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ARTHUR FRANCIS BUDDINGTON

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A Biographical Memoir by

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Photograph by Harold L. James

ARTHUR FRANCIS BUDDINGTON

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BY HAROLD L. JAMES

ARTHUR FRANCIS BUDDINGTON was one of the most respected and most effective teachers of geology of his generation and a productive research scientist whose contributions spanned a wide segment of the geologic spectrum. For nearly sixty years he was identified with Princeton University, where he is remembered with pride and honor; he had a parallel career as a field geologist with the New York State Museum and the U.S. Geological Survey, organizations that would also gladly claim him as one of their own. He was a man of parts, and he left his mark on geologic science in America.

Buddington, known affectionately if somewhat irreverently as "Bud" to his friends, colleagues, and ex-students, was born in Wilmington, Delaware, the son of Osmer G. Buddington, a Baptist minister, and Mary Salina Buddington, née Wheeler. Although the family was temporarily domiciled in Delaware, its roots were set firmly in New England: Buddingtons (also spelled Budington or Boddington) and Wheelers had lived in Connecticut since the 1600s, and men from both sides of the family served in Connecticut contingents of the Revolutionary Army. In 1904 Osmer Buddington returned with his family to Connecticut, where he became minister of the country church at Poquonnock Bridge. He augmented his salary with commercial gardening and poultry culture, activities that involved but did not enchant his teenage son.

Young Arthur's early education was in the public schools of Wilmington (Delaware), Mystic (Connecticut), and Westerly (Rhode Island). In 1908 he graduated from Westerly High School and entered Brown University. After a year in the liberal arts curriculum (during which he acquired an often expressed lifelong distaste for Latin and Greek), he began to specialize in the sciences, first in botany and chemistry, then in geology. He graduated in 1912, second in his class, and continued his studies, receiving the M.S. degree in 1913.

Buddington's master's thesis was a geobotanical study of fossiliferous Carboniferous shales exposed in a newly driven tunnel on College Hill—his first and only venture into the arcane realms of paleontological research. The same year—1913—also marked the beginning of his long association with Princeton University, where he had been awarded a fellowship. He became a member of the 1913 Princeton field party in Newfoundland and began a field study that developed into his doctoral thesis. He was awarded the degree in 1916.

At Princeton, Buddington was probably influenced most strongly by two individuals: A. H. Phillips, an able chemist–mineralogist active in both departmental and civic affairs, and C. H. Smyth, a distinguished petrologist of broad interests and—in Buddington's words—"the epitome of a scholar and a gentleman." But it is likely that much of his intellectual growth during this period should be attributed to close association with other budding scientists and scholars in the newly constructed residential Graduate College. This group included men such as Harlow Shapley in astronomy, Alan Waterman and Arthur Compton in physics, and William Cumberland in economics.

For the next several years, however, Buddington's course was irregular, doubtless a direct or indirect reflection of the turmoil of World War I. After receiving the Ph.D. degree from Princeton, he held a postdoctoral fellowship there for a short period and, under the auspices of the New York State Museum, began his first studies in Adirondack geology. In 1917, after briefly considering a career in the burgeoning petroleum industry, he accepted a position at Brown—only to return the following spring to Princeton to teach aerial observation under his friend Edward Sampson. This Princeton tenure was again brief for Buddington: in April 1918, with the United States now in the war, he enlisted as a private in the Signal Corps. Because of his chemistry background, he was transferred within months to the Chemical Warfare Service and assigned research duties under R. C. Tolman. Mustered out at war's end with the rank of sergeant, Buddington returned to Brown to finish the academic year as an instructor.

In 1919 Buddington accepted an appointment to the Geophysical Laboratory of the Carnegie Institution, then (and now) one of the leading experimental geology laboratories in the world. It was a decisive move. Not only did it lead to personal acquaintance and lasting friendship with some of the nation's outstanding geochemists (including N. L. Bowen, C. N. Fenner, H. E. Merwin, and H. S. Washington), but it also expanded his already strong background in chemistry with "hands-on" experience in mineralogical experimentation and the preparation of phase equilibria diagrams. With chemist J. B. Ferguson, he completed what was then a definitive study of the melilite group of minerals before returning to Princeton in 1920 as an assistant professor. Buddington remained at Princeton for the next half century to provide leadership in the study of rocks as chemical and physical systems.

