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## Tribute to Roger Revelle and his contribution to studies of carbon dioxide and climate change

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I first came to Scripps Institution of Oceanography (SIO) in the summer of 1939, after completing my junior year at the California Institute of Technology. Roger Revelle was 30 years old, with the rank of instructor (long since abolished by the University of California), and a lieutenant junior grade in the Naval Reserve. Roger invited me to come along on an experiment to measure currents in the waters over the California borderland. The standard tool was an Ekman Current Meter; for every 100 revolutions of a propeller, a 2-mm ball is dropped into a compass box with 36 compartments, each corresponding to a 10° segment in current direction. The trouble was that the balls would not fall into the compartments. Roger was up all night doggedly fussing with the current meter until, at breakfast time, the release was functioning. This is my earliest memory of Roger.

### Scripps and the War Years

After taking up geology at Pomona College under the legendary teacher Alfred “Woody” Woodford, followed by a graduate year at University of California at Berkeley, Roger came to Scripps in 1931 to study deep-sea muds. By 1936 he had completed his thesis, “Marine Bottom Samples Collected in the Pacific Ocean by the Carnegie on Its Seventh Cruise,” and stayed on as an instructor (Fig. 1). During his year at Berkeley, Roger married Ellen Clark, a grandniece of E. W. Scripps and Ellen B. Scripps, after whom the Scripps Institution of Oceanography was named.

After a year at the Geophysical Institute in Bergen, Norway, he returned to Scripps. Roger went on active naval duty 6 months before the bombing of Pearl Harbor and stayed in the Navy for 7 years. He was instrumental in organizing the Office of Naval Research. In 1946 he was officer in charge during Operation Crossroads of the geophysical measurements taken during the atomic bomb tests at Bikini Atoll. None of the participants will ever forget this experience. For many years, Roger contributed to the understanding of the environmental effects of radiation and to questions of disposal of atomic wastes at sea (1). [Revelle contributed to the report in ref. 1 as Chairman of the National Academy of Sciences Panel on Biological Effects of Atomic Radiation (BEAR).] I suspect that Roger’s participation for so many years, from 1958 to 1981, in the Pugwash Disarmament Conferences can be traced to the Bikini bomb tests.

### The Scripps Directorship

After more than 40 years as a local marine station, Scripps Institution had agreed to undertake a program to study the disappearance of sardines from California waters (Fig. 2). This involved the commissioning of two vessels. Scripps Director

Harald Sverdrup was anxious for Roger to return to La Jolla to succeed him as director of Scripps. Sverdrup (2) wrote, “regardless of the capacity in which you return here, you are the logical man to take charge . . . of the work at sea.”

And Roger (3) agreed:

Sverdrup’s support for me as successor is also based upon the fact that I am practically the only person available who has had extensive experience at sea, in particular in the organization and carrying out of expeditions. He feels that Scripps must be, at least in part, re-oriented toward work on the high seas rather than the inshore and laboratory type of research which is being largely done at present.

Sverdrup’s statement “regardless of the capacity in which you return” was a reference to a developing opposition to Roger as the next director. One Scripps professor complained that Roger was too untidy to be trusted with administration (3), noting that he “just let everything pile up on his desk” and “was too easily diverted.” Again Roger agreed (3), referring to his own “obvious and numerous weaknesses, such as a tendency to procrastinate, to take on too many obligations, not to delegate authority, to be high-handed.”

The outcome was that Carl Eckart was appointed director of Scripps in 1948, and Roger was appointed associate director with the expectation to succeed Eckart in a few years. It wasn’t that easy! A 1950 letter to University of California President Robert Sproul (4), signed by more than half the Scripps faculty, states:

We understand that the impression has been gained in some quarters that opposition is vanishing at Scripps Institution to Dr. Revelle as a candidate for Director. We assure you that whereas we have a high regard and friendship for him, we feel as strongly as before that his appointment . . . would not be in the interest of the institution. His recent administrative actions confirmed our conviction.

Roger was appointed director in 1950. It is a tribute to Roger’s disdain for pettiness that some years later one of the writers referred to Roger’s “brilliant Directorship” (13).

