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ROGER RANDALL DOUGAN REVELLE
1909–1991

A Biographical Memoir by

THOMAS F. MALONE, EDWARD D. GOLDBERG,
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Biographical Memoir

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March 7, 1909–July 15, 1991

BY THOMAS F. MALONE, EDWARD D. GOLDBERG,
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ROGER REVELLE WAS ONE of the twentieth century's most eminent scientists. His life's work personified Ernest Boyer's four categories of scholarship: discovery, integration, dissemination, and application of knowledge. He brought his talents in these categories to bear on the study of the planet we inhabit and our interaction with that planet. His interests and intellectual reach spanned the physical, biological, and social sciences, engineering, and the humanities. He enhanced the status of oceanography in world science, pioneered in the study of global warming, and brought a fresh approach to issues of population, world poverty, and hunger. Revelle was an inspiring leader of scientific enterprises and an insightful and sagacious educator. He was the intellectual architect for the creation of a great university. He excelled in the communication of science and its implications to policy makers and to the public. Revelle was an exemplary citizen in his community, his country, and the world.

ROOTS

Roger Revelle was born in Seattle on March 7, 1909, into a family of Huguenot descent on his father's side and Irish descent on his mother's side. His parents William Roger

Revelle, an attorney and later a schoolteacher, and Ella Robena Dougan Revelle, also a schoolteacher, were both graduates of the University of Washington. As a schoolboy, Revelle earned high scores in an intelligence test administered by psychologist Lewis Terman.

Admitted to Pomona College at the age of sixteen, Revelle entertained thoughts of a career in journalism. However, under the influence of charismatic professor Alfred Woodford, he became interested in geology and, after receiving his B.A. in 1929, spent a year of additional study with him. Revelle entered graduate studies in this subject at the University of California, Berkeley, in 1930 under the tutelage of geologist George Louderback, who stimulated his interest in marine sedimentation.

EARLY YEARS

Impressed with Revelle's research potential, Louderback recommended him to John Fleming, director of the Department of Terrestrial Magnetism at the Carnegie Institution of Washington, and T. Wayland Vaughan, director of the Scripps Institution of Oceanography (SIO), who were seeking a graduate student to study sediment cores taken on a cruise of the vessel *Carnegie*. At that time, SIO was a small marine station with one main laboratory building, one small research vessel, a staff of twenty-six, and precarious annual funding of less than $100,000. Appointed a research assistant at SIO in 1931 with a stipend of $1,200 per year, Revelle married Ellen Clark, whom he had courted while he was still at Pomona and she was a student at nearby Scripps College. She is a grandniece of Edward Willis Scripps and Ellen Browning Scripps, who had founded the institution some thirty years earlier.

Revelle's seagoing experience started with his arrival at SIO. In his own words:

SIO and one "ship," a retired purse-seine fishing vessel named *Scripps*, sixty-four feet, ten inches long . . . Her single crew member was an ex-locomotive engineer who apparently believed that the best way to keep a boat in good shape was to cover it with grease like a steam engine. With this craft we were able to leave the port of San Diego for one- or two-week expeditions to various islands off the southern California coast . . . .

One of Revelle's proudest moments was when he obtained a license to operate a small boat and became a part-time captain. In 1934 he worked briefly aboard the USC&GS steamer *Pioneer* off Point Arguello. A year later, he took water samples along a section from the Aleutians to Pearl Harbor aboard the *USS Bushnell*, an experience that led to a commission in the U.S. Navy Reserve.

Revelle's entry into science as a geologist began with doctoral studies on the composition and physical properties of deep-sea sediments, primarily those collected on the seventh cruise of the *Carnegie*. He was especially concerned with the nature of the marine carbonates and the factors that governed their formation and hence their persistence. Collaboration with marine chemists stimulated his interest in the buffering capacity of sea water through its contents of carbonic and boric acids and its control of carbonate solubility. These early investigations provided a broad platform from which to launch his many concerns later in life. Among these are the impacts of fossil fuel-generated carbon dioxide on the ocean and atmospheric systems and the organisms accumulated therein.