Buddington's parallel career as a field geologist also took shape about this time. His career in this area had sputtered along during the years previous to and during World War I, but in 1921 he received an appointment to the U.S. Geological Survey and began an association that would last for more than forty years. His first assignment for the Survey was the geologic mapping of southeastern Alaska; he attributed this assignment (perhaps rightly) more to his Newfoundland experience in handling small boats than to his technical qualifications. The work occupied five seasons during which some 4,000 miles of rugged coastline were mapped, with traverses up the glacially oversteepened slopes of the Alaskan fjords and occasional ventures across glacial ice. Conditions often were atrocious—Buddington recorded that in 1921 it rained eighty-seven of the ninety days spent in the field. Yet later he would say that these five seasons were the most satisfying of his entire career.

This sort of devotion to field studies is perhaps difficult for a laboratory scientist to understand, and, considering that it often calls for exhausting physical effort under conditions that may be far from benign, perhaps not too easy to explain either. Part of the lure undoubtedly is aesthetic—the deep emotions evoked by close contact with nature in all its variety. Beyond that, however, are the excitement, the challenge, and the intellectual satisfaction that comes from seeing a geologic story emerge, outcrop by outcrop. In any case, field studies were an activity to which Buddington remained devoted throughout his life.

Buddington's teaching load at Princeton, even during his fourteen-year tenure as departmental chairman, was never light. Normally it consisted of one senior-level undergraduate course in petrology and, at the graduate level, courses given in alternate years in chemical geology and petrology. His impact on students, particularly in graduate classes, was profound; yet there was no Buddington "school" of petrologic thought. What was implanted in students was not a set of organized conclusions but a method of approach that would outlast the concepts of any given date. Buddington placed heavy emphasis on the application of theoretical and experimental chemistry to the understanding of natural systems. Such emphasis, however, always carried the expressed recognition that the rocks themselves represent completed experiments of far more complex design.

Because Buddington's petrology had no artificial limits, the coverage in his courses was broad, including ore deposits and chemical sedimentary rocks along with the traditional igneous and metamorphic suites. His graduate-level lectures, generally two hours in length, were meticulously prepared and delivered, even though the class might consist of fewer than a dozen students, and they were illustrated with blackboard diagrams drawn with care and precision. Buddington never resorted to dogmatic assertion: the door was always left open for reconsideration based on new evidence. After presenting an experimentally derived phase diagram—perhaps of sulfate assemblages—and discussing with some enthusiasm its application to certain natural deposits, he might conclude: "But I don't say," he would caution, waving at the blackboard illustration, "that this necessarily pertains. But I do say"—and his voice would become emphatic—"that *this is the sort of thing that pertains!*" It left the student with the zeal to discover for himself just what "sort of thing" might in fact apply.

Robert Hargraves (1984) records that 174 Ph.D. degrees in geology were awarded during the Buddington years. Of these, 100 were in petrology, ore deposits, and related fields. It is safe to say that Buddington's influence, whether direct or indirect, was important to all of them.

Buddington strove mightily during his long tenure as a lead professor and as departmental chairman (1936–1950) to establish Princeton as a center of excellence in petrology and ore deposits—in general, the study of chemical processes in rock formation. Progress was made, but it was an uphill battle for many years in a department with long-established traditions in vertebrate and invertebrate paleontology. In the mid-1920s Buddington induced Norman L. Bowen, the distinguished petrologist of the Geophysical Laboratory, to present a series of lectures at Princeton, which were published in 1928 by the Princeton University Press. This thin volume, *Evolution of the Igneous Rocks,* is a masterly exposition of the application of experimental data to natural systems. It became a veritable Bible to petrologists of that day, and Princeton shone in reflected glory. By the mid-1930s, with the addition of Harry Hess to the staff, Princeton was recognized as one of the nation's leading schools in "hard rock" geology. But it was not until 1949 that Buddington's ambitions were fully realized, and the department's first program in experimental geology using high-temperature–high-pressure apparatus was inaugurated under John C. Maxwell.