### The Heady Expedition Days

The era opened in 1950 with the Mid-Pacific expedition into the equatorial waters of the central Pacific Ocean. This was followed in 1952–1953 by an extended voyage to the South Pacific, which was called Capricorn. Both expeditions were led personally by Roger. It was discovered that only a thin veneer of sediments overlies the solid rock, that the heat flow through the sea floor is about the same as that on land, and that the flat-topped seamounts at a depth of 2,000 m had been volcanic islands less than 100 million years ago. All of this spoke for great mobility of the “solid” Earth. When Roger and his



FIG. 1. Roger Revelle as an instructor at Scripps (circa 1936). Photo by Eugene LaFond. [Reproduced with the permission of the SIO Archives, UCSD.]

colleagues tried to core and dredge the Tonga Trench, the instruments came up battered and bent, and empty. If there were any sediments, they were sparse and thin. The observations could best be explained if the rocky sea floor was disappearing into the Earth along the axis of the trench (this is now called subduction). On Capricorn, Ronald Mason towed a magnetometer behind the vessel and recorded a complicated set of wiggles that no one could understand. Later Mason produced a map of the magnetic field under the sea floor showing stripes of normal and reverse magnetization.

With hindsight, the evidence was all there for proclaiming the doctrine of plate tectonics. And when, 10 years later, the puzzle was put together, Scripps unfortunately did not play a leading role. Still, I think of the 1950s as the great era of the Institution. When Roger left in 1961, Scripps had a Navy bigger than that of Costa Rica.

### Greenhouse

Even as he led the exploration of the Pacific, Roger was active for several years in promoting the International Geophysical Year (IGY). In 1956 he became chairman of the IGY Panel on Oceanography. That same year, Charles David Keeling joined the Scripps Institution staff to head the IGY program on Atmospheric Carbon Dioxide and to start the measurements at Mauna Loa and Antarctica. And that is why we are here 40 years later. Keeling credits Harry Wexler and Roger Revelle for insisting on the continuity of the measurements; such time series are few and far between and worth their weight in gold.

In 1957, Roger and Hans Suess demonstrated that carbon dioxide had increased in the air as a result of the consumption

of fossil fuels, in a famous article published in *Tellus* (5). Roger's interest in CO<sub>2</sub> was to engage his attention for the rest of his life. In 1965, the President's Science Advisory Committee Panel on Environmental Pollution under Roger's leadership published the first authoritative report that recognized CO<sub>2</sub> from fossil fuels as a potential global problem (6). Public opinion was influenced through a widely read article in *Scientific American* (7).

Roger participated in the exploration of the atmospheric greenhouse problem from the 1950s, when it was a cottage industry for a few academics, to the 1990s, when global climate change involved industry and government on an international scale. He once estimated that he had spent 20% of his time keeping current with the issues.

### THE MOHOLE PROJECT

In 1957 Roger and I were among a group that called themselves the American Miscellaneous Society (AMSOC). AMSOC promoted an attempt to drill through the ocean floor into the Earth's mantle. A test off Guadalupe Island successfully drilled through 200 m of sediments into the basalt in water 4,000 m deep, demonstrating the feasibility of "dynamic positioning." This MOHOLE project (Fig. 3) eventually failed because of poor Washington management but led some years later to the successful Ocean Drilling Program.

### Ocean Leadership

The U.S. ocean program was then firmly in the hands of three men: Maurice Ewing, Columbus Iselin, and Roger Revelle. There has not been a comparable ocean leadership since those days.\*

While Revelle served as a founding member of the National Academy of Sciences Committee on Oceanography (NASCO), the funds budgeted nationally for oceanography rose from \$12 million in 1957 to \$97 million in 1960. Roger played a major role in organizing the IGY and in forming the Scientific Committee for Ocean Research (SCOR) and the International Oceanographic Commission (IOC), and then served as Chairman of a joint IOC/SCOR Committee on Climate Changes and the Ocean. These organizations continue to play an important role in international oceanography.

Roger enjoyed an international reputation as oceanographer in the 1950s but became better known to the greater scientific community and to the public through his work for the National Academy of Sciences as a science spokesman with broad knowledge of the environment. He worked very hard behind the scenes to frame the important scientific questions and then to secure the resources to answer them. Policy makers looked to him for a reasonable assessment of which scientific problems should take priority. Scientists sought his advice and support to focus research and get it funded. Congressman Emilio Daddario (8) has remarked on Roger's "combined experience, intelligence and good judgment about issues."

