

Dr. Gilbert has made major applications of the inverse theory to the study of the Earth. Specifically, this dealt with the "spherically symmetrical Earth"; more recently, he has attempted to interpret the observed normal modes in terms of lateral variations in the Earth's mantle.

Dr. Haubrich is concerned with the applications of time series analyses to geophysical problems. He was the first to show that certain types of microseisms can be associated with travelling storms at sea. He is measuring the tilt of the Earth by ocean loading. He is now concerned with the geophysical causes of the Earth's wobble.

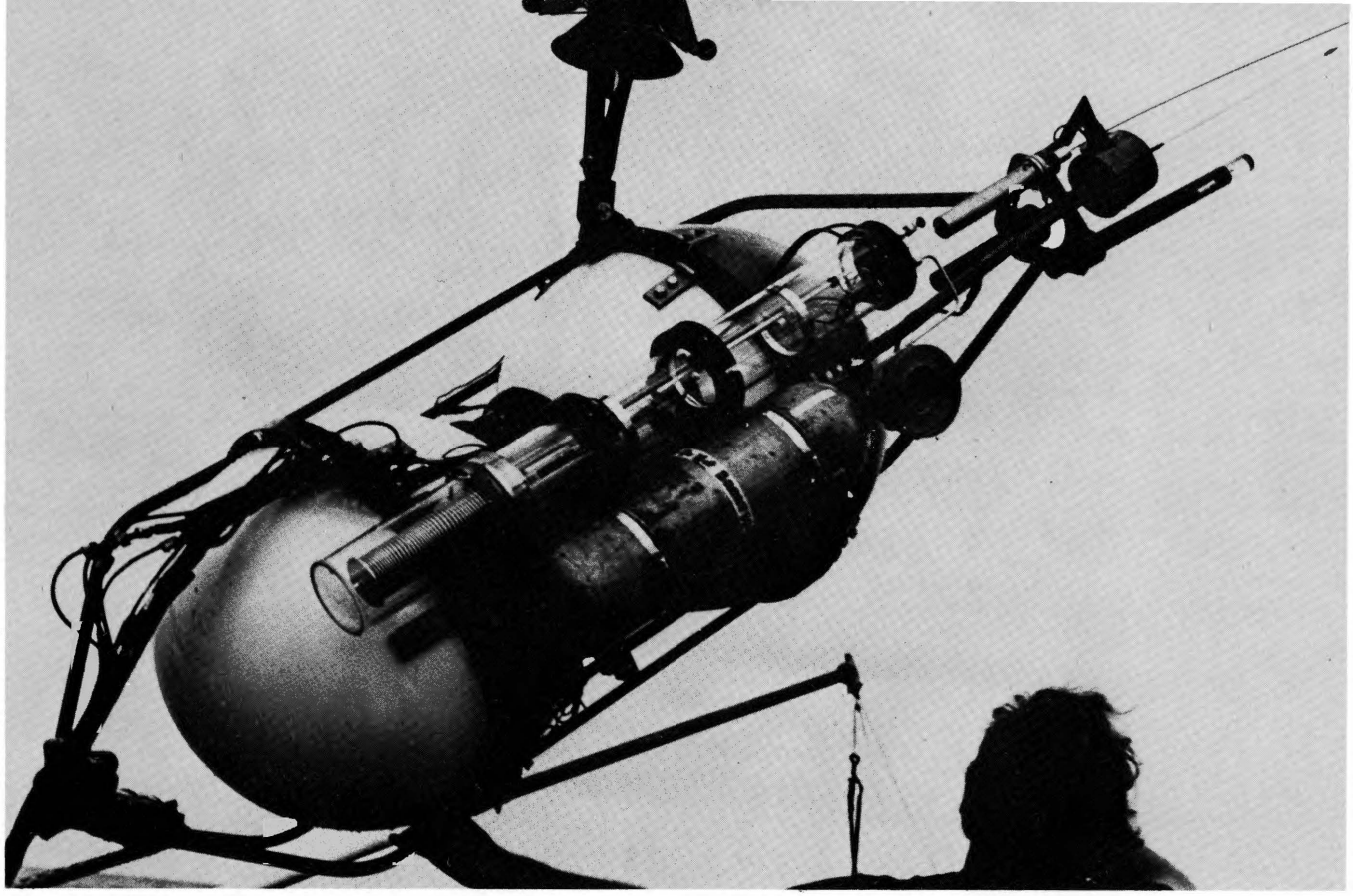
Dr. Block has developed a horizontal broad-band accelerometer to complement the vertical broad-band accelerometer already in operation. These instruments have been used in earth normal mode and surface wave studies. Measurements of surface wave detection thresholds were made both at the surface and at deep mine sites.

Drs. Lovberg and Berger developed and deployed at nearby Elliott Geophysical Observatory a laser interferometric strain meter of high sensitivity and exceptionally long-term stability.

Dr. Berger continues his work in the development of the Piñon Flat Geophysical Observatory in the San Bernardino National Forest. The installation of the third of a three-axes array of laser strain meters is underway. A low drift quartz accelerometer of the Block-Moore design, a LaCoste gravimeter, several two-axes tilt-meters, and a microbarograph developed in Dr. Berger's laboratory are currently in operation. A cryogenic gravimeter developed by Dr. John M. Goodkind, of the UCSD Physics Department, and Dr. Prothero will shortly be installed. 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 and its association with regional seismicity.

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. More recently, he has investigated the effect on tidal propagation of changes of the orientation of the coastline.

Dr. Brune, whose field is earthquake mechanisms, has interpreted 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. In a joint effort with Drs. Bradner and Prothero, aftershocks in ocean areas are being studied with sea-bottom seismometers. A study of the relation between earthquake source mechanisms and plate tectonics is be-



Deep-sea instrument capsule, modified by Institute of Geophysics and Planetary Physics technicians to be neutrally buoyant, is here launched from R/V Ellen B. Scripps *for mid-water measurements of internal waves and temperature microstructure.*
Institute of Geophysics and Planetary Physics

ing undertaken by Drs. Brune and Molnar, with a view toward applications to earthquake hazards.

Drs. Munk and Snodgrass and Zetler are 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 Ocean. 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. The capsule has also been adapted to a free-float mode for measuring internal waves and microstructures at mid-depth.

Institute of Marine Resources

The Institute of Marine Resources (IMR) has statewide facilities, with headquarters at Scripps Institution, and is concerned with research, education, and public service in relation to man's uses of the resources of the sea. In addition to providing a basis for an improved supply of extractable materials, living, mineral, and other, the Institute also fosters the accumulation and dissemination of knowledge about resource aspects, such as transportation, pollution, and recreation, and provides for studies of social, legal, economic, and political aspects of man's related activities.

