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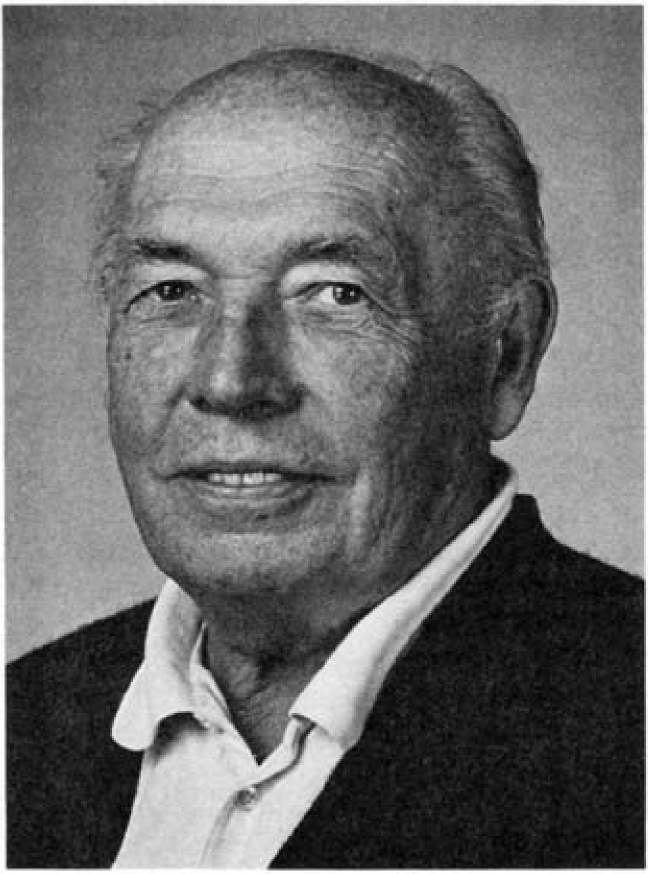
ROBERT MINARD GARRELS

1916—1988

A Biographical Memoir by
ROBERT A. BERNER

Biographical Memoir



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Robert M Garrels

ROBERT MINARD GARRELS

August 24, 1916–March 8, 1988

BY ROBERT A. BERNER

WITH THE PASSING of Robert M. Garrels, the world has lost a unique individual. He is among the handful of persons that over the past half century truly altered the course of geochemistry, which was his specialty, as well as that of earth science in general. Hidden within this modest, affable, kind, and considerate man was the soul of a revolutionary, and it is the hope of this biographical memoir to document the revolution that he led.

Bob Garrels was born in Detroit, Michigan, on August 24, 1916, the second of three children of John Carlyle and Margaret Anne Garrels. His father was a successful chemical engineer who, in his youth, was an outstanding athlete both as an All-American football player and as an Olympian who placed second in the 110-meter hurdles and third in the shotput in the 1908 Olympics. (Can you imagine the same individual being able to successfully compete in both events today?) Bob inherited the love of athletics from his father and was athletically active all his life until he was felled by cancer during his last year. In fact, for a few months Bob was the holder of the world's high-jump record for fifty-seven-year-old men.

Bob's childhood years, from age six through twelve, were spent in Saltville, in the mountainous southwestern part of

Virginia, where his father worked for a chemical company that used local salt and limestone as raw materials. His boyhood was spent mainly in outdoor activities such as hunting, exploring, and swimming. The formative factors that motivated him toward a scientific career are best summarized in his own words taken from his unpublished autobiography (written for the National Academy). He states (words in brackets are my additions):

> There were three factors, I think, that pushed me toward a scientific career. First, of course, my father's interest; second, the richness of the area [southwestern Virginia] in natural lore. The presence of salt deposits attracted animals, and fossils of Pleistocene forms were often uncovered at construction sites. The rocks of the hills surrounding the town contain abundant Paleozoic fossils. The third factor was the presence of James Moore, a middle-aged bachelor who was a first-rate amateur astronomer, and who delighted in teaching me and my friends about the universe.

