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# Memorial of Paul Brian Moore 1940–2019

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Paul Moore died on March 2, 2019, in Houston, Texas, and Science lost the greatest mineralogist of the 20th Century. Paul excelled at structural crystallography, crystal chemistry, descriptive mineralogy, and mineral paragenesis, and was the first scientist to combine the results of these approaches into a deeper understanding of minerals *sensu late.*

Paul Brian Moore was born on November 24, 1940, in Stamford, Connecticut. At the age of nine, he moved to New Jersey, and three years later he was captured by the world of minerals. He became an enthusiastic field collector of minerals, particularly at Franklin and Sterling Hill in New Jersey. Paul never ceased to stress the significance of field studies and the importance of amateur mineralogists to the advancement of science. At eighteen, he went to Michigan College of Mining and Technology to study mining engineering but soon became more interested in mathematics, physics, and chemistry. After receiving his B.S. in Chemistry in 1962, he moved to the University of Chicago to do graduate work and became associated with Joe Smith, who recognized Paul's brilliance. He flourished in this environment and completed his Ph.D. in two and a half years. An NSF Fellowship enabled him to go to the Swedish Natural History Museum in Stockholm to work on minerals from Långban, a setting similar to his favorite Franklin and Sterling Hill localities. Following this, Paul returned to the University of Chicago as a faculty member, attaining the rank of Full Professor at the early age of thirty-two. He was a Life Fellow of the Mineralogical Society of America, and in 1973, he received the MSA Award for outstanding published contributions to mineralogy before the age of thirty-five. Three years later, he received a Fellowship from the Alexander Humboldt Foundation to work in Germany for six months.

Paul was a prolific describer of new minerals, particularly from Långban, from the Palermo No.1 pegmatite (New Hampshire), and from the granitic pegmatites of the Black Hills (South Dakota). For him, the description of a new mineral had to involve the solution of its crystal structure, and his almost incandescent enthusiasm for these new atomic arrangements corruscates from the papers involving their description. His early involvement with both basic minerals of Långban-Franklin and acid late-stage minerals of granitic pegmatites gave him a wide appreciation of crystal structures, and he very rapidly developed penetrating insights into the general atomic arrangements of minerals. His paper (Moore 1965) on a structural classification of the basic iron-orthophosphate-hydrate minerals broke new ground in quantitatively relating structural arrangement to chemical composition and, for the first time, emphasized the importance of understanding the different roles of $H_2O$ in crystal structures. In a paper of true elegance (Moore 1970), he

Paul Brian Moore, 1974. (Color online.)

identified the $[^{[6]}M\Phi_5]$ chain of corner-sharing octahedra as present in many phosphate, sulfate, and silicate minerals, and showed how decoration by tetrahedrally coordinated oxyanion groups could lead to stereoisomerism that gives rise to a plethora of related atomic arrangements. However, instead of just comparing these structures, Paul derived all the different ways in which tetrahedra can decorate this type of chain, producing a scheme that not only included all known structures of this type but also predicted all possible structures that can occur (subject to some boundary conditions). Paul also showed how these chains could cross-link into sheet and framework structures and went on to solve the crystal structures of many minerals containing this chain. Later discoveries by many other mineralogical crystallographers attest to the pioneering nature of this work. Three years later, Paul produced a masterful exegesis of the calcium orthosilicates and alkali sulfates (Moore 1973a), colorfully entitled "Bracelets and Pinwheels: A Topological-Geometrical Approach..." that again examined isomerism in linked polyhedra as a basis for structural understanding. In 1974, Paul considered the question of clusters of nearest-neighbor octahedra (Moore 1974): he showed that there are 144 topologically distinct clusters, derived their stoichiometries, and noted that those that occur in crystal structures tend to have maximal point symmetry and a minimum of [1]-coordinated vertices.

Paul introduced the idea that one may deductively examine the possible ways in which polyhedra may link together from a purely topological perspective, an approach that introduces links between structures that have hitherto been seen only as vaguely similar, and puts their similarities and differences on a quantitative basis. The work outlined above transformed our approach to dealing with the crystal structures of minerals, for example, how

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to identify their most important features and how to relate them to each other. Paul then took the next crucial step: he began to relate crystal structure arrangements to paragenesis. His 1973 paper in the *Mineralogical Record* (Moore 1973b) "Pegmatite phosphates: Descriptive mineralogy and crystal chemistry" assigns phosphate minerals first into "primary" and "secondary" divisions and then into subdivisions according to the mechanisms of formation, develops a detailed paragenetic scheme, and correlates aspects of their structural connectivities with paragenetic sequence. This seminal paper illuminated the way to a more complete understanding of the factors affecting the crystallization of minerals and has significantly influenced work over the last 45 years.