An executive committee composed of faculty members and an advisory council comprising public members—all appointed by the president of the University—assist the director with advice and guidance on policy and plans for research activities. The activities of the Institute during the year were supported by a University budget of $241,105, and by contracts and grants of $2,063,828, the latter including the Sea Grant Program budget for the University of California and the California State University at San Diego, which IMR administers.

IMR scientists and those affiliated with IMR carried out research in many disciplines during 1971-72. This report is restricted to a bare mention of the more cohesive studies. They are more fully reported in the annual reports issued by IMR, the Food Chain Research Group, and the Sea Grant Program, as well as extensive references carried in those reports.

Geological, geochemical, and geophysical processes were investigated along the California coast and in the Gulf of California. The Shore Processes Study Group seeks to define basic unifying criteria for coastal planning. To this end, it is developing sensors and systems that permit effective monitoring of coastal climate and sediment transport. Cooperation continued with the National Oceanic and Atmospheric Administration's Marine Mineral Technology Centers in the application of geophysical techniques to ocean engineering studies and offshore mineral prospecting. Hypogene Expedition to the Gulf of California in the spring of 1972 served nine different programs; it yielded few surprises but a wealth of basic geochemical and geophysical data for a clearer picture of that region's geology and mineralogical resources.

Work on environmental aspects included study of marine floatables, surface films, and slicks of waste-water origin. Allied with these studies is the development of electrochemical monitoring systems that can operate in the marine environment. The effect of sewage discharge off Southern California on phytoplankton growth and productivity was assessed in five short cruises. Sometimes these waters were somewhat inhibitory and at other times stimulatory, but the general result of discharge is a doubling or tripling of nearshore chlorophyll in the region of the outfalls. Analyses of mercury and chlorinated hydrocarbons have been initiated on a number of marine organisms and in the water column. These pollutants seem to concentrate in the larger fishes and the sea surface.

The Marine Food Science Group continued studies on storage and color stability of marine food and feed products, and experimented with antioxidants and color stabilizers to improve shelf life. Closely related are investigations into the basic biochemistry of myoglobins, which affect color of canned marine products.

The Food Chain Research Group seeks fundamental information for an understanding of the entire marine food web. This large group of scientists pursued its mission with trophodynamic studies of phytoplankton and zooplankton population in the north central Pacific and at the San Diego outfall, with zooplankton analyses in the upwelling regions off Peru, with the isolation of marine bacteria that develop without the help of the generally used high-nutrient media, with the study of nitrogen assimilation of phytoplankton and comparing analytical techniques, with attempts to raise various marine animals in the laboratory, and with the development of underwater holographic camera systems, both still and live, for *in situ* observation of planktonic organisms. These are but a few of the major directions of research.

Another program affiliated with IMR is the Scripps Tuna Oceanography Research (STOR) program. It is charged with establishing a scientific basis for improving the effectiveness of the U. S. tuna fishery in the eastern Pacific. Analysis and publication of EASTROPAC data (an extensive survey program of broad-scale ocean features in 1967-68) continues in the form of individual papers and an Atlas series. Detailed resource assessment cruises for skipjack tuna in 1970-71 confirmed expectation from EASTROPAC data of a primary equatorial maximum. Conclusions about commercial fishing possibilities can, however, not be drawn directly from these results. Other work of STOR included culture efforts with phytoplankton, investigations into the effect of sewage discharge on phytoplankton, and the commencement of a taxonomic revision of the genus *Carangoides* Bleeker, 1851, a group of subtropical carnivorous fishes.

IMR supports research by graduate students related to the mission of the Institute. A number of these researches led to PhD theses. Abstracts of six theses and of six ongoing or completed studies are given in the current IMR Annual Report. That report also contains a listing of the IMR Reference Series and IMR Technical Report Series; the former consists of progress, data, and technical reports of limited distribution, and the latter comprises marine topographic charts and marine technician handbooks. The IMR Annual Report is available from the Institute.

SHORE FACILITIES AND COLLECTIONS

Facilities

Thomas Wayland Vaughan Aquarium-Museum (5). The Aquarium-Museum provided 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 80 volunteer docents, conducts a manifold educational program. More than 50,000 students annually tour the Aquarium-Museum in educational groups, and a career experience program is offered to high school and college students considering an aquarium career. Federal Sea Grant funds support a full-time coordinator for educational programs.

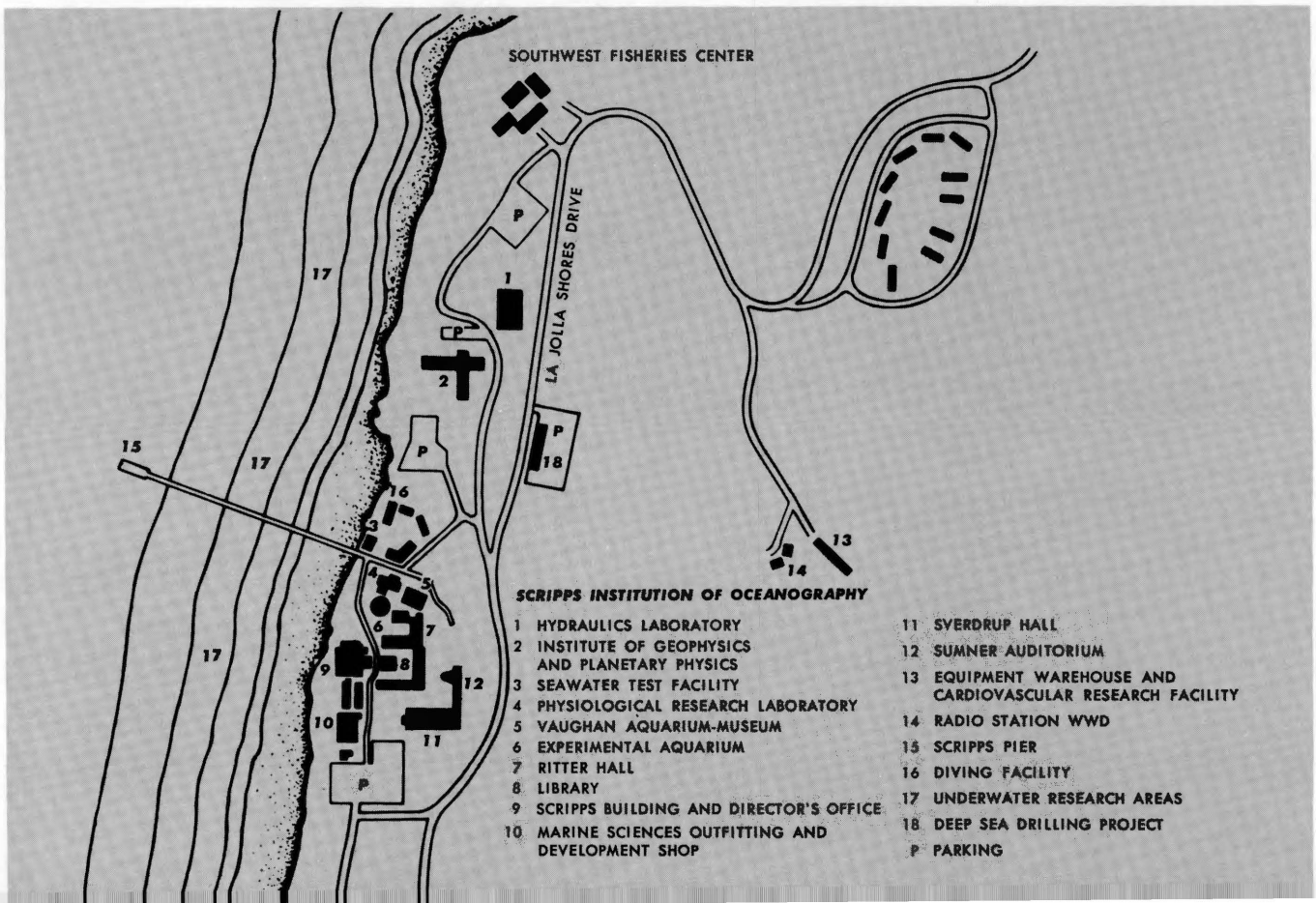
Although admission is free, voluntary contributions from many of the more than 350,000 yearly visitors provide significant financial support.