Buddington briefly resumed work with the U.S. Geological Survey in 1930 when he spent a most enjoyable season mapping the Bohemia and North Santiam mining districts of the Oregon Cascades. But his major post-Alaska involvement with the Survey began in 1943, when he accepted the leadership of a program of field research on iron ores of the northeastern states. This program, with some redirection in its later stages, was to continue for the next seventeen years. It involved many geologists, among them H. E. Hawkes, A. W. Postel, Cleaves Rogers, B. F. Leonard, P. K. Sims, P. E. Hotz, and D. R. Baker. (The latter four subsequently earned the Ph.D. degree at Princeton using material derived from the Survey studies as bases for doctoral dissertations.)

The field studies of regional geology and iron deposits, coupled with use of the newly available airborne fluxgate magnetometer under the direction of J. R. Balsley, resulted in the discovery of several ore bodies of small to moderate size (Hawkes and Balsley 1946). The economic success of the program was gratifying to Buddington's canny New England instincts. The work also resulted in a plethora of good scientific reports and papers, among them one by Preston Hotz that provided a definitive answer to the question of the origin of Cornwall-type magnetite deposits (Hotz 1950). The field program also nurtured two other significant developments in geology. One (noted above) was aerial magnetic surveying using equipment that had been developed for wartime submarine detection; it was first used systematically on low-level flights in the Adirondacks in 1944, often with Buddington aboard as an observer. The other significant development was exploration geochemistry, in large part the brainchild of project member H. E. Hawkes (Hawkes 1976).

Buddington's contributions to regional geology are recorded in a number of major documentary-type publications, notably: *Geology and Mineral Deposits of Southeastern Alaska* (U.S. Geological Survey Bulletin 800, with T. Chapin); *Metalliferous Mineral Deposits of the Cascade Range in Oregon* (U.S. Geological Survey Bulletin 893, with E. Callaghan); *Geology and Mineral Resources of the Hammond, Antwerp, and Lowville Quadrangles, N.Y.* (New York State Museum Bulletin 296); *Regional Geology of the St. Lawrence Magnetite District, N.Y.* (U.S. Geological Survey Professional Paper 376, with B. F. Leonard); *Ore Deposits of the St. Lawrence Magnetite District, N.Y.* (U.S. Geological Survey Professional Paper 377, with B. F. Leonard); and *Geology of the Franklin and Part of the Hamburg Quadrangles, N.J.* (U.S. Geological Survey Professional Paper 638, with D. R. Baker). These data-laden reports are not stimulating reading and are rarely referenced; nevertheless they are recognized as the stuff of which the nation's geologic data base has been built. Not so evident, and often overlooked, is the linkage between these field studies and Buddington's better known topical papers in which new concepts and new ideas are introduced. A few illustrative examples follow.

Buddington's 1959 paper delineating and explaining depth-related differences among igneous intrusives—a most useful and illuminating concept—is based on his perceptive field observations of igneous intrusives in the greatly different geologic environments of Newfoundland, the Alaska Coast Ranges, the Oregon Cascades, and the Adirondacks of New York. (Buddington's additional observation of the progressive changes, west to east, in the dominant composition of the Coast Range batholith of Alaska would have to wait forty years for explanation. Not until the concepts of plate tectonics and subduction zone geometry were developed would this progressive change be understood.) Another paper, published in *Economic Geology* in 1935, introduced the concept of a "xenothermal" (shallow depth, high-temperature) class of hydrothermal ore deposits, an idea clearly based on observations of the character of the shallow intrusives and associated ore deposits of the Oregon Cascades. This represents perhaps the first formal break with the then-dominant but now largely superseded Lindgren-Emmons classification, in which depth of emplacement and temperature of formation were assumed to vary sympathetically. Buddington's pioneer contribution was explicitly noted in R. W. Hutchinson's 1983 presidential address to the Society of Economic Geologists (Hutchinson 1983).