At age twelve, Bob and his family moved to Grosse Ile, Michigan, where he attended high school. Although he excelled in mathematics and chemistry, his principal interests seemed to be reading and athletics. Also, his mother saw to it that he became a "reasonably good pianist." He mentions in his autobiography that his first scientific thrill came from building a crude stroboscope to determine the rate at which an automobile wheel was turning. He used the device to win a prize at a Detroit department store for the person who guessed the number of turns made by the wheel in a shopping day. In fact, he was able to show that the department store was not holding the rotation rate constant, thus demonstrating scientific skepticism at an early age.

Garrels entered the School of Liberal Arts at the University of Michigan in 1933. Although his original intention was to become a chemist like his father or a novelist, by the end of his sophomore year because of a bad teacher he hated chemistry (this attitude would change in graduate school) and realized that creative writing was not his forte. This led to geology, of which he knew little other than the fact that he loved the outdoors and had a general inclination toward science. He enjoyed majoring in geology and graduated with a B.S. degree with honors in 1937.

His graduate school experience is best summarized in his own words (and autobiography):

> In 1937 I entered the Graduate School at Northwestern University, only because they needed a teaching assistant at $50 per month and the best job I could find paid $75. The Department of Geology at Northwestern was small but excellent; my fellow graduate students were compatible, competitive, and capable. I soon ran out of geology courses, and took chemistry courses to fill in my program; to my amazement [considering his undergraduate experience] I found them fascinating and useful. Professor John T. Stark of the Department of Geology was a tremendous influence on me during my graduate years, and remains to this day my best friend. He was very close to the students, and a man of remarkable intellectual breadth. His teaching method was that of being the Devil's advocate, and I have adopted and used it with great pleasure. He gave me the first real discipline of my career; no statement went unquestioned, and I began to try to apply some of the principles relating to methodology and epistemology, that I had learned in [undergraduate] philosophy [courses], to earth science.
>
> Professor C. H. Behre, Jr. was my sponsor for a thesis. He suggested a geochemical problem related to the formation of lead and zinc deposits, and arranged with Professor F. T. Gucker, Jr. of the Chemistry Department for my guidance in the laboratory aspects of the work. To Gucker I give the credit for any ability I may have in chemistry. We met regularly, and each week he suggested what I should accomplish. His standards were high, he was sympathetic but firm, and I worked harder than I have before or since. He led me into problems that required more chemical training than I possessed, and somehow made me understand that it was unthinkable for me not to solve them. So, of course, I did.

Garrels received the M.S. degree from Northwestern in 1939, based on a thesis concerning some iron ores of Newfoundland that he had studied during the summer of 1938. In 1941 he received the Ph.D. degree; the thesis research was largely a laboratory study, using electrochemical techniques, of complex formation between lead and chloride ions in aqueous solution. The thesis won the Sigma Xi award for the best one submitted that year at Northwestern. He presented his results, in the broadened context of the role of complex ions in the transport of metals in underground waters, to the Boston meeting of the Geological Society of America. This was his first scientific contribution and one of a pathfinding nature. Unfortunately, as he once told me, almost no one attended his talk because its significance was unappreciated by geologists at that time.

After obtaining his Ph.D., degree Garrels stayed on at Northwestern as a replacement for Charles Behre, who had left. Then in 1944, due to the war he became affiliated with the Military Geology Unit of the U.S. Geological Survey in Washington. Shortly thereafter he was assigned to the Beach Erosion Board of the Corps of Engineers in Hawaii, working on beaches that were to be invaded by the U.S. military attempting to gain control of Pacific islands from the Japanese. He once confided to me that had it not been for the atomic bomb dropped on Japan he would have had to do *on site* mapping and reconnaisance to prepare for a U.S. invasion of the Japanese home island of Honshu, a very dangerous task.