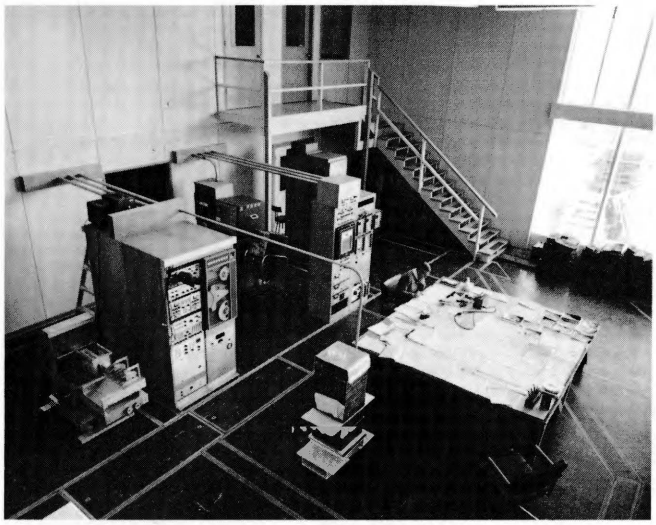
New museum exhibits, expansion of educational programs, and a museum curator are supported by gifts pledged to the Foundation for Ocean Research by the Southern California First National Bank for the benefit of the Aquarium-Museum.

Research is carried out on problems centering around maintenance of marine animals, biochemistry, and ecology of coloration in fishes.

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 equipped with precision tools and has a staff of tool and die makers who participate in the design, development, and fabrication of research equipment and instrumentation in support





Some of the pulse analyzers at Soledad Mountain Laboratory. The detectors used for counting traces of marine radioactivities are located in separate rooms.

The act of feeling is the best teacher for these elementary school children who are among the more than 50,000 students visiting the Vaughan Aquarium-Museum annually to learn about the sea and oceanography from their point of view.

Pat Kampmann

of the various laboratories at Scripps, the Southwest Fisheries Center—National Marine Fisheries Service, UCSD, the Scripps fleet, and other educational and governmental organizations throughout the United States.

Radio Station WWD (14). Licensed to the National Marine Fisheries Service and operated by Scripps personnel, Station WWD provides communications services to both organizations as well as to other government and institutional scientific ships. The station has worldwide capabilities. Voice, CW, 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, winds, 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, 1972, the library held 93,456 bound volumes, 43,235 maps and charts, 20,611 reprints, 17,816 documents, reports and translations, and 2,229 pieces of microcopy.

Hydraulics Laboratory (1). This laboratory is equipped with a wind-wave channel 43x2x2 m in size with a simulated beach and a tow cart for instrument and model towing; a 15x18-m wave basin with an adjustable simulated beach; a 40-m, glass-walled wave-and-current channel; a 6x12x3-m-deep concrete pool equipped with a slurry pumping system for developing new methods of sand transfer; and an insulated, refrigerated, cylindrical seawater tank 10 m deep and 3 m in diameter used for various physical and biological studies. All wave generators in the laboratory are programmable and can be computer-controlled. An IBM 1130 computer system is the central controller for data acquisition and data processing in conjunction with experimental use of the various facilities.

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

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

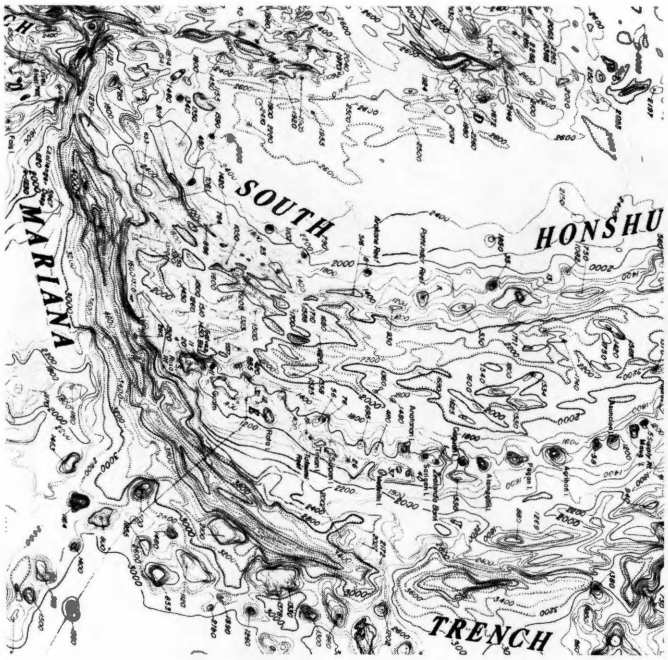
Electron Microprobe Laboratory (11). This laboratory handles the chemical analysis of volumes as small as one cubic micron at concentration levels above a few hundred parts per million. This is achieved by accurate spectrographic measurements of the X-radiation from the area analyzed, which is excited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

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

Scripp'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.