The systematic descriptions of and distinctions between anorthosite of Grenville-type massifs and that of layered gabbroic complexes were expressed most completely in Buddington's 1960 paper published by the Geological Survey of India. These findings obviously derive from field studies in the Adirondacks, coupled with observations on the Stillwater Complex of Montana that were made during his supervision of the thesis studies of Princeton graduate students A. L. Howland and J. W. Peoples. Buddington's conclusions were summarized in a 1970 symposium paper: massif-type anorthosite is derived by fractional crystallization of gabbroic anorthosite magma, genetically distinct from associated rocks of the quartz syenite-mangerite series. Although this finding was challenged by other workers in the 1960s, it has since been affirmed by studies of rare-element distribution.

Buddington also produced a series of papers, variously coauthored with J. R. Balsley, D. H. Lindsley, and others, that described mineralogical variations in the Fe-Ti-O system and their significance. These contributions stemmed from the extensive field program of the U.S. Geological Survey in New York–New Jersey, which was led by Buddington. Many concepts of value were produced, among them the relationship between mineralogy and magnetic anomalies. (For example, it was discovered that reverse remanent magnetism was a characteristic property of Ti-bearing hematite, information of great value in the interpretation of measured magnetic anomalies in the region.) Buddington himself valued most highly the 1964 paper with D. H. Lindsley of the Geophysical Laboratory in which it was shown that compositions of minerals of the ilmenite-titaniferous magnetite suite could be used as a measure of partial pressure of oxygen and of temperature at the time of origin. The paper drew worldwide attention and stimulated extensive follow-on research.

Buddington tended to be somewhat orthodox and conservative in his scientific thinking—disciplined rather than venturesome; yet he was not bound by orthodoxy. New concepts were examined critically and without bias; those aspects that were found to be supported by empirical data or cogent theoretical analysis were woven into existing theory, expanding rather than replacing. For example, without changing his basic thesis that massif-type anorthosite originated by fractionation of gabbroic anorthositic magma, he found that the concept of "flow differentiation," which was advanced in the late 1950s by W. R. A. Baragar in Canada (Baragar 1960), provided an acceptable mechanism for separation of a plagioclase-rich fraction. He consequently incorporated the concept into his model for origin.

During the great "granitization" debate of the 1940s and 1950s, a number of well-known geologists in Europe and North America were converted to the radical doctrine that large bodies of granitic rock were formed by metasomatic replacement of pre-existing materials rather than by crystallization from silicate melts. Buddington, however, emerged as he had entered; a staunch magmatist. But even so, his rejection of the hypothesis as a major geologic process was not out-of-hand; it came only after the examination of possible examples of granitization in the Adirondacks and the viewing of cited field evidence elsewhere—and after many a spirited discussion with more "heretical" colleagues. It is likely that most geologists and geochemists today would share Buddington's skepticism of the importance of the granitization process. Somewhat ironically, however, with respect to the Adirondacks, it is also likely that Buddington's strictly magmatic interpretation of certain bodies of alaskite and layered gneiss in the dominantly metasedimentary terrane of the Adirondack Lowlands will have to yield to a more complex model: one that involves partial melting, diapiric movement, and at least some degree of high-temperature metasomatic replacement.

Exclusive of abstracts, medal presentations, and the like, Buddington's bibliography consists of about seventy papers, twenty-three of them published after his formal retirement in 1959. What is impressive about this list is not the number of papers but the tremendous range of subject matter and its extraordinarily high quality. Few if any are trivial, many are important, and some are recognized as true classics. Among the latter is *Adirondack Igneous Rocks and Their Metamorphism* (Geological Society of America Memoir 7), a monumental work that contains a vast amount of first-class data and dozens of significant geological conclusions. With few exceptions the petrologic concepts expressed in the Memoir—many of which were expanded or further developed in later papers—have proved remarkably sound. Buddington's colleague in later Adirondack work, B. F. Leonard, has remarked that the Memoir is "a contribution that still seems to me a full generation ahead of its time," a conclusion that is eminently justified by the record.

