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CLAIR CAMERON PATTERSON

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A Biographical Memoir by
GEORGE R. TILTON

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Clair C. Patterson

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BY GEORGE R. TILTON

Clair Patterson was an energetic, innovative, determined scientist whose pioneering work stretched across an unusual number of sub-disciplines, including archeology, meteorology, oceanography, and environmental science—besides chemistry and geology. He is best known for his determination of the age of the Earth. That was possible only after he had spent some five years establishing methods for the separation and isotopic analysis of lead at microgram and sub-microgram levels. His techniques opened a new field in lead isotope geochemistry for terrestrial as well as for planetary studies. Whereas terrestrial lead isotope data had been based entirely on galena ore samples, isotopes could finally be measured on ordinary igneous rocks and sediments, greatly expanding the utility of the technique.

While subsequently applying the methodology to ocean sediments, he came to the conclusion that the input of lead into the oceans was much greater than the removal of lead to sediments, because human activities were polluting the environment with unprecedented, possibly dangerous, levels of lead. Then followed years of study and debate involving him and other investigators and politicians over control of lead in the environment. In the end, his basic views prevailed, resulting in drastic reductions in the amount of lead entering the environment. Thus, in addition to measuring the age of the Earth and significantly expanding the field of lead isotope geochemistry, Patterson applied his scientific expertise to create a healthier environment for society.

Clair Patterson (known as "Pat" to friends) was born and grew up in Mitchellville, Iowa, near Des Moines. His father, whom he describes as "a contentious intellectual Scot," was a postal worker. His mother was interested in education and served on the school board. A chemistry set, which she gave him at an early age, seems to have started a lifelong attraction to chemistry . He attended a small high school with fewer than 100 students, and later graduated from Grinnell College with an A. B. degree in chemistry. There he met his wife-to-be Lorna McCleary. They moved to the University of Iowa for graduate work, where Pat did an M. A. thesis in molecular spectroscopy.

After graduation in 1944 both Pat and Laurie were sent to Chicago to work on the Manhattan (atomic bomb) Project at the University of Chicago at the invitation of Professor George Glockler, for whom Pat had done his M. A. research. After several months there, he decided to enlist in the army, but the draft board rejected him because of his high security rating and sent him back to the University of Chicago. There it was decided that both Pat and Laurie would go to Oak Ridge, Tennessee, to continue work on the Manhattan Project. At Oak Ridge, Patterson worked in the ^{235}U electromagnetic separation plant and became acquainted with mass spectrometers.

After the war it was natural for him to return to the University of Chicago to continue his education. Laurie obtained a position as research infrared spectroscopist at the Illinois Institute of Technology to support him and their family while he pursued his Ph.D. degree.

In those days a large number of scientists had left various wartime activities and had assembled at the University of Chicago. In geochemistry those scientists included Harold Urey, Willard Libby, Harrison Brown, and Anthony Turkevich. Mark Inghram, a mass spectrometer expert in the physics department, also played a critical role in new isotope work that would create new dimensions in geochemistry. The university had created a truly exciting intellectual environment, which probably few, possibly none, of the graduate students recognized at the time.

Harrison Brown had become interested in meteorites, and started a program to measure trace element abundances by the new analytical techniques that were developed during the war years. The meteorite data would serve to define elemental abundances in the solar system, which, among other applications, could be used to develop models for the formation of the elements.

The first project with Edward Goldberg, measuring gallium in iron meteorites by neutron activation, was already well along when Patterson and I came on board. The plan was for Patterson to measure the isotopic composition and concentration of small quantities of lead by developing new mass spectrometric techniques, while I was to measure uranium by alpha counting. (I finally also ended up using the mass spectrometer with isotope dilution instead of alpha counting.) In part, our projects would attempt to verify several trace element abundances then prevalent in the meteorite literature which appeared (and turned out to be) erroneous, but Harrison also had the idea that lead isotope data from iron meteorites might reveal the isotopic composition of lead when the solar system first formed. He reasoned that the uranium concentrations in iron meteorites would probably be negligible compared to lead concentrations, so that the initial lead isotope ratios would be preserved. That was the goal when Patterson began his dissertation project, however attaining it was to take considerably longer than we imagined at the time.

Patterson started lead measurements in 1948 in a very dusty laboratory in Kent Hall, one of the oldest buildings on campus. In retrospect it was an extremely unfavorable environment for lead work. None of the modern techniques, such as laminar flow filtered air, sub-boiling distillation of liquid reagents, and Teflon containers were available in those days. In spite of those handicaps, Patterson was able to attain processing blanks of circa 0.1 microgram, a very impressive achievement at the time, but now approximately equal to the total amount of sample lead commonly used for isotope analyses.