By 1936 Revelle had earned his doctorate from the University of California and had been promoted to instructor at SIO. On his way to Bergen, Norway, for a year of postdoctoral studies at the Geophysical Institute with Bjorn Helland-Hansen, Revelle attended a meeting at Edinburgh of the International Union of Geodesy and Geophysics (IUGG) and its Association of Physical Oceanography. His

encounter with such legendary figures as Jacob Bjerknes, Columbus Iselin, Carl-Gustaf Rossby, Seymour Sewell, and Joseph Proudman started him on a path of leadership in international scientific affairs, much of it through the International Council of Scientific Unions and UNESCO. Twenty-seven years later at the General Assembly of IUGG in Berkeley, he was elected president of what had become the International Association for the Physical Sciences of the Ocean.

On his return from Bergen in 1937 Revelle participated on *R/V Scripps* in the first comprehensive hydrographic survey of the Gulf of California; he taught marine geology at Scripps and gave an introductory course on physical oceanography at the University of California at Los Angeles.

THE WAR YEARS

Called to active duty in the U.S. Navy six months before the attack on Pearl Harbor, Revelle was involved in research on radar propagation and sonar performance. In 1942 he was assigned to the Bureau of Ships with responsibilities for formulating a wide-ranging program in oceanographic research applied to wartime needs and translation of the results into naval terms. In 1945, as a member of the staff of the Commander, Amphibious Forces, Pacific Fleet, Revelle worked on operations Olympic and Coronet, planning the invasion of Japan. He remained in Washington when the war ended and was assigned to Joint Task Force One, the military command supervising the first postwar atomic test on Bikini Atoll (Operation Crossroads). He organized the Crossroads scientific program, which included a study of the diffusion of radionuclides in the atoll and their impact on marine life.

His involvement with artificial radionuclides at Bikini brought to Revelle's attention the ability of advanced soci-

eties to alter the nature of the marine environment. These investigations made him well aware of the dangers of the promiscuous release of the artificial radionuclides produced from the fissions of uranium and plutonium, especially as increasing amounts were sought for use in energy reactors. They also left him with a lifelong concern for averting nuclear war, leading him to participate in the work of Pugwash.

In a follow-up survey on Bikini in 1947 he furthered his interest in carbonates with the drilling of atoll sediments to depths of 800 meters. The deepest strata had ages of 30 million years and were reef corals laid down in shallow waters. These findings confirmed the argument of Darwin that atolls are sunken volcanic islands on which enormous layers of skeletons of reef-building organisms accrete during the sinking process.

While still with Operation Crossroads, Revelle was transferred to the Office of Naval Research and was appointed head of its Geophysics Branch. The creation of ONR was an auspicious event in that it recognized the national stake in basic research. ONR served as the first conduit for the federal government's support of basic research at the universities. It was a model for the National Science Foundation. Under policies established by Revelle, the Geophysics Branch had a profound impact on the development of geophysics, nationally and internationally. NSF's Geosciences Directorate in the 1990s is a heritage of the early days of that branch. In 1948 Revelle left the Navy as a commander and returned to SIO.

THE SCRIPPS YEARS

SIO director Harald Sverdrup was anxious for Revelle to return to La Jolla to take charge of the seagoing work associated with a new program sponsored by the California State Legislature to study the disappearance of sardines from Cali-

fornia waters. Revelle agreed: "I am practically the only person available who has extensive experience at sea . . . (Sverdrup) feels that Scripps must be, at least in part, reoriented towards work on the high seas rather than the inshore and laboratory type of research, which is being largely done at present." Because of his experience with hydrographic surveys in the Gulf of California, Revelle was asked to organize and lead the survey constituting the heart of the Marine Life Research Program (MLR). He assembled enough instruments and personnel to support three ships and imbued the program with an environmental approach to fisheries biology. This endeavor blended physical oceanography with biological and chemical oceanography for the first time at SIO and was a cornerstone of modern fisheries science.