Analytical Facility (11). The facility was organized two years ago to provide the Scripps graduate student and staff with analytical instruments and professional assistance to aid in thesis or project research. Capabilities of the facility include an X-ray diffractometer for crystal lattice parameter and mineral identification; X-ray spectrometer for qualitative and quantitative analysis of elements above atomic number 12; atomic absorption spectrometer (A.A.) for quantitative determination of elements in solution; heated graphite atomizer (attachment to A.A.) for determination of elements in solids with detection limits of 1×10^{-12} grams; amino acid analyzer for amino acid characterization; gas chromatograph for separation and identification of molecules in the gas phase; carbon dioxide analyzer for sample carbon and carbonate content in terms of carbon dioxide; scanning electron microscope for examination of sam-



Geological data collected by Scripps vessels are cataloged and stored at Geologic Data Center. This detailed section of Chart No. 6, part of a set of ten, shows bathymetry of Mariana Trench and South Honshu Ridge. Sets are available in color, at approximately 1:6,000,000, from Institute of Marine Resources.
Geologic Data Center

High school students participating in a summer work-experience program conducted by Vaughan Aquarium-Museum work with staff members to collect specimens from a seine net.
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ples at magnifications up to 100,000X enhanced by the depth of field far surpassing the light microscope. The facility offers complete sample preparation laboratories (including wet chemistry and rock processing laboratories, a table top Olivetti computer, and geological field equipment.

Mass Spectrographic Equipment (7) and (11). Eight mass spectrographs are available, including two .02-m, Nier-type spectrometers for isotopic analysis of light elements; a .02-m, Nier-type spectrometer for rare gases; a ten-inch, Nier-type spectrometer for ratio measurements of He3/He4; a .04-m, 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 Scripps Clinic and Research Foundation, La Jolla, this facility consists of an experimental animal colony and equipment for physiological research involving measurements of circulatory and cardiac functions in free-moving animals.

Physiological Research Laboratory Pool Facility (4). This facility consists of a holding pool for large marine mammals and fish; a ring pool of 10-m radius equipped with a variable speed trolley carrying instruments for various hydrodynamic and biological studies of mammals and man; and a behavioral pool for echo-location studies and animal training. A central island within the ring pool contains small, dry laboratories and a "wet" laboratory equipped to handle large animals. A flow channel through the island permits transfer of animals from the ring pool into the laboratory.

Soledad Laboratory (Mt. Soledad). This laboratory, because of its highly specialized equipment and because of its isolation from other research areas where relatively large amounts of radioactivity are employed, provides for the study of characteristics of the natural radioactive background in the ocean. It also provides for the detection and measurement of minute traces of artificial radioactivities that are entering the ocean and accumulating in many of its organisms as a result of weapon tests and as a result of industrial and research use of nuclear materials. These studies yield information needed for predicting the impact expected from increased use of nuclear fuels in the future.

Kendall-Frost Mission Bay Marsh Reserve (Mission Bay, San Diego). Approximately 20 acres of marshland in Mission Bay belonging to the University constitute a marsh preserve and wildlife refuge designated for teaching and research, as one unit of the University of California Natural Land and Water Reserve System. Surrounding tidal and shoal waters have been designated by the City of San Diego to be retained in a natural condition. The Reserve has been used considerably for teaching and research by UCSD and other local colleges, and a laboratory has been planned and funded to facilitate further use of the area.

San Vicente Lake Calibration Facility (30 miles northeast of San Diego). This facility, operated by the Marine Physical Laboratory, is equipped for testing and calibrating acoustic transducers used in oceanographic research. The equipment is located on an 8x15-m enclosed platform in 12 m of water offering 1,372 m of unobstructed range.

Special Collections

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

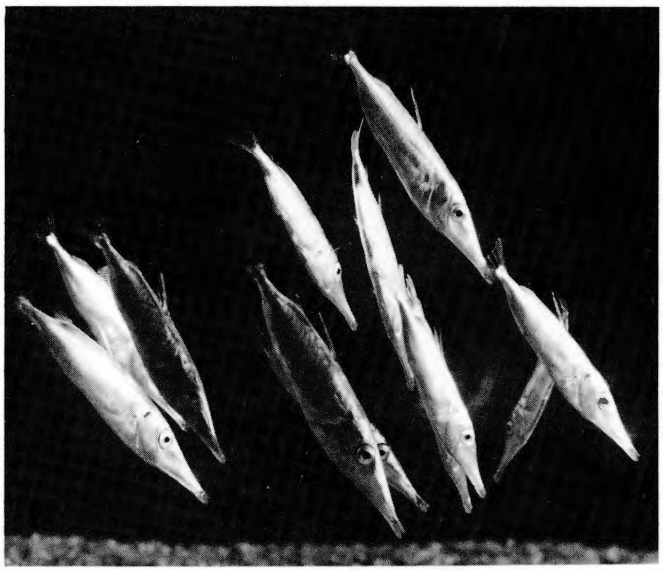
scale and are kept at the Geologic Data Center, where they are displayed and continually updated.

Marine Vertebrates (Fish Collection, 5 and 7). This consists of some 750,000 specimens of 2,500 cataloged species of marine fishes. Added in 1970 and 1971 were 700 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 Isaac-Kidd mid-water 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.

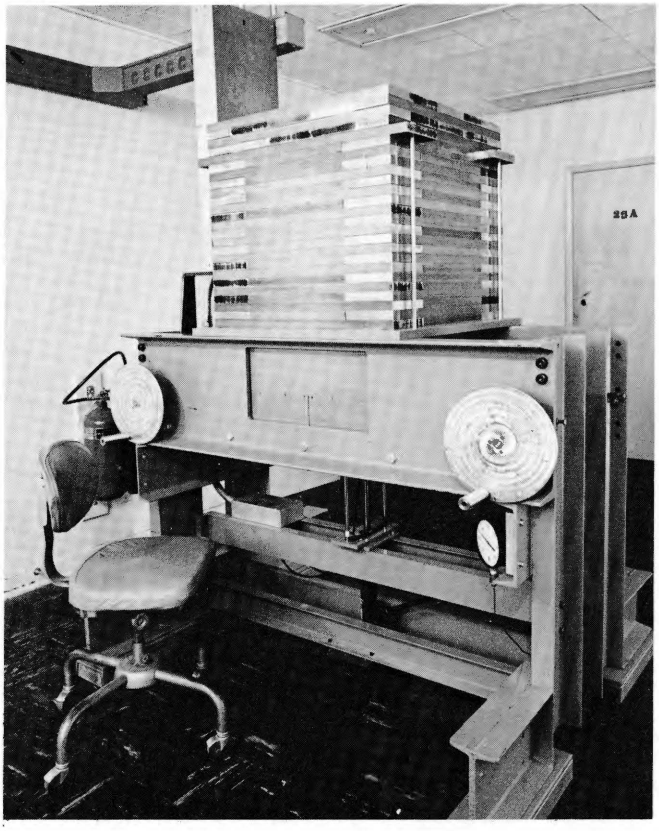
Deep Sea Drilling Project Core Repository (Located in north end of DSDP headquarters). Scripps houses the West Coast Repository for cores collected by DSDP. The DSDP is part of the National Science Foundation's (NSF) National Ocean Sediment Coring Program, and these collections are a national archive.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



Snipefish (Macrorhamphosus gracilis) *are just one of the species of fish that attract more than 350,000 visitors to the 22 tanks in the Vaughan Aquarium-Museum annually.*

Milling machine operator Ray Blei, at work in Marine Sciences Development and Outfitting Shop, bores hole in fitting.