His dissertation in 1951 did not report lead analyses from meteorites; instead it gave lead isotopic compositions for minerals separated from a billion-year-old Precambrian granite. On a visit to the U.S. Geological Survey in Washington D.C., Brown had met Esper S. Larsen, Jr., who was working on a method for dating zircon in granitic rocks by an alpha-lead method. Alpha counting was used as a measure of the uranium and thorium content; lead, which was assumed to be entirely radiogenic (produced by the decay of uranium and thorium), was determined by emission spectroscopy. Despite several obvious disadvantages, the method seemed to give reasonable dates on many rocks. Brown saw that the work of Patterson and me would eliminate those problems, so we arranged to study one of Larsen's rocks. We finally obtained lead and uranium data on all of the major, and several of the accessory, minerals from the rock. Particularly important was the highly radiogenic lead found in zircon, which showed that a common accessory mineral in granites could be used for measuring accurate ages. As it happened, the zircon yielded nearly concordant uranium-lead ages, although that did not turn out later to be true for all zircons. In any case, that promising start opened up a new field of dating for geologists, and has led to hundreds of age determinations on zircon.

In parallel with the lead work, Patterson participated in an experiment to determine the branching ratio for the decay of ^{40}K to ^{40}Ar and ^{40}Ca. Although the decay constant for beta decay to ^{40}Ca was well established, there was much uncertainty in the constant for decay to ^{40}Ar by K electron capture. This led Mark Inghram and Harrison Brown to plan a cooperative study to measure the branching ratio by determining the radiogenic ^{40}Ar and ^{40}Ca in a 100-million-year-old KCl crystal (sylvite). The Inghram group would measure ^{40}Ar while Patterson and Brown would measure ^{40}Ca. They reported a value that came within circa 4% of the finally accepted value.

After graduation, Patterson stayed on with Brown at Chicago in a postdoctoral role to continue the quest toward their still unmet meteorite age goal. He obtained much cleaner laboratory facilities in the new Institute for Nuclear Studies building, where he worked on improvement of analytical techniques. However, after a year this was interrupted when Brown accepted a faculty appointment at the California Institute of Technology. Patterson accompanied him there and built facilities that set new standards for low-level lead work. By 1953 he was finally able to carry out the definitive study, using the troilite (sulfide) phase of the Canyon Diablo iron meteorite to measure the isotopic composition of primordial lead, from which he determined an age for the Earth. The chemical separation was done at CalTech, and the mass spectrometer measurements were still made at the University of Chicago in Mark Inghram's laboratory. Harrison Brown's suspicion was finally confirmed! The answer turned out to be 4.5 billion years, later refined to 4.55 billion years. The new age was substantially older than the commonly quoted age of 3.3 billion years, which was based on tenuous modeling of terrestrial lead evolution from galena deposits.

Patterson's reactions on being the first person to know the age of the Earth are interesting and worthy of note. He wrote,[1]

> True scientific discovery renders the brain incapable at such moments of shouting vigorously to the world "Look at what I've done! Now I will reap the benefits of recognition and wealth." Instead such discovery instinctively forces the brain to thunder "*We* did it" in a voice no one else can hear, within its sacred, but lonely, chapel of scientific thought.

There "we" refers to what Patterson calls "the generations-old community of scientific minds." From my observations, he lived that ethic. To him it must have been an exercise in improving the state of the "community of scientific minds." His attitude recalls the remark of Newton: "If I have seen farther than others, it is because I have stood on the shoulders of giants."

The age that Patterson derived has stood the test of time, and is still the quoted value forty-four years later. In the meantime, there have been small changes in the accepted values for the uranium decay constants, improvements in chemical and mass spectrometric techniques, and a better understanding of the physical processes taking place in the early solar system and Earth formation, but these have not substantially changed the age Patterson first gave to us. Some textbooks have given diagrams showing that the logarithm of the supposed age of the Earth plotted against the year in which the ages appeared approximated a straight line, but Patterson's work has finally capped that trend.