Revelle's involvement in the kind of research, education, and service that transcend traditional disciplinary boundaries followed naturally from his primary interest in oceanography. Physics, chemistry, biology, engineering, and human activity are inextricably linked in ocean studies. The establishment of MLR in 1947 provided the impetus for Revelle's gravitation to the holistic point of view that was to become the hallmark of much of his subsequent work. Revelle brought together the fisheries biologists with the marine scientists to formulate a monitoring program that continues to this day and is one of the longest collections of physical and chemical characteristics of the coastal ocean. The data has been especially useful in the ancillary studies of El Niño.

It had been Sverdrup's intention for Revelle to succeed him as director, but opposition on the Scripps faculty postponed this until July 1951. The ambition for the position by some of his colleagues and a presumed unacceptability of his work habits formed the basis. Revelle himself refers

to his "obvious and numerous weaknesses, such as a tendency to procrastinate, to take on too many obligations, not to delegate authority, and to be high-handed. . . ."

Revelle's first years as director were characterized by a rapid expansion of the SIO fleet and the acquisition of physical scientists with modern instrumentation and shop facilities. With the clarion call "the Pacific is our oyster," Revelle led a timid faculty into the blue water of the deep Pacific. He personally led the MidPac expedition into the equatorial waters of the central Pacific and the Capricorn expedition to the South Pacific. This sparked the circum-Pacific geophysical studies, which played a crucial role in the development of plate tectonics.

Among the discoveries were the extreme thinness of deep-sea sediments, the similarity of heat flow on the ocean floor and in the continental region, the young ages of seamounts, and the occurrences of enormous fault zones. On hindsight, the evidence was all there for proclaiming the doctrine of plate tectonics. Ten years later, when the puzzle was put together, Scripps's field observations played a key role. We think of the 1950s as the great era of his career. Revelle wrote, "In those heady days of the 1950s one could hardly go to sea without making an important, unanticipated discovery." When Revelle left Scripps in 1961, it had a navy larger than the fleet of Costa Rica.

One of his major accomplishments was his proposal that the continuing addition of carbon dioxide to the atmosphere, oceans, and biosphere could lead to global warming. In a seminal paper in 1957, Revelle and Hans Suess of SIO argued that the world's citizenry was performing "a great geophysical experiment" and called on the scientific community to monitor changes in the carbon dioxide content of waters and airs as well as the rates of production of plants and animals. Changes in the earth's albedo, the ex-

tent of polar ice and changes in sea level, and atmospheric temperatures were sought. Revelle brought in David Keeling from the California Institute of Technology to initiate carbon dioxide studies, initially at Mauna Loa. Atmospheric levels of carbon dioxide were shown to have increased since 1957 in both the northern and southern hemispheres. This increased carbon dioxide can trap outgoing infrared radiation from the earth, thereby heating the atmosphere.

By now the concerns of Revelle and Suess have gone well beyond a "global geophysical experiment." The developing nations of the world are demanding special treatment in the adoption of mitigating measures by the countries of the developed world (i.e., limitations on the combustion of fossil fuels). The carbon dioxide problem has become "a global economic experiment."

Revelle's predecessor Sverdrup had initiated Wednesday staff luncheons. On assuming the directorship, Revelle turned these into Wednesday noon seminars attended by the entire staff. He would call on one of his colleagues to discuss his or her present investigations. But rarely did that person finish. The questions came quickly and rapidly. In this way, Revelle became familiar with nearly all of his institution's scientific work. (The seminars became a victim of the continued growth of the institution.)

Revelle's involvement in biology continued. Recognizing that all phases of marine science could be involved in the safe disposition of radionuclides introduced from energy plants as wastes into the oceans, be brought together in 1956 nineteen distinguished scientists to consider the effects of atomic radiation on ocean processes and on fisheries. This exercise initiated further studies by national and international organizations such as the National Commission on Radiological Protection and the International Council on Radiological Protection, which, along with the U.N. In-

ternational Atomic Energy Agency, formulated guidelines for management of artificial radionuclides.

