Rock Stars

Norman L. Bowen: The Experimental Approach to Petrology

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The greatest petrologist of the 20th century is clearly Norman Levi Bowen (1887–1956). He promoted the solution of petrological field problems by the application of principles deduced from simple phase diagrams of the end members of common rock-forming minerals, thereby providing a quantitative approach to a field previously concerned only with observation and classification. Despite his quiet personality, subdued presentations, droll sense of humor, and even his small stature, he was a giant.

Work and Play

As a youth, Bowen helped his father in the family bakery, driving the delivery rig—an experience that resulted in his enduring distrust of horses. Winters were spent ice skating, and during the summer months he became a strong breast-stroke swimmer and took part in races. He sang in the choir of the local Anglican church and is alleged to have had a fine tenor voice.

The Field Experience

Public schools in Kingston, Ontario, had prepared him for college entrance examinations at Queen's University. Even though registered in the arts course with the intent of becoming a teacher, Bowen had the urge, as many young people do, to see new and alluring country and to earn some money. He joined an Ontario Bureau of Mines geological mapping party to Larder Lake under the leadership of R. W. Brock. Brock, who was an outstanding personality and eventually became Director of the Geological Survey of Canada, had so much confidence in Bowen's inherent abilities, in addition to his skills for surviving in the bush, that he left the young man to carry out the work alone! Travel in the bush was by canoe, and traversing in search of outcrops was done under a blanket of mosquitoes and black flies. Bowen could use an axe and tump line, make pace-and-compass surveys, and cook. In the course of his mapping, he became interested in the differentiation of diabase.

Courses Chosen

As a result of his field experiences, when he returned to Queen's University, Bowen registered in the School of Mining, taking mineralogy and geology. After two more field seasons around Lake Abitibi and Gowganda Lake, again paying attention to the diabases, he won a prize of $25 and the President's gold medal from the Canadian Mining Institute for the best paper submitted by a student: "Diabase and aplite of the cobalt-silver area." (See 1956 edition of Bowen [1928] for references to his published works.) Trained in the Canadian bush on the myriad of variables in natural geological processes, he had rapidly absorbed the principles of geology and chemistry. On graduation in 1909, he won a London Exhibition of 1851 Scholarship, which gave him the opportunity to continue on in graduate school.

Norman L. Bowen on his first job involving land surveying.

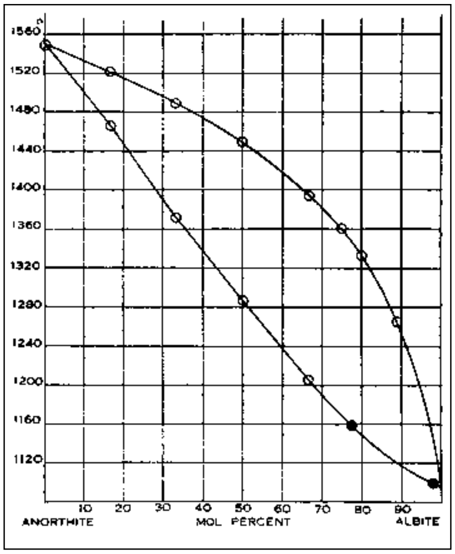
Charismatic Teachers

He was first attracted to Norway because of J. H. L. Vogt's (1903–1904) book, *Die Silikatschmelzlösungen* and by W. C. Brøgger, who had applied physicochemical principles developed in the investigation of slags to the problem of differentiation. Bowen was discouraged, however, from going to Norway because of the language barrier and because Brøgger was too busy with legislative duties. Instead, Bowen went to MIT to study under the sparkling and charismatic teacher Reginald A. Daly, who indoctrinated him with the idea that basaltic liquid was a primary magma and all others were derivative. He also introduced Bowen to some of the possible causes of differentiation, such as diffusion, fractional crystallization, crystal segregation, gaseous transfer, immiscibility (liquation), and assimilation. Probably Charles H. Warren imbued Bowen with the principles of physical chemistry as applied to mineralogical and petrological problems. It was clear that he had already focused on igneous differentiation and the principles of physical chemistry.

The Experimental Experience

In 1910, at the suggestion of T. A. Jaggar, then at MIT, Bowen applied to the Geophysical Laboratory at the Carnegie Institution of Washington to do an experimental study related to a geological field problem for partial fulfillment of the requirements of the Ph.D. As the laboratory's first predoctoral Fellow, he was assigned the "nephelite problem," a favorite topic of J. P. Iddings. At that time, most of the experimental techniques for high temperatures used today were all in their early stages of development. The controllers for the high-temperature furnaces were very large street-car-type banks of resistor coils; platinum-rhodium thermocouples had just been calibrated to 1755 °C by Day and Sosman (1911); the quenching method had just been invented by Shepherd, Rankin, and Wright (1909). Wright (1910) had perfected a new petrographic microscope for examining fine-grained synthetic preparations. Particularly important was the development of a calculation scheme for translating the chemical analyses of rocks, whether crystalline or glassy, into a set of end-member minerals, the CIPW normative system (Cross et al., 1902), that could be simplified for laboratory experimentation. In addition, the theory of solid solutions had been laid out by H. W. Bakhuis Roozeboom (1901). In short, Bowen arrived at a most opportune time to do the nepheline-anorthite system—all the tools and theory were in hand. The nepheline-anorthite diagram was determined with considerable efficiency with 17 different mixtures and 55 quenching experiments under the tutelage of E. S. Shepherd and F. E. Wright. That simple system, the first example found in silicates of solid solu-

The courtship of N. L. Bowen and Mary Lamont, a medical student in Boston.