Patterson next focused on dating meteorites directly instead of inferring their ages from the Canyon Diablo troilite initial lead ratios. He did this by measuring lead isotope ratios in two stone meteorites with spherical chondrules (chondrites) and a second stone without chondrules (achondrite). A colleague, Leon Silver, had recommended the achondrite because of its freshness and evolved petrologic appearance. Coupled with the iron meteorite troilite lead, the complete data yielded a $^{207}Pb/^{206}Pb$ age of 4.55 ± 0.07 billion years. The achondrite data were especially important because the Pb ratios in the two chondrites were close to those of modern terrestrial lead, raising questions about possible Earth contamination, but the exceptionally high uranium/lead and thorium/lead ratios in the Nuevo Laredo achondrite produced lead with isotope ratios that were unlike any isotopic compositions that have ever been found in terrestrial rocks. They also fit the 4.55 Ga age, which removed any doubts about major errors in the date.

The meteorite work led indirectly to his second major scientific accomplishment. The new ability to isolate microgram quantities of lead from ordinary rocks and determine its isotopic composition had opened for the first time the path for measuring lead isotopes in common geological samples, such as granites, basalts, and sediments. That led him to start lead isotope tracer studies as a tool for unraveling the geochemical evolution of the Earth. As part of that project he set out to obtain better data for the isotopic composition of "modern terrestrial lead" by measuring the isotopic composition of lead in ocean sediments. By 1962 Tsaihwa J. Chow and Patterson reported the first results in an encyclopedic publication that initiated Patterson's concern with anthropogenic lead pollution, which was to occupy much of his attention for the remainder of his scientific career.

The isotope data revealed interesting patterns for Atlantic and Pacific Ocean leads that could be related to the differences in the ages and compositions of the landmasses draining into those oceans. However, in studying the balance between input and removal of lead in the oceans, the authors calculated that the amount of anthropogenic lead presently dispersed into the environment each year was circa eighty times the rate of deposit into ocean sediments. Thus, the geochemical cycle for lead appeared to be badly out of balance. The authors noted that their calculations were provisional; the analytical data were scarce or of poor precision in many cases, however this was the seminal study that started Patterson's investigations into the lead pollution problem.

The limitations in the analytical data on which many of the conclusions in the 1962 paper were based led Patterson to start new investigations to attack the problem. In 1963 he published a report with Mitsunobu Tatsumoto showing that deep ocean water contained 3 to 10 times less lead than surface water, the reverse of the trend for most elements (e.g., barium). This provided new evidence for disturbance in the balance of the natural geochemical cycle for lead by anthropogenic lead input.

In the 1965 paper entitled "Contaminated and Natural Lead Environments of Man,"[2] Patterson made his first attempt to dispel the then prevailing view that industrial lead had increased environmental lead levels by no more than a factor of approximately two over natural levels. He maintained that the belief arose from the poor quality of lead analyses in prehistoric comparison samples in which much of the lead reported was actually due to underestimation of blank contamination. He compiled the amounts of industrial lead entering the environment from gasoline, solder, paint, and pesticides and showed that they involved very substantial quantities of lead compared to the expected natural flux. He estimated the lead concentration in blood for many Americans to be over 100 times that of the natural level, and within about a factor of two of the accepted limit for symptoms of lead poisoning to occur.

R. A. Kehoe, a recognized expert on industrial toxicology[3] accused him of being more of a zealot than a scientist in the warnings he had raised.[4] Another leading toxicologist had just returned from a World Health Organization conference where fifteen nations had agreed that environmental lead contributions to the body burden had not changed in any significant way, either in blood or urinary lead contents, over the last two decades. He called Patterson's conclusions "rabble rousing."[5]

Patterson's reactions are recorded in a letter to editor Katharine Boucot accompanying the revised manuscript:

> The enclosed manuscript does not constitute basic research and it lies within a field that is outside of my interests. This is not a welcome activity to a physical scientist whose interests are inclined to basic research. My efforts have been directed to this matter for the greater part of a year with reluctance and to the detriment of research in geochemistry. In the end they have been greeted with derisive and scornful insults from toxicologists, sanitary engineers and public health officials because their traditional views are challenged. It is a relief to know that this phase of the work is ended and the time will soon come when my participation in this trying situation will stop.[6]

Patterson's participation did not stop; instead on October 27, 1965, he wrote to California Governor Pat Brown restating the points from his 1965 review and emphasizing the dangerously high levels of lead in aerosols, particularly in the Los Angeles area. In it he claimed that the California Department of Public Health was not doing all it should to protect the population from the dangers of lead poisoning. His first request drew a polite rejection. A second letter on March 24, 1966, had better success, perhaps because of a letter from a high state official.[7] On July 6, 1966, Governor Brown signed a bill directing the State Department of Public Health to hold hearings and to establish air quality standards for California by February 1, 1967. Although that deadline was not met, Patterson clearly played a role in advancing concern over California air control standards.