Revelle was aware of the rather uninspiring and conventional research in marine biology and tried to start a revolution in the discipline in 1954 with a million-dollar grant from the Rockefeller Foundation. Five young faculty members came to the SIO to apply modern concepts and technologies from biochemistry and microbiology to ocean science. As chairman of the Oceanography and Fisheries Panel of the National Academy of Sciences' Committee on the Biological Effects of Atomic Radiation, he contributed substantially to that committee's 1956 report. He went on to the chairmanship of the U.S. National Committee for the International Biological Program in 1961.

Revelle played a key role in the creation in 1970 of the Scientific Committee on Problems of the Environment of the International Council of Scientific Unions (ICSU). It was he who suggested the objective for the ICSU's International Geosphere-Biosphere Program initiated in 1986: "To describe and understand the interaction of the great global physical, chemical, and biological systems regulating planet Earth's favorable environment for life, and the influence of human activity on that environment."

Global integration of national scientific advances was high on Revelle's list of priorities. He recognized complementary roads to his goals: the nongovernmental organizations affiliated with ICSU and the intergovernmental organizations under the auspices of the United Nations. The latter brought the political sectors into the scientific arena. Revelle was deeply involved in a wide variety of U.N. and ICSU activities for nearly four decades.

He was a prime mover in the establishment of the International Oceanographic Commission (IOC) in UNESCO in 1956, the creation by ICSU in 1958 of the Scientific Com-

mittee on Ocean Research (SCOR), and in 1969 of the Scientific Committee on Problems of the Environment. As the first president of SCOR, he participated in planning the International Indian Ocean Expedition. As president of the first International Oceanographic Congress at the United Nations in New York City in 1959 he finalized these plans for implementation in the mid-1960s. The congress brought together a thousand registrants from fifty-four countries.

UNIVERSITY OF CALIFORNIA, SAN DIEGO

The publication in the 1950s of a new master plan for the University of California with provisions for two new campuses in southern California gave Revelle an opening for which he had been looking. No oceanographic institution, he had said, could maintain intellectual excellence for more than a generation without an attachment to a great university. That said, he tackled the challenge with characteristic attention to fundamental principles.

Revelle's initial vision of a university at La Jolla involved the creation of a modern-day Athens where scholars would have a golden environment in which to think and create. Its format would incorporate features found at John Hopkins University and the University of Chicago, with heavy concentration on graduate education. The plan ran into opposition from a 1956 UCLA review committee, which proposed that San Diego should be permitted to offer only lower division undergraduate courses at first, and only after a later review, to add upper division courses, but not a graduate program. Revelle pointed out that Scripps had been training doctoral students when UCLA was still a teacher's college.

Revelle put an enormous effort into recruiting faculty for the new school originally housed on the Scripps campus, among them Harold Urey, Joseph and Maria Mayer,

David Bonner, and Martin Kamen. The "secret" of his recruiting success was not a secret at all. He put in a major effort to learn what these people really wanted and then went all out to provide the opportunity for them to realize their dreams.

It was generally taken for granted that Revelle would serve as its first chancellor. Edwin Pauley, an oil magnate and chairman of the board of the University of California regents, wanted the campus in Balboa Park in downtown San Diego; Revelle wanted it next to Scripps. Revelle won that battle, but as it happened to King Pyrrhus of Epirus, he had won one too many. When it came time to appoint the first chancellor, the regents chose Herbert York. It was a major blow to Revelle, reminiscent of the long delays in his appointment as Scripps director. Revelle determined that his continued presence on the campus would make it difficult for York to function effectively. He went to Washington as science advisor to Secretary of the Interior Stewart Udall and then returned to California as University Dean of Research, a position he found to entail only token responsibilities. He then accepted an appointment as Richard Saltonstall Professor of Population Policy at Harvard University, served as Director of the Center for Population Studies from 1964 to 1974, and continued in the chair until 1978.