After the war, in 1945, he returned to Northwestern and taught there until 1952, holding the positions of assistant and then associate professor. He continued his research on ore deposits and taught introductory geology and introductory physical science. His teaching of geology led to the writing of a book, *A Textbook of Geology,* published in 1951. This underappreciated book was not a big seller (because it contains liberal doses of physics and chemistry) but demonstrated Garrels's original approach to earth science and his unusual propensity for being ahead of his time. Some noteworthy papers published by Garrels during this "first Northwestern period" (see Selected Bibliography) were concerned with diffusion in water-saturated rocks, the study of fluid inclusions as a guide to geologic thermometry, activity coefficients of lead and chloride ions in aqueous solution, the origin of Clinton iron ores as revealed by laboratory experiments, and a study of crystal growth. In 1952 he also published, along with W. C. Krumbein, a paper that was to become a classic, "Origin and Classification of Chemical Sediments in Terms of pH and Oxidation–Reduction Potentials." This work was to show how the study of sediments and sedimentary rocks could be approached from a physical–chemical standpoint, and was required reading for anyone (like myself) studying sedimentary rocks during the 1950s. One couldn't think of Garrels without thinking of Eh–pH diagrams.

In 1952, Garrels left Northwestern (he was to return two more times) to become head of the Solid State Group, Geochemistry and Petrology Branch, of the U.S. Geological Survey, where he was to remain for three years. There he concentrated on experimental and theoretical aspects (more Eh–pH diagrams) of uranium and vanadium geochemistry. He states in his autobiography:

> [At the survey] it was a fascinating experience to work with a large number of people on every aspect of geochemistry of just two elements.
>
> After the University, in which I represented the entire discipline of geochemistry, and in which my collaboration with others was on the basis of other disciplines, it was like changing one's view from 10 fold to 1000 fold magnification.

Bob never liked being an administrator and found that his personnel-related duties at the USGS were getting to be too much. Thus, in 1955 he returned to academic life, accepting the position of Associate Professor of Geology at Harvard University. (He was promoted to professor in 1957.) This, as it turned out, was one of the best appointments Harvard could have made at the time, for it was there that his research and teaching talents flourished. Because of Garrels, graduate students could obtain invaluable training in theoretical and experimental aspects of geochemistry, practically unobtainable elsewhere. I know because I was one of these fortunate graduate students (although Garrels was not my primary advisor; I worked instead under Raymond Siever). Garrels's lab was a hub of activity, with my contemporaries measuring Eh and/or pH in mineral equilibrium experiments (e.g., Paul Hostetler, Owen Bricker, and Don Langmuir), doing theoretical calculations (e.g., Hal Helgeson and Al Truesdell), forcing water through clay packs (Bruce Hanshaw), and turning sulfide minerals into electrodes (M. Sato).

It was while he was at Harvard that Garrels's book *Mineral Equilibria at Low Temperature and Pressure* was published in 1960. This book was one of the first of its kind to show earth scientists how to directly apply chemical thermodynamics to geology with emphasis on the construction of stability diagrams from thermodynamic data. It and its successor, *Solutions, Minerals, and Equilibria* (coauthored with C. L. Christ) have been enormously influential since that time. Proof of this was the designation of the latter book as a Citation Classic, because of its high frequency of citation, by the organization that publishes *Science Citation Index.*

Also while at Harvard, Garrels was involved in a very profitable collaboration with Mary E. Thompson and Ray Siever. Such classic papers were published by these three, in various combinations, as "Oxidation of Pyrite by Iron Sulfate Solutions" (1960,2), "Stability of Some Carbonates at 25°C and One Atmosphere Total Pressure" (1960,3), "Control of Carbonate Solubility by Carbonate Complexes" (1961), and "A Chemical Model for Sea Water at 25°C and One Atmosphere Total Pressure" (1962,2). This last paper, by Garrels and Thompson, showed how ion-pairing and complex formation could be used to calculate activities of the principal ions of seawater. It has been so influential that it was also cited by *Science Citation Index* as a classic paper.

Eventually Garrels became chairman of the Geology Department at Harvard and again disliked the administrative duties so much that it eventually contributed to his leaving to return to Northwestern in 1965. This time he stayed at Northwestern for four years. It was during this "second Northwestern period" that he undertook a close and fruitful collaboration with F. T. Mackenzie. Garrels's enthusiasm for the ideas of Lars Gunnar Sillen led him to the idea that the chemical composition of seawater is buffered by reactions with silicate and, to a lesser degree, carbonate minerals. This led to publication with Mackenzie of papers dealing with the chemical mass balance between rivers and oceans and the silicate–bicarbonate balance in the ocean. A key concept in this work was that of reverse weathering, whereby fine-grained cation-free silicates (e.g., clays) carried to the oceans are reconstituted by the uptake of cations and silica, resulting in the conversion of bicarbonate to CO_2. Such reactions were needed at the time to explain the chemical balance of seawater composition; however, they have been rivaled subsequently by processes accompanying basalt–seawater reaction.