He had simultaneously started parallel actions at the national level as well. On October 7, 1965, he sent a communication similar to the Brown letter to Senator Muskie, chairman of the Subcommittee on Air and Water Pollution. In it he offered to appear before the committee. He was subsequently invited to a hearing held on June 15, 1966, in Washington. There Patterson emphasized that most officials failed to understand the difference between "natural" and "normal" lead body burdens, the former based on incorrect data from pre-industrial humans, the latter on averages in modern populations. In support of that assertion he cited his newer work in Greenland showing the large increases in lead in snow starting with the industrial revolution. He furthermore believed it was wrong for public health agencies to work so closely with lead industries, whom he considered often biased in matters concerning public health.

His views drew support from some of the public (e.g., Ralph Nader), but were once again strongly opposed by others, notably by R. A. Kehoe, the highly regarded authority on industrial poisoning. A battle line was drawn that was to last about two decades.

By 1970 Patterson and his colleagues had completed studies of snow strata from Greenland and Antarctica that showed clearly the increase in atmospheric lead beginning with the industrial revolution in both regions. Modern Greenland snow contained over 100 times the amount of lead in pre-industrial snow, with most of the increase occurring over the last 100 years. The effect was about ten times smaller in Antarctic snow, but it was clearly observable. Later work with improved blanks reduced that figure to two.

In 1971 the National Research Council released a report entitled "Airborne Lead in Perspective" to guide the Environmental Protection Agency's policies on lead pollution. The panel was widely accused of not being forceful enough in interpreting its data and being too heavily weighted toward industrial scientists.[8] Patterson's work was largely ignored, however by December 1973 the EPA did announce a program to reduce lead in gasoline by 60-65% in phased steps. Thus was the beginning of the removal of lead from gasoline.

Meanwhile Patterson continued to work on the lead problem from another perspective by measuring lead, barium, and calcium concentrations in bones from 1600-year-old Peruvian skeletons.[9] The results indicated a 700- to 1200-fold increase in concentrations of lead in modern man, with no change in barium, a good staind-in for lead, and calcium. In a letter Patterson once said, "I have a passionate interest in this paper."[10]

In the late 1970s Patterson turned his attention to lead in food. In 1979 he wrote to the commissioner of food and drugs at the Environmental Protection Agency asserting that "your headquarters laboratory cannot correctly analyze for lead in tuna fish muscle."[11] He maintained that the laboratory blanks were too high to permit accurate analyses for lead concentrations below 1 ppm. When asked if he could cite other laboratories that agreed with his results, Patterson responded that scientific matters are not decided by majority vote.[12] That contact finally led to his participation in a symposium on analytical methods of analyzing for lead in food at the sub-1 ppm level, held October 10, 1981, in Washington. It was attended by both EPA and Bureau of Foods representatives. Patterson made three recommendations for improvements that seem to have been taken seriously.[13] These were (1) to use Bureau of Standards mass spectrometers to permit mass spectrometric lead analyses; (2) to equip EPA field laboratories better; and (3) to promote more contacts between EPA and academic laboratories. A few months later Patterson wrote that he believed the analytical work being done at the headquarters EPA laboratory met his standards.[14]

In 1980 Dorothy M. Settle and Patterson[15] published a warning on the amount of lead entering the food chain due to lead solder used in sealing cans. Although the National Marine Services laboratories had reported only twice as much lead in canned albacore muscle as in fresh tuna (700 versus 400 nanograms per gram), the authors found 0.3 nanogram per gram of lead in fresh and 1400 nanograms/gram in canned muscle. Barium varied by only a factor of two in the samples. A sample of fresh muscle prepared at CalTech and analyzed at the fisheries laboratory gave 20 nanograms per gram for lead, still much higher than the CalTech value. By 1993 lead solder was removed from all food containers in the United States. Patterson's influence is again clearly evident.

Although he was excluded from the earlier 1971 National Research Council panel that produced the report on airborne lead, in 1978 Patterson was appointed to a new twelve-member NRC panel to evaluate the state of knowledge about environmental issues related to lead poisoning. The panel report[16] is noted for containing majority and minority evaluations. The majority report cites the need to reduce lead hazards for urban children; notes that the margin between toxic and typical levels for lead in adults needs better definition; and concedes that typical atmospheric lead concentrations are 10 to 100 times the natural backgrounds for average populations and 1,000 to 10,000 times greater for urban populations. The report asks for further research on these subjects, as well as on relationships between lead ingestion and intellectual ability. The need for improved analytical work was emphasized.