WASHINGTON, D.C., AGAIN

Before taking up his duties at Harvard, Revelle, as the first science advisor to the Secretary of the Interior, had become directly involved in a broad set of resource problems. An initial issue involved the problem of increasing populations and diminishing resources (e.g., the availability of irrigation waters). Identified by a distinguished twenty-person White House and Department of the Interior panel on waterlogging and salinity in West Pakistan, which Revelle

chaired, the issue arose because meeting the food demands of the Pakistanis was inhibited by a rise in the water table and soil salinity as a consequence of canal leaks that reduced agricultural production. The panel proposed networks of large tube wells for lowering the water table with the extracted water to be used in irrigation. The adoption of these recommendations resulted in an increase of agricultural productivity in Pakistan of 7% per year for the next decade.

Revelle recognized the vulnerability of the marine systems to alien inputs from the continents. He was sympathetic to the 1962 volume *Silent Spring* by Rachel Carson, which argued that ecosystems were being disrupted by the entry of halogenated hydrocarbon pesticides such as DDT and dieldrin. As scientific advisor to Secretary Udall, Revelle gave Carson his backing. In 1972 the Environmental Protection Agency strongly regulated the usage of such biocides. This was a radical and sophisticated step, as previous controls on toxic material management, such as the artificial radionuclides, were based on the maintenance of public health; here the concern was the protection of all forms of life.

THE HARVARD YEARS

From 1964 to 1978, as the Richard Saltonstall professor of population policy at Harvard University and Director of the Center for Population Studies, Revelle brought together a team of colleagues dedicated to understanding the problems of population change and of the parameters that influence it—social, biological, and economic. He coupled these concerns with those of food supply, energy availability, health, and environmental quality.

The Marine Life Research Program at SIO had ignited Revelle's interest in world food problems. This interest found

expression again during Revelle's tenure at Harvard. He brought a refreshing perspective to global food problems, embedding them in the matrix of population, resources, economic development, energy, and, of course, knowledge—discovered, integrated, communicated, and applied. No doomsday prophet, he wrote in the *Proceedings of the National Academy of Sciences* in 1966 that "in the foreseeable future, there should be no serious difficulty in maintaining the quantity and improving the quality of food supplies per person in the developing countries . . . ." with the provision that inordinate population growth be reduced, educational opportunities be enhanced, industrialization proceed, social patterns change, agricultural acreage and productivity increase, and appropriate responsibility be accepted by the developed countries. This analysis and prescription are as good (and as dependent on knowledge) today as they were the day they were written.

The plight of developing countries, particularly India, which he visited frequently and productively, was Revelle's continuing and very active concern. He chaired the National Academy of Sciences' Board on Science and Technology for International Development from 1968 to 1973, advised the U.S. Agency for International Development, the White House, UNESCO, and the United Nations, and played an important role in the creation of the International Foundation for Science in Stockholm, participating in its imaginative programs to strengthen the knowledge base in developing countries.

RETURN TO THE UNIVERSITY OF CALIFORNIA, SAN DIEGO

In 1976 Revelle returned to San Diego to become professor of science and public policy. His appointment was in the UCSD program in science, technology and public affairs, where he initiated a series of seminars in marine policy

and resource management. These he kept up as long as he lived. His activities at Harvard since leaving Scripps had sharpened his Socratic teaching abilities. These undergraduate classes with a dozen or so students, were eagerly sought and often oversubscribed. He very effectively used outside experts as lecturers and subjected them to his critical yet sympathetic questioning.

SIO director Edward Frieman turned over his seaside study (adjoining the director's office) to Roger, and it was from there that Roger gently influenced the institution during the remaining years of his career. When questioned about his profession, Roger would reply, "I am an oceanographer." But this was hardly restrictive, because he had defined the profession of oceanography as "whatever anyone at Scripps does."

Roger Revelle died at the age of eight-two on July 15, 1991, from complications of cardiac arrest. At a farewell tribute at SIO, director Frieman announced that a multidisciplinary research ship, commissioned in 1996, was to be named the *RV Roger Revelle*.