In the early 1970s, Paul became associated with Takaharu Araki and their collaboration saw the solution of some of the most spectacular mineral structures known to science, e.g., cacoxenite (Fig. 1), steenstrupine, and mitridatite. It is also worthy of note that Paul solved these structures before the advent of routine structure solution using direct methods. Rather, he commonly used Patterson maps, which require sophisticated mental gymnastics to apply to the solution of complex structures.

Paul was a gifted communicator who took his job as a professor very seriously, and he was awarded the Quantrell Award for excellence in undergraduate teaching by the University of Chicago. It was impossible to be bored by him; he would explain both simple and complex ideas with the same irrepressible enthusiasm for their intellectual beauty. He was expert in the use of scientific equipment such as optical goniometers, petrographic microscopes, and Gandolfi, Weissenburg, and precession X-ray cameras, and he ensured that his students developed this expertise. Paul was always approachable, whether sharing a drink with graduate students at Jimmy's (just off-campus) or collecting minerals with them in the field.

Paul was an accomplished organist and had an organ in his apartment close to the University of Chicago where he played music of the Baroque and Romantic periods. He was even known to give impromptu "recitals" on the wondrous pipe organ at the University's Rockefeller Memorial Chapel. He was a fanatical butterfly collector and a member of the Lepidopterists Society, and traveled to New Guinea and Peru on extended collecting expeditions. On one occasion, he returned from New Guinea to North America with butterfly larvae taped to his body to keep them warm, and he hatched them in the facilities of the university.

Paul suffered from bipolar disorder, a condition he shared with many eccentric geniuses before him (e.g., Isaac Newton, Charles Dickens, Ludwig van Beethoven, Vincent van Gogh). He took lithium for most of his adult life, often self-medicating in attempts to extend the periods of mania and curtail the periods of depression, and it amused him that he needed an element that is an important constituent of many granitic pegmatites.

In 1977, Paul was involved in a car accident in which he was thrown from an open Jeep and suffered a severe concussion. He was unconscious for several weeks and remained in the hospital for an extended period. The road back was slow and difficult for Paul; eventually, he largely recovered physically, but his psyche was indelibly altered. Through the 1980s and early 1990s, Paul became more and more troubled by his psychological issues and less and less accepted by the academic establishment. Indeed, a nomination for a major medal

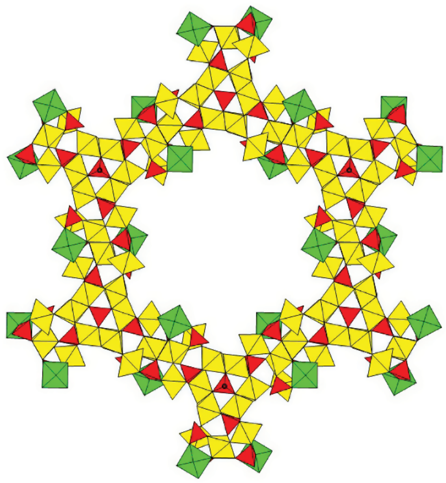

**FIGURE 1.** The crystal structure of cacoxenite. Red = $PO_4$ tetrahedra; green = $AlO_6$ octahedra; yellow = $FeO_6$ octahedra. (Color online.)

was not accepted by a scientific society on the grounds that Paul was too unstable to be given the opportunity to speak in public.

Paul retired early from the University of Chicago and moved to Warwick, New York, to a property where years before he had rediscovered the site of the original discovery of warwickite. After several years, diminishing financial resources forced him to sell the property and move in with his younger sister Lauren in Spring, Texas, for several years. Since 2015, he was living in a senior assisted-living establishment in Houston, Texas. In his later years, he suffered from various physical conditions, the most serious of which was Parkinsonism. Nevertheless, he never stopped working on problems involving crystal structures and would occasionally phone or email colleagues to discuss them. Two of his last publications were on the new Långban mineral philolithite, including its description (Kampf et al. 1998) and its crystal structure (Moore et al. 2000). The name philolithite is derived from the Greek φίλος (philos), "friend", and λίθος (lithos), "stone", in honor of the Friends of Mineralogy; it is extremely appropriate that these were two of Paul's final scientific publications, as he himself was one of Mineralogy's greatest friends.

Paul Moore was a brilliantly successful scientist and a flamboyant, but ultimately tragic figure. We will give him an epitaph that he would have appreciated: Magister Ludi of the Glass Bead Game.

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