Shielded multi-dimensional gamma spectrometer in Soledad Mountain Laboratory built for study of extremely small traces of radioactivities in marine specimens.



Scripps Institution's Soledad Mountain Laboratory for the study of marine radioactivity is located on the northeast crest of Soledad Mountain, above La Jolla. Lower floor is below ground level.

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.

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 1971-1972, 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 listed below:

Volume 18: CHEN, Lo-Chai. Systematics, variation, distribution and biology of rockfishes of the subgenus *Sebastomus* (Pisces, Scorpaenidae, *Sebastes.)* 1971. 115 p.

Volume 19: JOHNSON, Martin W. The Palinurid and Scyllarid lobster larvae of the tropical eastern Pacific and their distribution as related to the prevailing hydrography. 1971. 36 p.

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 1529, La Jolla, California, 92037.

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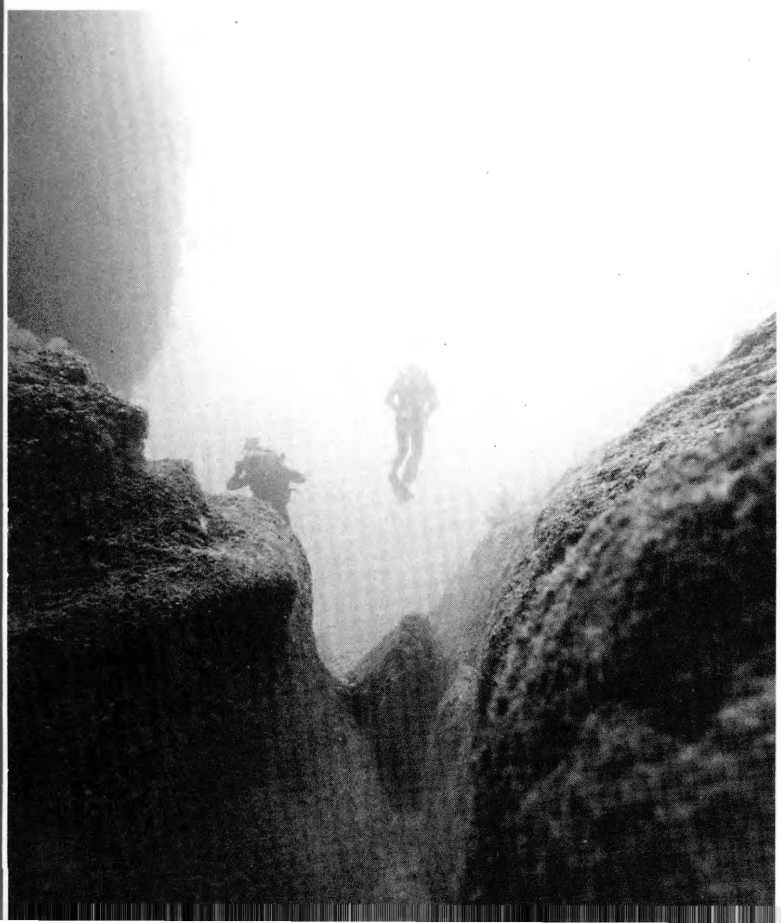

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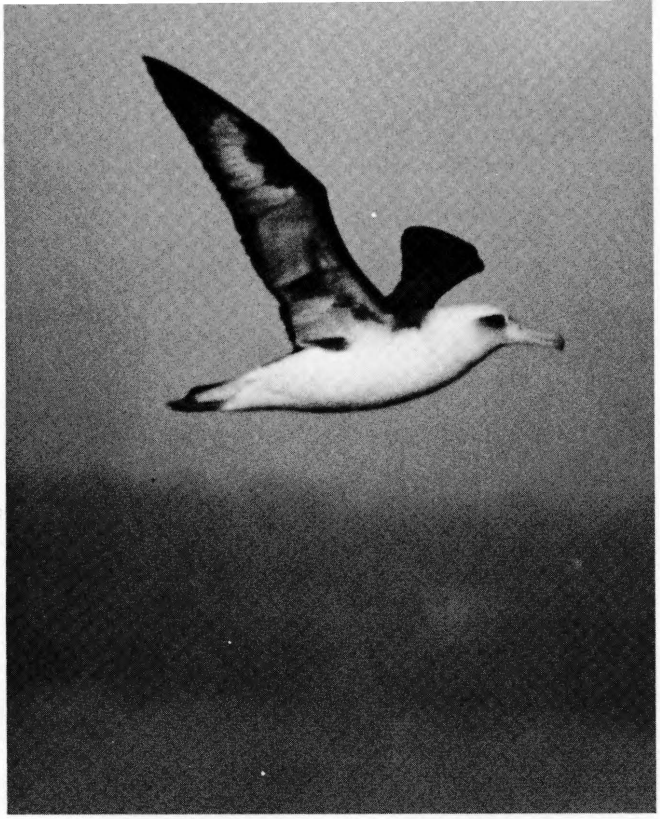