FAVORS AND GRACE

Elected to the National Academy of Sciences in 1958, Revelle received the Academy's Agassiz Medal "for outstanding achievements in oceanography" in 1963. He was elected a fellow of the American Academy of Arts and Sciences in 1958 and a member of the American Philosophical Society in 1960. President Mohammed Ayub Khan of Pakistan decorated him with the order of the Sitara-Imtiaz in 1964 for his work on the waterlogging and salinity in West Pakistan. In 1968 Revelle was awarded the highest prize of the American Geophysical Union, its William Bowie Medal. Revelle was the Tyler Medallist in 1984 for his contributions to ecology and the environment. Italy's President Francesco

Cossig presented him with the Balzan Prize for oceanography and climatology in 1986. In that same year he received the Roger Revelle Award for outstanding contributions to education from UCSD's Revelle College, which had been named after him. He received the National Medal of Science in 1991 "for his pioneering work in the areas of carbon dioxide and climate modifications, oceanographic exploration presaging plate tectonics, and the biological effects of radiation in the marine environment, and studies for population growth and global food supplies." To a reporter asking why he received the medal, Revelle said, "I got it for being the grandfather of the greenhouse effect."

In light of Revelle's influence on international science, it is fitting that the American Association for the Advancement of Science (for which he served as President in 1974) has created in his honor, and through the generosity of the Revelle family, a fellowship program on global stewardship and a special conference room in its Center for Science and Engineering.

The Revelles were patrons of the arts in San Diego, something of what the Medicis had been in Florence. The La Jolla Chamber Music Society's 1991 Summerfest and a season of San Diego Symphony (which the Revelles had rescued from bankruptcy in 1986) were dedicated to his memory. The La Jolla Playhouse and other cultural and civic groups similarly honored him. He became a town councilor and San Diego Rotary Club's Man of the Year for 1990. Roger took the lead in acquiring some land for faculty housing adjacent to the Scripps campus. He and Ellen presented the Save Our Heritage Organization with an irrevocable ocean view easement from a choice piece of property owned by the family. Roger spearheaded a group of SIO scientists to formulate wastewater management strategies that saved San Diego billions of dollars. Yet, his community regarded

Revelle with some apprehension for his independent views. He was responsible for exorcising an unwritten covenant against selling land in La Jolla to Jews; Roger later received an award from the American Jewish Committee.

AN APPRECIATION

We don't want to leave the impression that this memoir is an exercise in hagiography; to suppress Revelle's weaknesses would be to discredit his most formidable strengths. Here we refer to Revelle's own words of critical self-appraisal (three transcripts of "Oral History with Roger Revelle," Roger Revelle papers MC6 and MC6A, Scripps Institution of Oceanography, University of California, San Diego). He never let a clock or calendar interrupt a conversation or a train of thought. Important people were left waiting, and publication deadlines were missed. At times, he was observed to be writing his speech while being introduced at the podium. He was casual about money—after his death archivists found several uncashed wartime Navy paychecks in his files. He was so focused on the future that he did not bother to maintain a full bibliography of his own publications. When he thought something was important, he took responsibility, which meant that he was often spread too thin. When he knew he was right, he did not spare the feelings of his opponents.

He took a dim view (one of his favorite expressions) of people who acted from greed and ignorance, and he let this be known: "carborundum non illegitimatum" was a favorite advice. And though he could be combative, he was never vindictive. In all the years we knew him, we never saw a trace of pettiness. He would announce his decision without fanfare, like "I see no reason why we shouldn't go ahead, do you?" If the decision called for new responsibility, he accepted this responsibility without concern and not as a

burden, but as one more piece to be added to the mosaic of a rich life.

Revelle had a curiosity without bounds and without boundaries. Once aroused, he immersed himself in a problem by endless talks, by extensive reading, and by recall from an unfading memory. We do not agree with his self-assessment: "It is important to remember that I am not a very good scientist." Certainly his mathematical dexterity was limited. But he arrived at his conclusions not by following an analytical process, but by muddling through all the evidence. One can be sure that his judgment was very much his own and that prejudice, self-interest, or seeking popular approval played no part.

Revelle found teaching a part of the learning process, and his learning process never stopped. Whether on the podium or as a member of an audience, his Socratic stance was known to all. If the subject matter appealed to him, he sought a complete understanding gained by unlimited questioning and discussion. His teaching was not restricted to the academic community. It was all too often that one would find Roger in conversation with a janitor, housewife, or seaman, explaining to them the intricacies and beauties of science. He chaired the Academy committee that oversaw development of the film *Planet Earth*, which brought an understanding of the habitat of humanity to millions of individuals.