### Building the University of California at San Diego (UCSD), 1954–1961

In parallel with these developments came the beginnings of the UCSD. No oceanographic program, Roger said, could maintain intellectual excellence for more than a generation without an attachment to a great university. The obvious site was some 1,100 acres of largely undeveloped public land just to the north of the Scripps Institution of Oceanography. Fortuitously, Roger's initiative coincided with a new master plan for the

\*This may have changed; in the last several years, Admiral (U.S. Navy, ret.) James Watkins has become a recognized national spokesman for ocean affairs.



FIG. 2. Gulf of California Expedition, 1939. (Left to Right) Erik Moberg, Roger Revelle, Seaman Andrew Boffinger, Richard Fleming (with binoculars), Machinist Bob MacDonald, George Hale, Lee Haines, Engineer Walter Robinson, Martin Johnson, and Loye H. Miller. [Reproduced with the permission of the SIO Archives, UCSD.]

University of California, which foresaw the need to establish two new campuses in southern California.

Roger had in mind a major university in the manner of The John Hopkins University or the University of Chicago, with a heavy concentration of graduate students. The plan ran into opposition by a 1956 University of California at Los Angeles

(UCLA) review committee, which proposed that UCSD 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. We pointed out that Scripps had been granting Ph.D. degrees when UCLA was still a teacher's college.



FIG. 3. MOHOLE project, aboard the *CUSS I* off Guadalupe Island in 1961. (Left to Right) John Steinbeck, Josh Tracey, Unidentified, William Riedel, Roger Revelle, Walter Munk, Gustav Arrhenius, and Willard Bascom, examining specimen. Photograph by Fritz Goro, *Life Magazine* (© Time Inc.).

Roger (9) roasted them for trying to forestall competition:

The Committees on Educational Policy . . . were experts at seeing clouds no bigger than a man's hand. It was clear to them that a new graduate school would draw money away from their own campuses; it might even attract outstanding scientists. . . . They thought it would be nice to have an undergraduate school at La Jolla, managed by a farm team of dedicated teachers, which could provide well-trained new graduate students for their own laboratories.

Roger put in an enormous effort in recruiting faculty for his new school, originally housed on the Scripps Campus; among the recruits were Harold Urey, Joseph and Maria Mayer, Jim Arnold, David Bonner, Walter Elsasser, Martin Kamen, Bernd Matthias, and Bruno Zimm. The secret of Roger's recruiting success was not a secret at all. He put in a major effort to learn what these people really wanted to do and then went out to provide the opportunity for them to live their dream. But he was not unwilling to exercise some salesmanship. Judith and I were on the recruiting route, and Roger would end up at our home with an exhausted candidate in tow at cocktail time, saying, "And here is a typical faculty house."

There was at the time an unspoken covenant among La Jolla Realtors not to sell to Jews. Roger went out to break this covenant, realizing that it was incompatible with his vision of the university. He was somewhat aided by the fact that most members of the real estate community were not fundamentally opposed to enhancing their commissions.

The chairman of the University of California Board of Regents at the time was the oil magnate Edwin Pauley. Pauley wanted the campus in Balboa Park in downtown San Diego. Roger wanted it next to Scripps. Regent Pauley had commissioned a study that concluded that the aircraft noise associated with Miramar Naval Air Station would make the site 20% more expensive than that at Balboa Park. Roger had gotten hold of a previous report by that same architect dealing with the location of Scripps Hospital (under the same flight pattern and even closer to the Air Station) which concluded that the noise would not appreciably increase the cost!

Roger won that battle, but as it happened to King Pyrrhus of Epirus, he had won one too many. In 1961, when it came time to appoint the first chancellor, the Regents selected Herbert York. It was a major blow to Roger, reminiscent of the long delays in his appointment as Scripps Director.

### The Exile

Roger determined that his continued presence on the campus would make it very difficult for Herbert York to function effectively, so he left for what turned out to be a 14-year exile. President Kerr appointed Roger to the meaningless position as Dean of Research for the University of California statewide. Roger next became Science Advisor to Secretary of Interior Morris Udall and then was appointed Richard Saltonstall Professor of Population Policy at Harvard University, a chair he held for just over a decade. Among his students was Benazir Bhutto and Albert Gore. Gore credited Roger with having aroused his interest in environmental problems.

Many years later, during the 1992 presidential campaign, Gore was accused of having misrepresented Roger's position on global warming. The problem arose in connection with an article first published in the *Cosmos Club Journal*, "What to Do About Greenhouse Warming: Look Before You Leap." The cautionary admonition "look before you leap" is uncharacteristically tame for Roger, and it is my contention that it represented more the views of the other authors, Fred Singer and Chauncey Starr.