In his lengthy 78-page minority report Patterson argued that the majority report was not forceful enough. Basically he said that the dangers of the prevalent practices were already clearly enough defined and that efforts should start immediately to drastically reduce or completely remove industrial lead from the everyday environment. That included gasoline, food containers, foils, paint, and glazes. He also cited water distribution systems. He urged "investigations into biochemical perturbations within cells caused by lead exposures ranging down from typical to 1/1000 of typical." He had long criticized assigning a sharp limit for lead in air or blood to denote a dividing line between poisonous and non-poisonous levels.

The above items give some, but by no means a complete, indication of the efforts Patterson devoted toward reducing the environmental lead burden. Many others joined the campaign with the passage of time, but he was clearly a principal player, and could be said to have initiated some of the changes that have occurred. Around 1973 lead began to be reduced in gasoline; it was removed completely in 1987. Lead solder has been removed from U. S. food containers a well as from paints and water lines. By 1991 scientists could report that the lead content of Greenland snow had fallen by a factor of 7.5 since 1971.[17]

Patterson will be remembered for having first discovered the differences between "natural" and "common" or "typical" lead abundances in the human population, and for arguing that point until it was universally accepted. That in turn has stimulated considerable medical research to study the effects of lead at below the toxic poisoning level on the human learning ability.[18]

Beginning in the early 1980s, Patterson's interests began to turn toward what I call the third stage of his intellectual career. It involved an introspective, philosophical evaluation of the place of man (H. s. sapiens, as he often stated it) in society. He distinguished between what he termed the engineering versus the scientific modes of thinking. His thoughts are best spelled out in the two articles in the 1994 special issue of *Geochimica et Cosmochimica Acta* in his honor. He sees the scientific mind as the inquiring mind that seeks to uncover the world's secrets, while the engineering mind seeks to control the natural world. This undoubtedly grew out of his experience as a scientist in discovering the age of the Earth, while the engineering mind would be equated with the technology that utilized the large amounts of lead that had polluted the environment. Thus he says,[19] "Most persons cannot see the ills of a culture constructed by 10,000 years of perverted utilitarian rationalizations because they perceive only its material technological forms through the eyes of a diseased *Homo sapiens sapiens* mind." At the end he was working on a book to express his ideas on those and other matters, such as population control. We will never know what it might have contained, but we can guess that it would have been a stimulating, unique, and undoubtedly controversial treatment.

As a person, Patterson was modest about his own accomplishments and generous in acknowledging the contributions of colleagues, especially those of his co-workers. He opened his laboratory to scientists from around the world and trained them in the techniques he had developed. He was self-assured in science and not one to follow the beaten path. Although he was very sensitive to the negative criticisms his work generated, he pursued his beliefs vigorously with what some would (and some did) call a fanatical drive. Perhaps any lesser degree of motivation would have led him to give up the struggle without seeing it through to the finish. He cared deeply about the welfare of society and applied his scientific knowledge toward seeking and making a better future for all. His final efforts on the book he hoped to write were directed toward that goal. His unique personality has been eloquently portrayed in the Saul Bellow novel *The Dean's December,* in which Patterson is the model for Sam Beech.[20] He was truly a one-of-a-kind person.

Patterson's many accomplishments were recognized in 1995 by the award of the Tyler Prize for Environmental Achievement, a most fitting reward for his prolonged efforts on behalf of the environment, the Goldschmidt Medal of the Geochemical Society in 1980, and the J. Lawrence Smith Medal of the National Academy of Sciences in 1973. He was elected to the National Academy of Sciences in 1987, and received honorary doctorates from Grinnell College in 1973 and the University of Paris in 1975, as well as the Professional Achievement Award from the University of Chicago in 1983. An asteroid (2511) and a peak in the Queen Maude Mountains, Antarctica, are named for him.

He is survived by his wife Lorna Jean McCleary Patterson, who resides at The Sea Ranch, California, and children Cameroon Clair Patterson, Claire Mai Keister, Charles Warner Patterson, and Susan McCleary Patterson.

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NOTES

1. Historical changes in integrity and worth of scientific knowledge. *Geochim. Cosmochim. Acta* 58(1994):3141.

2. Contaminated and natural environments of man. *Arch. Environ. Health* 11(1965):344-60.

3. As an employee of the Ethyl Corporation Kehoe discovered that deaths among workers manufacturing lead tetraethyl in the early 1920s were due to absorption of lead through the skin and