To his family he was an endearing husband, father, and grandfather. Dinner at the Revelle family table was like a seminar, for which children and grandchildren were expected to be on their mettle and hold their own.

In an address at Carnegie-Mellon University in 1971, Revelle outlined the philosophy that epitomized his life:

> We must work to improve the quality of the social environment created by human beings . . .

We must stem the deterioration of our natural environment by preserving its wonder, beauty, and diversity . . .

We must face the facts of world population growth . . .

We must re-inspire our universities . . .

We should work for the abolition of atomic weapons . . .

To create a new world, we must first create within ourselves a higher concern for good, a stronger will for right action, and a deeper sense of brotherhood . . . .

Those words from this uniquely Homeric figure of the twentieth century were an inspiring legacy for future generations.

WE ARE INDEBTED TO Deborah Day for providing us with extensive material from the archives of the Scripps Institution of Oceanography and for reviewing this memoir.

SELECTED BIBLIOGRAPHY

1934

Physico-chemical factors affecting the solubility of calcium carbonate in sea water. *J. Sediment. Petrol.* 4:103-10.

1935

The deep-sea bottom samples collected in the Pacific on the last cruise of the Carnegie. *J. Sediment. Petrol.* 5:37-39.

1939

With F. P. Shepard. Sediments off the California coast. In *Recent Marine Sediments*, ed. P. E. Trask, pp. 245-82. Tulsa, Okla.: American Association of Petroleum Geologists.

With F. P. Shepard and R. S. Dietz. Ocean bottom currents off the California coast. *Science* 89:488-89.

1944

Marine bottom samples collected in the Pacific Ocean by the *Carnegie* on its seventh cruise. Carnegie Institution of Washington Publication no. 556.

1951

With K. O. Emery. Barite concretions from the ocean floor. *Geol. Soc. Am. Bull.* 62:707-24.

1952

With A. E. Maxwell. Heat flow through the floor of the eastern North Pacific Ocean. *Nature* 170:199-200.

1954

The earth beneath the sea—Geological exploration under the ocean. In *Modern Physics for the Engineer*, ed. L. N. Ridenour, pp. 306-29. New York: McGraw-Hill.

1955

With R. L. Fisher. The trenches of the Pacific. *Sci. Am.* 193:36-41.

1956

With E. C. Bullard and A. E. Maxwell. Heat flow through the deep-sea floor. *Adv. Geophys.* 3:153-81.

1957

With H. E. Suess. Carbon dioxide exchange between atmosphere and ocean and the question of an increase of atmospheric CO_2 during the past decades. *Tellus* 9:18-27.

1965

With R. Dorfman and H. Thomas. Waterlogging and salinity in the Indus Plain: Some basic considerations. *Pak. Dev. Rev.* 5(3):331-70.

1966

Just how limitless are the ocean's food supplies? *Conserv. Catalyst* 1:2-5.

1967

International Biological Program. *Science* 155:957.

1968

On technical assistance and bilateral aid. *Bull. At. Sci.* 24:17-19.

1969

The harvest of the sea and the world food problem. *Oceanus* 14:1.

1971

The population dilemma: People and behavior. *Psychiatr. J.* 1:1.

1975

With V. Lakshminarayana. The Ganges water machine. *Science* 188:611-617.

1977

Overview and recommendations. *Energy and Climate.* Washington, D.C.: National Academy of Sciences.

1978

The past and future of ocean drilling. *Joint Oceanographic Institution.* Washington, D.C., p. 4.

1981

Introduction: The oceanic lithosphere. In Vol. 7, *The Sea*, ed. C. Emiliani. New York: Wiley and Sons.

1982

Carbon dioxide and world climate. *Sci. Am.* 247(2):35-43.

1987

How I became an oceanographer and other sea stories. *Annu. Rev. Earth Planet. Sci.* 15:1-23.