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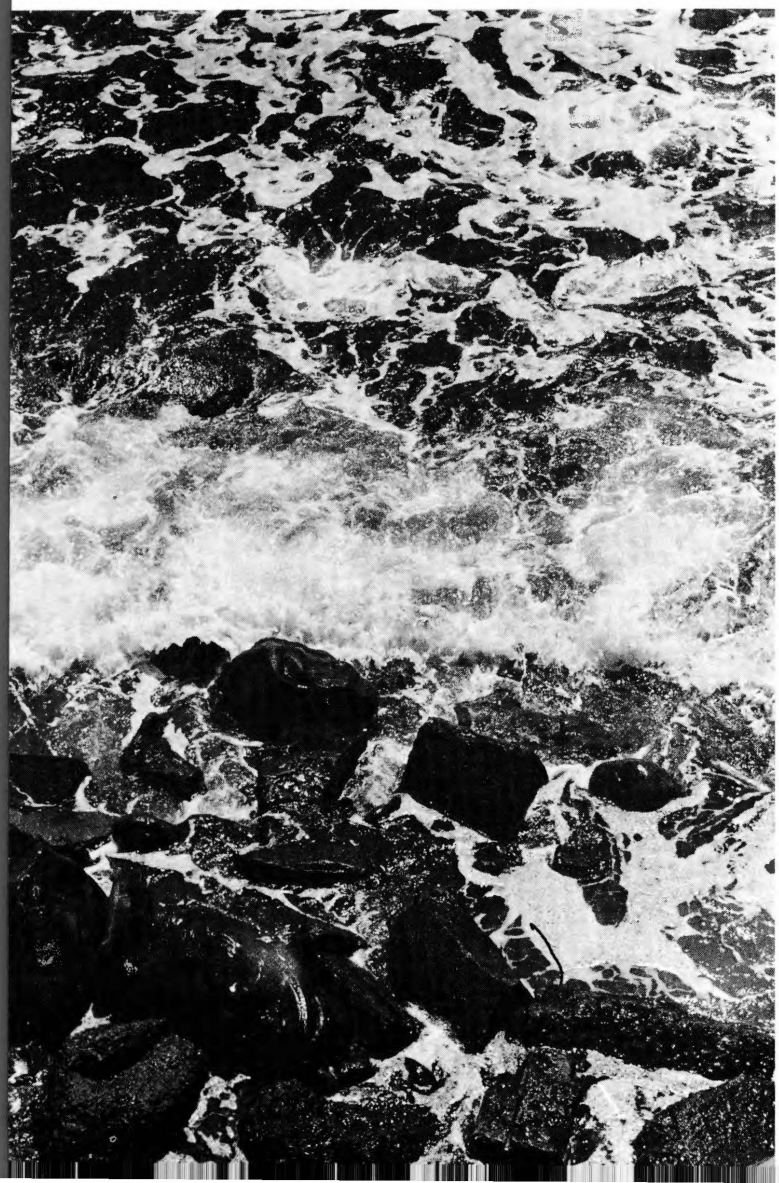

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Name	Research Group	Field
Gerald B. Morris	Marine Physical Laboratory	Geophysics
John D. Mudie	Marine Physical Laboratory/ Geological Research Division	Geophysics
Michael M. Mullin	Institute of Marine Resources	Biological Oceanography
Walter H. Munk	Institute of Geophysics and 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 Nemota	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
Catherine Clark Nigrini	Deep Sea Drilling	Paleontology
Benton B. Owen	Marine Physical Laboratory	Chemistry
Frances L. Parker	Geological Research Division	Paleontology
Robert L. Parker	Institute of Geophysics and Planetary Physics/Ocean Research Division	Geophysics
Edward A. Perry	Geological Research Division	Chemistry
M.N.A. Peterson	Deep Sea Drilling/Geological Research Division	Marine Geology
Richard P. Phillips	Geological Research Division	Geophysics
Fred B Phleger	Geological Research Division	Oceanography
Anthony C. Pimm	Deep Sea Drilling	Geology
William A. Prothero	Institute of Geophysics and Planetary Physics	Geophysics
Arthur D. Raff	Deep Sea Drilling	Marine Geophysics
Russell W. Raitt	Marine Physical Laboratory	Marine Geophysics
**Norris W. Rakestraw	Ocean Research Division	Marine Chemistry
Robert A. Rasmussen	Marine Physical Laboratory	Marine Physics

Conservationist Arthur Godfrey, center, confers with Director Nierenberg and San Diego Mayor Pete Wilson, left, during visit to the city.

Speaking to faculty, staff, and students during the year was Capt. Jacques Cousteau, right, walking with Assoc. Dir. Fred N. Spiess toward Sumner Auditorium, location of his address.

Striking silhouette of three men and their wave-study instrument as they appear to be rising out of the surf.

Name	Research Group	Field
Stephen D. Rearwin	Marine Physical Laboratory	Physics
Michael L. Redfield	Center for Marine Affairs	Marine Law
Archibald M. Reid	Geological Research Division	Mineralogy
Freda M. Hunt Reid	Institute of Marine Resources	Taxonomy
Joseph L. Reid	Marine Life Research Group/ Ocean Research Division	Physical Oceanography
+Francois J. Resch	Institute of Geophysics and Planetary Physics	Turbulence Measurements
**Roger R. Revelle	Director Emeritus	Marine Geology
Paul G. Richards	Institute of Geophysics and 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 Micropaleontology
Philip Rudnick	Marine Physical Laboratory	Physics
Annika Berggren Sanfilippo	Geological Research Division	Paleontology
Marston C. Sargent	Scientific Support Division	Biological Oceanography
Henning Scheich	Neurobiology Unit	Neurophysiology
Walter R. Schmitt	Marine Life Research Group	Marine Resources
Per F. Scholander	Physiological Research Laboratory	Marine Physiology
Richard A. Schwartzlose	Marine Life Research Group	Physical Oceanography
John G. Sclater	Marine Physical Laboratory	Geophysics
Jonathan H. Sharp	Institute of Marine Resources	Biology
**Francis P. Shepard	Geological Research Division	Submarine Geology
George G. Shor, Jr.	Geological Research Division/ Marine Physical Laboratory/ Sea Grant Program	Marine Geophysics
Maxwell Silverman	Scientific Support Division	Marine Engineering
John Sinkankas	Geological Research Division	Mineralogy
+Zdenek J. Slouka	Center for Marine Affairs	Political Science
Raymond C. Smith	Visibility Laboratory	Physics
Stuart M. Smith	Geological Research Division	Submarine Geology
Frank E. Snodgrass	Institute of Geophysics and Planetary Physics	Geophysics
James M. Snodgrass	Scientific Support Division	Electronic Instrumentation
Bhamidipati L. Somayajulu	Geological Research Division	Geochemistry
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
Charles K. Stidd	Marine Life Research Group	Meteorology
Cornelius W. Sullivan	Marine Biology Research Division	Microbiology
Peter R. Supko	Deep Sea Drilling	Marine Geology
Bruce A. Taft	Marine Life Research Group	Physical Oceanography
John H. Taylor	Visibility Laboratory	Psychology
Wayne R. Thatcher	Institute of Geophysics and Planetary Physics	Geophysics

#Adjunct Professor series
**Emeritus
+Visiting

Name	Research Group	Field
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
Siegfried V. Wantrup	Institute of Marine Resources	Marine Economics
Ray F. Weiss	Geological Research Division	Geochemistry
Richard T. Wert	Marine Life Research Group	Meteorologist/Data Processing
Oscar E. Weser	Deep Sea Drilling	Marine Sedimentation
**Charles D. Wheelock	Institute of Marine Resources	Naval Architecture
+John T. Whetten	Geological Research Division	Geology
Thomas W. Whitaker	Marine Biology Research Division	Marine Biology
Antony White	Marine Physical Laboratory	Geophysics
Warren B. White	Marine Life Research Group	Oceanography
Gerald L. Wick	Institute of Marine Resources/ Sea Grant Program	Physics
Donald W. Wilkie	Aquarium-Museum	Marine Biology
Francis Williams	Institute of Marine Resources	Biological Oceanography
Peter M. Williams	Institute of Marine Resources	Biological Oceanography
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
John H. Wormuth	Marine Life Research Group	Oceanography
A. A. Yayanos	Physiological Research Laboratory	Physiology
Claude E. ZoBell	Marine Biology Research Division	Marine Microbiology