I cannot do justice to the many accomplishments during the exile era, but I need to mention one activity which goes back



FIG. 4. Revelle explaining core sample to roughneck aboard *CUSS I* in 1961. This is my favorite photograph of Roger; it shows his total attention to the person with whom he is speaking at the moment. Photograph by Fritz Goro, *Life Magazine* (© Time Inc.).

a long time: Roger's continuing love affair with India. Roger took many trips to India and served as an advisor to various government agencies on a broad range of topics, centered on food and population problems. I was amazed on a recent trip to learn of how many Indian careers and lives had been influenced by Roger.

Roger and Ellen thought of their Harvard years as some of the most fulfilling of their lives. Calling it an "exile" reflects my own provincial Scripps perspective.

### Coming Home

In 1975 Roger returned to UCSD to become Professor of Science and Public Policy. For the next 15 years he taught courses in marine policy and population, and he continued to be active in oceanographic affairs. When in 1978 the American Association for the Advancement of Science (AAAS) decided to focus its international efforts on a few selected issues, Roger chaired the AAAS group that identified the build-up of heat-absorbing gases in the atmosphere as one such issue. As a result, the AAAS Board created the Committee on Climate, and Roger served as its chairman for a decade. The Committee was responsible for the first effort to identify the costs and benefits of increased atmospheric carbon dioxide.

He received the National Medal of Science from President George Bush 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 of population growth and global food supplies.

To a reporter asking why he got the medal, Roger (10) said, "I got it for being the grandfather of the greenhouse effect."

It is difficult to do justice to a man with such broad accomplishments. When questioned about his profession, Roger would reply "I am an oceanographer." But this was hardly restrictive because he defined the profession of oceanography as whatever anyone at Scripps does. This has saved me on one occasion. During one of the chronic Scripps space



FIG. 5. Roger in 1976. Photo by Glasheen. [Negative AN24/41906/484/34, UCSD Special Collections.]

shortages, Director William Nierenberg surprised Judith and me in a SIO laboratory as we were using laser pulses to remove encrustation's from a renaissance statue. "What are you doing?" Bill asked. "I am doing oceanography," I replied.

### A Personal Appreciation

Roger and I have collaborated on a number of papers: on a global compilation of the seasonal change in sea level, on an attempt to infer the melting of the Greenland ice cap from the slowing of the Earth's rate of rotation and the motion of the pole toward Greenland, and on a 1977 National Academy of Sciences report (11) in which we traced the partition  $\text{CO}_2$  among the atmosphere, ocean, and biosphere. Roger's way of working was anything but analytical; rather he followed a Sherlock Holmes procedure of eliminating one hypothesis after another. In doing his sums, he showed an accountant's revulsion for dropping nonsignificant digits.

But my thoughts of Roger are not particularly related to these joint publications. He was my friend for 50 years. I remember weekends in the Revelle cottage in Julian, and sailing in the Aegean. I remember all-night sessions of Roger and Harry Hess at the Cosmos Club. I remember 9 months in the South Pacific, with a luncheon hosted by the Crown Prince, now King, of Tonga. I remember sleepless nights with Roger and John Steinbeck on the drilling ship CUSS I in Mexican waters prior to the demise of the MOHOLE Project.

Toward the end of his life, Roger's health deteriorated; he walked in pain and with some difficulty. One year before his death, I was visiting John Knauss, then Administrator of The National Oceanographic and Atmospheric Administration (NOAA), to seek help for the Heard Island Expedition, when Roger unexpectedly showed up. He had walked the endless corridors of the commerce building to lend his silent support. During the expedition, when all the equipment was demolished in a gale on station in the South Indian Ocean, Roger sent a soothing message by fax: "Wish I were with you; and then I am glad I'm not." Roger was upset by a critical news article on the Heard Island Expedition published in *Science* (14) and wrote a letter to the editor starting with the words: "Shame on you" (15). It was to be the last thing Roger published (Fig. 5).

In an obituary for the *Independent* of London (12), the oceanographer Henry Charnock spoke for many of us when he noted that, "[f]or an informed view on earth science, and on its repercussions on the human predicament, he was in a class of his own."

Deborah Day at Scripps Archives is responsible for much of this material.

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