Also during his second Northwestern period, Garrels was author or coauthor of pathfinding papers on the genesis of groundwaters, the origin of the chemical composition of springs and lakes, and the theoretical treatment of irreversible reactions in geochemical processes, the latter representing collaboration with his former student H. C. Helgesen, who was at Northwestern at the time. At this time Garrels began a long and successful collaboration with Roland Wollast of the University of Brussels. (He had previously met Wollast during a sabbatical in Belgium during 1962–63.) Also, he completed with Fred Mackenzie the book *Evolution of Sedimentary Rocks,* which was published in 1971. In this book, whose major influence is only recently being felt, Garrels and Mackenzie demonstrate the importance of the chemical recycling of sediments by way of weathering, dissolution, erosion, transport, sedimentation, burial, and diagenesis followed by uplift and restarting of the sedimentary cycle. Such sediment recycling is a fundamental concept which was originally emphasized by Hutton but which, until the work of Van Nieuwenkamp and Barth in the 1950s and 1960s, had laid practically dormant for over 150 years.

During the second Northwestern period there came a change in Garrels's personal life. He divorced his wife of twenty-nine years, Jane (Tinen), and married Cynthia A. Hunt in 1970. By then his children by the first marriage, Joan F., James C., and Katherine G., were essentially grown up. Not only was his new wife, Cynthia, an inspiration, but in fact she was eventually a coauthor of two books with him: *Water the Web of Life* (1972,1) and *Chemical Cycles and the Global Environment* (1975,1), the latter also with F. T. Mackenzie. He remained happily married to Cynthia until the end of his life in 1988.

While on the subject of human interest, I'd like to recount a humorous episode relating to the pleasant times our family and I had with Bob and Cynthia in Bermuda during the summers of 1970 and 1971. Bob had been doing research in Bermuda during summers of the previous several years and, as a spare-time activity, had organized the informal group called BBSAC, the Bermuda Biological Station Athletic Club. The BBSAC-ers all ran, swam, rowed, and, after these labors in the heat, enjoyed a few drinks. One Garrelsian rule was that a swim from the raft to the research vessel, *Panulirus,* and back, a distance of about 200 yards, entitled the swimmer to one gin and tonic. There were strong but variable currents in the swimming area, however, and some swimmers complained that a greater effort was expended when the currents were stronger. Garrels immediately realized that the current was not simply additive in one direction and subtractive in the other but was, instead, a true hindrance to performance. After all, the swimmer couldn't return to the raft if the current against him was faster than his still-water swimming speed. Garrels constructed a nonlinear plot of current speed versus extra effort in terms of a "gin and tonic factor," with the swimmer eligible for an infinite number of gin and tonics when the current speed equaled his still-water swimming speed! This episode exemplifies both Bob's clever wit and his ability to bring scientific order to even the most mundane of topics.

In 1969 Bob moved from Northwestern to the Scripps Institution of Oceanography, where he remained for just two years, and then to the University of Hawaii, where he spent another two years. During this time, 1969–74, he continued his collaborative researches with Fred Mackenzie and Roland Wollast and began an additional collaboration with Yves Tardy of the University of Strasbourg on theoretical calculation of the thermodynamic properties of silicate minerals. At both Scripps and Hawaii, he also worked with the late Ed Perry, which culminated in their paper, published in 1974, entitled "Cycling of Carbon, Sulfur, and Oxygen through Geologic Time." This has been a very influential paper which spawned a number of studies in the 1980s on the evolution of atmospheric oxygen.

In 1974 Garrels returned to Northwestern for the third time (actually the fourth time if you include World War II) and remained there until 1979. This constitutes his third, or last, "Northwestern period." During this time he continued his previous collaboration with Mackenzie, Wollast, and Tardy and added Abraham Lerman, of Northwestern, as an additional collaborator. With Abe's expertise they constructed computer models for geochemical cycles with emphasis on phosphorus, carbon, and sulfur. By means of some ingenious reasoning, Garrels, Mackenzie, and Lerman were able to predict that the sulfur and carbon isotopic records for Phanerozoic rocks should essentially correlate with one another, and this was later found to be correct.