Nelson Fuller

Appendix A

DIRECTOR—DEAN
W. A. Nierenberg

ASSOCIATE DIRECTORS
G. G. Shor, Jr.
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/V. C. Anderson

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

RESEARCH SUPPORT

AQUARIUM-MUSEUM
D. L. Wilkie

MARINE FACILITIES
P. G. Trapani/P. S. Branson

SCIENTIFIC SUPPORT DIVISION
J. D. Frautschy

RESEARCH DIVISION

GEOLOGICAL RESEARCH
F. B Phleger

MARINE BIOLOGY RESEARCH
A. A. Benson

OCEAN RESEARCH
J. L. Reid

RESEARCH GROUPS

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G. H. Fisher

CENTER FOR MARINE AFFAIRS
W. S. Wooster/G. L. Wick

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
Tuna Oceanography Research Group
Food Chain Research Group
Sea Grant College Office

OTHER SUPPORT

LIBRARY
W. J. Goff

PHOTOGRAPHIC LABORATORY
L. D. Ford

PUBLIC AFFAIRS
R. N. Fuller

Appendix B

SPONSORS OF RESEARCH AND GRADUATE INSTRUCTION

State:

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
  Corps of Engineers
Department of Commerce
  National Oceanic and Atmospheric Administration
  National Advisory Committee on Oceans and Atmosphere
  National Marine Fisheries Service
Department of Defense
  Advanced Research Projects Agency
  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
  Federal Aviation Administration

Other:

Abbott Laboratories
American Cancer Institute
American Chemical Society
American Heart Association
American Optical Corporation
ARCS Foundation
Chevron Oil Field Research Company
Wm. L. Dowd Memorial Fund
Ellen Browning Scripps Endowment Fund
Ewing Memorial
Fleet Admiral Chester W. Nimitz Fund
M. C. Fleischmann Foundation
Ford Foundation
Foundation for Ocean Research
Griffis Foundation
International Nickel Company
Kennecott Copper Corporation
Kennecott Exploration, Inc.
La Jolla Foundation for Earth Sciences
Lockheed Missiles and Space Company
John B. McKee Fund
Mrs. Theodora H. Ives
Mobil Foundation, Inc.
National Academy of Sciences
Nutrilite Products, Inc.
Peterson-Silberman Fund
Rockefeller Foundation
Scientific Committee on Oceanic Research
E. B. Scripps Foundation
Francis P. Shepard Foundation
A. P. Sloan Foundation
Scripps Industrial Associates
  Texaco, Incorporated
  Occidental Petroleum Corporation
  Gulf Oil Corporation
  Sun Oil Company
  AMOCO Production Co.
  Continental Oil Co.
  ESSO Production Research Co.
  Shell Oil Co
  Union Oil Co.
  Standard Oil Company of Califofrnia
  AGIP

Appendix C

MAJOR AWARDS AND HONORS

Dr. James N. Brune
Received Arthur L. Day Award from National Academy of Sciences.

Dr. Paul K. Dayton
Named winner of Louise Burt Award for Excellence in Oceanographic Writing, Oregon State University.

Dr. Carl Eckart
Received William Bowie Medal, American Geophysical Union.

Dr. Carl L. Hubbs
Awarded Shinkishi Hatai Medal of Japan Science Association.

Dr. Ralph A. Lewin
Awarded Doctor of Science Degree, Downing College, Cambridge University.

Dr. Jerome Namias
Received Honorary Doctor of Science, University of Rhode Island.

Dr. William A. Nierenberg
Appointed Chairman, National Advisory Committee on Oceans and Atmosphere.
Awarded the medal of "Officier de l'Ordre National du Merite" (National Order of Merit), French Government.

Dr. Fred N. Spiess
Received 1971 Compass Distinguished Achievement Award, Marine Technology Society.

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′	102′	95′	209′	45′	355′
Beam:	32′	31′	46′	25′	24′	40′	12′6″	20′/12′
Draft:	10′	10′5½″	15′	10′	6′	14′	5′1″	10′/300′
Displacement: tons (full):	825	512	2,075	206	115	1,362	28	2,100 (vertical)
Maximum speed:	11	12.3	12	11	9	12.5	9	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

1971–72 TOTAL DAYS AT SEA: 1,246

1971–72 NAUTICAL MILES STEAMED: 128,391

Appendix E

DOCTOR OF PHILOSOPHY DEGREES AWARDED IN 1971-72 WITH TITLES OF DISSERTATIONS

Earth Sciences

Leonard E. Johnson, "Inversion and Inference for Teleseismic Ray Data."

Robert D. Nason, "Investigation of Fault Creep Slippage in Northern and Central California."

Marine Biology

Katherine Y. Bowen, "The Growth and Development of the Deep Growing Marine Alga, *Maripelta rotata* (Daws.) Daws."

Barbara B. Hemmingsen, "A Membrane Bound, Mg^{2+}-dependent, Mono-Silicic Acid Stimulated Adenosinetriphosphatase from Protoplasts of the Apochlorotic Diatom *Nitzschia alba* Lewin and Lewin."

Robert K. Johnson, "A Revision of the Alepisauroid Family Scopelarchidae (Pisces: Myctophiformes)."

Dan H. Kerem, "Cerebral Tolerance to Asphyxia Hypoxia. A Comparative Study of the Dog and the Seal."

Charles F. Phleger, "Cholesterol and Hyperbaric Oxygen in Swimbladders of Deep Sea Fishes."

Thomas B. Scanland, "The Effects of Predation on Epifaunal Assemblages in a Submarine Canyon."

Cornelius W. Sullivan, "A Silicic Acid Requirement for DNA Polymerase, Thymidylate Kinase and DNA Synthesis in the Marine Diatom *Cylindrotheca fusiformis.*"

Leighton R. Taylor, Jr., "A Revision of the Shark Family Heterodontidae (Heterodontiformes, Selachii)."

Oceanography

Yu-Chia Chung, "Pacific Deep and Bottom Water Studies Based on Temperature, Radium, and Excess Random Measurements."

James D. Irish, "Australian-Antarctic Tides."

John P. Greenhouse, "Geomagnetic Time Variations on the Sea Floor off Southern California."

David A. Johnson, "Detailed Study of Pelagic Sedimentation Using a Deeply-Towed Instrument."

Lawrence A. Klapow, "The Ecology and Behavior of a Sand-Beach Isopod, Excirolana chiltoni: Distribution, Abundance and Temporal Patterns in Molting, Reproduction and Swimming Activity."