The plagioclase phase diagram, with temperature in °C and the seven new synthetic and two natural anorthite-albite compositions studied, indicating the liquidus (upper curve) and solidus. The melting point of anorthite was already well established and used as a point for thermocouple calibration.

tion combined with polymorphism, generated in Bowen's mind a much larger picture. While writing his thesis he also managed to produce in 1912 a paper of lasting value, "The order of crystallization in igneous rocks." With this publication at age 25, Bowen had introduced the precursor to a major change in the approach to petrology.

Career Decision

In the summer of 1911 Bowen was in the field again with Reginald Daly, surveying the Shuswap terrane of British Columbia, famous for its crosscutting granites and wholesale injection. In spite of his absences from Boston, he managed to court Mary Lamont, and they were married on October 3, 1911. Upon graduation from MIT on June 4, 1912, he had offers from Jaggar, then at the Volcano Observatory in Hawaii, for a post in economic geology at Tucson, for a position at the Geological Survey of Canada, and for the job of assistant petrologist at the Geophysical Laboratory. After another field season in British Columbia, in charge of his own field party, he decided to join the Geophysical Laboratory staff, arriving September 1, 1912 (Yoder, 1992).

Critical Mineral Systems

Plagioclase is the most abundant mineral in Earth's crust, so Bowen next undertook a study of the two-component system albite-anorthite. That system, studied earlier by Day, Allen, and Iddings (1905), was the subject of the first official publication of the Geophysical Laboratory. They had been able to determine the melting temperature only from An_{100} to $An_{26.1}$ $Ab_{73.9}$. Kinetic problems prohibited their measuring the solidus temperature with the cooling-curve method, even though they recognized the system as one of the Roozeboom theoretically possible types, with continuous solid solution containing neither a maximum nor minimum. With the quenching method and run times of only 1/2–2 hours, Bowen was able to generate the entire plagioclase diagram, well documented with later studies. It provided the basis for his subsequent views on magma differentiation and crystal fractionation, both old ideas (Scrope, 1825; Becker, 1897) but lacking experimental demonstration.

A New Integrated Approach

Several alternatives for the processes leading to magma diversity had already been presented and explicitly summarized by Iddings (1892). But Bowen set out his prejudices forcefully and clearly in 1915 in two papers after studying only two more, yet most critical, phase diagrams illustrating the reaction principle. One paper, "The later stages of the evolution of igneous rocks," provided a flexible, broad theory based on quantitative experimental observations that he defended with rigorous argumentation. As a result of his incredible perceptiveness and intuition, Bowen had integrated all the new experimental methods, physicochemical theory, and field observations into a unified new approach to petrology. It was his clarity of presentation, documentation of principles with experimental demonstrations, and application to specific field problems that eventually made his 1928 book *The Evolution of the Igneous Rocks,* the handbook for petrologists worldwide. It was with some reluctance that field geologists eventually accepted Bowen's philosophy as leading to the most satisfactory interpretation of the facts as they were perceived by geologists: (1) recognition of a set of field observations that appear to be related; (2) simplification of these relations into a set of laboratory experiments analogous to the conditions believed to have existed in nature; (3) execution of those experiments in an unambiguous manner; (4) application of the principles derived from the experimental results to specific field occurrences; (5) re-examination of the field relations and testing the new principles with additional observations; and (6) reiteration of the above sequence until a satisfactory solution is achieved, recognizing that any new observation or inconsistency may initiate the process again.

Successful Philosophy

After half a century, it is clear that his philosophy had been successful even though new interpretations of the details were required (Yoder, 1979). Bowen's legacy, in addition to the many accurate and precise phase diagrams of the end members of common rock-forming minerals, is the construction of an experimental and theoretical basis for the interpretation and documentation of the diversity of igneous and metamorphic rocks.

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Walcott Biography To Be Published

GSA original Fellow and 13th president Charles Doolittle Walcott is the subject of a biography by Ellis L. Yochelson; it will be published in June. Yochelson's Rock Star profile of Walcott, a famous paleobiologist and biostratigrapher, was in the January 1996 issue of *GSA Today.* The book covers Walcott's life from birth in 1850 until 1907, when he resigned as third director of the U.S. Geological Survey to become secretary of the Smithsonian Institution.

The book is available from Kent State University Press, P.O. Box 5190, Kent, OH 44242 **(not available through GSA Publication Sales)**. *Charles Doolittle Walcott, Paleontologist* is available at the prepublication price of $40, including postage and handling, for a limited time (after July 31, 1998, the price will be $53). All orders must include payment and the title of the book; Ohio residents add 6.25% sales tax.