The last phase of Garrels's career began in 1979, when he was appointed to the Marine Science Department of the University of South Florida at St. Petersburg with the title of Research Professor, and was present there from 1980 until his death in 1988. Although by now he was well into his sixties, his mind and accomplishments hadn't diminished a bit. I had the good fortune of collaborating with him when he visited Yale University during the fall of 1979 and several summers thereafter. (He held then the position of Adjunct Professor at Yale.) His enthusiasm for geochemical cycling was contagious, and he drew me into this field. Together the two of us, along with Antonio Lasaga, also of Yale, published a paper in 1983 entitled "The Carbonate–Silicate Geochemical Cycle and Its Effect on Atmospheric Carbon Dioxide over the Past 100 Million Years." In this paper we tried to show how one might calculate the change of atmospheric CO_2 over time, how it was affected by plate tectonics, and how CO_2 could have acted as a "greenhouse gas" as a control of past global climates.

Later in the St. Petersburg period, Bob Garrels wrote a brilliant paper with his student Lee Kump on "Modeling Atmospheric O_2 in the Global Sedimentary Redox Cycle" (1986,1). He was still active right up to the time of his death. In May of 1987 he was diagnosed as having cancer which had metastasized from his colon. For the rest of 1987 Bob fought his disease and continued to work. During the year a book summarizing thermodynamic data on minerals was published (coauthored by Terri Woods), as was his last major paper, entitled "A Model for the Deposition of the Microbanded Precambrian Iron Formations." Although severely debilitated by his disease and the effects of chemotherapy and radiation therapy, he was able to present a talk at the fall meeting of the Geological Society of America and to write a reply to some critical comments served up on his model for banded iron formations. This was true heroism and, characteristic of Garrels, done in good humor with no health complaints.

During the early months of 1988 Bob quickly grew worse, and he finally expired on March 8, 1988. The news of his death arrived the next day at a scientific meeting that I was attending, and which he had so much wanted to attend himself, on the GAIA hypothesis. The meeting was being held in honor of his good friend James Lovelock, and he had many ideas he wanted to air at it. Needless to say, the news created a pall over the meeting, and a number of us found it hard to keep our eyes dry. His wife and now widow, Cynthia, characteristic of her selflessness, urged that Bob's close friends at the meeting not rush to St. Petersburg but stay at the meeting and give our talks, as Bob would have wished. This we did.

Over his long career Bob received many honors, too numerous to mention here. The more notable ones are election to the National Academy of Sciences (1961); president of the Geochemical Society (1962); the Arthur L. Day Medal of the Geological Society of America (1966); the Goldschmidt Award of the Geochemical Society (1973); the Penrose Medal of the Geological Society of America (1978); the Wollaston Medal of the Geological Society of London (1981); the Roebling Medal of the Mineralogical Society of America (1981); and honorary doctorates from the Université Libre de Bruxelles (1969), the Université Louis Pasteur, Strasbourg (1976), and the University of Michigan (1980). He also served on many committees, including those of the Geological Society of America, Society of Economic Geologists, the Mineralogical Society of America, the National Academy of Sciences, and the National Science Foundation.

In summary, Bob Garrels, as I said at the beginning, was a unique revolutionary. He not only brought physical chemistry to earth science but also made it understandable to ordinary geologists so that they could apply it to a wide variety of problems. He made us think in terms of cycling and recycling of rocks and impressed on us the importance of trying to treat geochemical cycles in a quantitative manner, with a combination of both chemical and geological insight. He showed us how to look at the composition of seawater, spring water, and lake water, and deduce all sorts of wondrous things from a little data. He pointed the way to how ore deposits form. Above all, he set an example of good humor, humility, optimism, and consideration for the feelings of others. He never attacked or criticized his opponents; he only disagreed with them. His time was always available for discussions with students, and he was patient with both the dullard and the smart show-off. He was never pompous and always scrupulously honest. His death has surely been a loss to the world; I wish there were more like him.

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