Ronald K. Lam, "Atoll Permeability: Calculated from Ocean and Ground Water Tides."

Robert W. Owen, Jr., "The Scattering of Light by Particulate Substances in the Sea."

Michael R. Petersen, "The Claisen Rearrangement and Its Application to the Synthesis of trans-Trisubstituted Olefinic Bonds: The Synthesis of Squalene and Insect Junveile Hormone."

Joseph N. Suhayda, "The Shoaling Transformation of Waves on Beaches."

Wayne H. Wilson, Jr., "Underwater Lighting by Low-Coherence Submerged Sources."

John H. Wormuth, "The Biogeography, Systematics and Interspecific Relationships of the Oegopsid Squid Family Ommastrephidae in the Pacific Ocean."

MASTER OF SCIENCE DEGREES AWARDED IN 1971-72

Oceanography

Neil J. Adler
Gerard Yves Conan
John Murrah Harding, Jr.
Stephan Eberly Thompson, Jr.
David Milton Checkley, Jr.
Sheldon Morton Sanders

Earth Sciences

None

Marine Biology

Ralph Vincent Dykes
Malladi Venkata Lakshmana Rao
Isabel Foster Downs

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
Bert L. Smith
President of the Alumni Association of the University of California
Charles J. Hitch
President of the University

APPOINTED REGENTS

Edward W. Carter
Mrs. Randolph A. Hearst
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
Robert O. Reynolds
Dean A. Watkins
John H. Lawrence, M.D.
William A. Wilson

REGENTS DESIGNATE

William B. Keene
George H. Link

PRINCIPAL OFFICERS OF THE REGENTS

Thomas J. Cunningham
General Counsel
Owsley B. Hammond
Treasurer
Marjorie J. Woolman
Secretary

OFFICE OF THE PRESIDENT

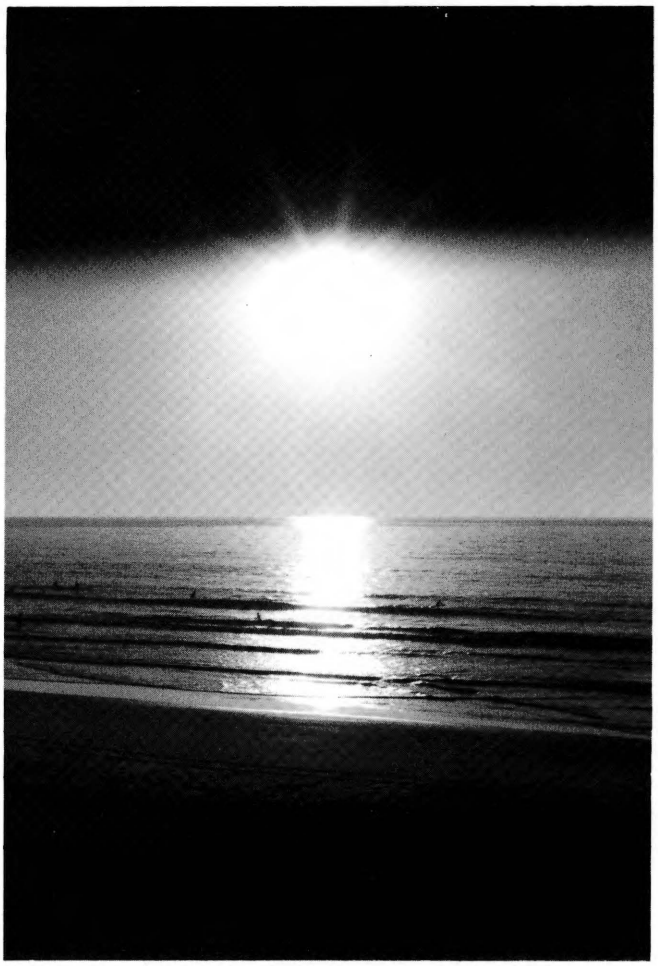
Charles J. Hitch
President of the University
Chester O. McCorkle, Jr.
Vice President of the University
Robert L. Johnson
Vice President — University Relations
Angus E. Taylor
Vice President — Academic Affairs
John A. Perkins
Vice President — Administration
James B. Kendrick, Jr.
Vice President — Agricultural Sciences
Frank L. Kidner
Vice President — Educational Relations
David P. Gardner
Vice President — Extended Academic and Public Service Programs
Jay D. Michael
Vice President — Governmental Relations
Joseph W. McGuire
Vice President — Planning

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
Francis A. Sooy
Chancellor at San Francisco
Vernon I. Cheadle
Chancellor at Santa Barbara
Dean E. McHenry
Chancellor at Santa Cruz



Appendix G

CURRENT FUNDS EXPENDITURES BY MAJOR UNITS AND FUNCTIONS BY FUND SOURCE
1971-1972

	Scripps Institution of Oceanography	Institutes: Geophysics and Planetary Physics	Institutes: Marine Resources	Total
STATE OF CALIFORNIA				
General	$ 2,802,619	$124,854	$148,945	$ 3,076,418
Other	80,496	—	—	80,496
Total State of California	2,883,115	124,854	148,945	3,156,914
STUDENT TUITION AND FEES	—	—	—	—
UNITED STATES OF AMERICA				
Grants —				
Department of Defense — Air Force	—	—	—	—
Department of Health, Education and Welfare	16,428	372	1,709	18,509
National Aeronautics and Space Administration	123,672	—	—	123,672
National Institutes of Health	167,262	—	—	167,262
National Science Foundation	5,179,733	347,651	159,125	5,686,509
Other	518,698	52,088	6,940	577,726
Total Grants	6,005,793	400,111	167,774	6,573,678
Contracts —				
Atomic Energy Commission	169,378	—	221,621	390,999
Department of Defense				
Air Force	391,717	71,346	—	463,063
Army	30,790	—	—	30,790
Navy	6,250,554	304,602	—	6,555,156
Department of Health, Education and Welfare	—	—	—	—
Department of Interior	—	—	2,170	2,170
National Aeronautics and Space Administration	—	—	—	—
National Science Foundation	7,977,335	—	—	7,977,335
Other	181,297	22,510	34,797	238,604
Total Contracts	15,001,071	398,458	258,588	15,658,117
Total United States of America	21,006,864	798,569	426,362	22,231,795
ENDOWMENT FUNDS	296,059	10,232	20,734	327,025
GIFTS AND PRIVATE GRANTS	457,015	21,775	13,921	492,711
SALES AND SERVICES	49,339	—	36,352	85,691
ORGANIZED ACTIVITIES	1,329	—	—	1,329
OTHER SOURCES	7,067	—	—	7,067
AUXILIARY ENTERPRISES	—	—	—	—
RESERVES	—	—	—	—
Total Current Funds Expenditures	$24,700,788	$955,430	$646,314	$26,302,532