Buddington earned many honors and awards during his distinguished career. Most seemed to surprise him, although he was human enough to be deeply gratified. In 1942 Brown University recognized its distinguished alumnus with an honorary Sc.D. degree. He was elected to the National Academy of Sciences in 1943, to the American Academy of Arts and Sciences in 1947; in 1954 he was awarded the Penrose Medal of the Geological Society of America—America's highest honor in geology—and in 1956 the Roebling Medal of the Mineralogical Society of America. Franklin and Marshall College granted him an honorary L.L.D. degree in 1958, and in 1960 he received the André H. Dumont Medal of the Geological Society of Belgium. *Petrologic Studies: A Volume in Honor of A. F. Buddington,* written and edited by former students, was published by the Geological Society of America in 1962. The Department of the Interior, at the instigation of the U.S. Geological Survey, presented him with its highest honor, the Distinguished Service Award, in 1963. In 1964 came a different kind of honor, one that pleased Buddington greatly: a new mineral discovered by his former student Donald E.

White was given the name buddingtonite (Erd et al. 1964). The University of Liège in 1967 presented him with an honorary degree in "applied science." And finally the symposium volume *The Origin of Anorthosite and Related Rocks,* which was published in 1970 by the New York State Museum and Science Service, is dedicated most appropriately to Arthur F. Buddington in honor of his geologic work in the Adirondacks and his more than fifty years of association with the Museum.

Buddington was inclined to be impatient with formal rules and procedures, whether of stratigraphic nomenclature or management practice. His long stint—from 1936 to 1950—as departmental chairman at Princeton was notable for a minimum of formality and officiousness; to the student and the outsider the department appeared simply "to run itself." It didn't, of course; there were many problems to be solved and many serious decisions to be made. But most were handled quietly and effectively on a person-to-person basis. After fourteen years of his administrative leadership the department was one of increased strength and status.

As a responsible member of a number of professional societies, Buddington was often called upon to serve on committees and advisory panels. He did so willingly, enjoying the opportunities to become acquainted with fellow geologists, but he never actively sought high office. Some of his major areas of service included membership on the Council (1939–41) and the vice-presidency (1943 and 1947) of the Geological Society of America (breaking with custom, Buddington declined the semiautomatic move into the presidency of the society after serving as vice-president); membership on the Council (1936–40) and the presidency (1942) of the Mineralogical Society of America; the presidency of the Volcanology Section (1941–44) of the American Geophysical Union;

the chairmanship of the Geology Section (1954–57) of the National Academy of Sciences; and membership on the Advisory Board (1950–61) of the *Geochimica et Cosmochimica Acta*. He also served as associate editor of *American Journal of Science* (1950–69) and *American Scientist* (1961–62).

In 1924 Arthur Buddington married Jene Elizabeth Muntz of David City, Nebraska, whom he had met while with the Geophysical Laboratory in Washington, D.C. She was to be his loved and treasured helpmate until her death in 1975. Buddington depended on her absolutely in social affairs, and she was a gracious hostess to generations of Princeton graduate students—for years the Buddingtons regularly visited and in turn entertained incoming students and their wives, engendering an esprit de corps at Princeton rarely matched in academic circles. Mrs. Buddington also served as a loyal chauffeur during Adirondack field work, "driving over all kinds of roads in all kinds of weather," because Buddington, oddly enough, never learned to drive a car—even though he was entirely at ease at the helm of a motor-driven small boat in rough water. The Buddingtons had one daughter, Elizabeth Jene (Mrs. Lyle Branagan), who now lives in Cohasset, Massachusetts.

Honesty and integrity are two of the best remembered elements of Buddington's character. He was a man of true modesty, a trait that led him to give fair hearing to views with which he disagreed, whether expressed by lowly student or professional peer. He did enjoy—both as a participant and as a listener—a brisk exchange of opinions, particularly in the field, but he was not of an argumentative disposition. He had a loud and gusty laugh that often echoed down the corridors of Guyot Hall, and even if sometimes it seemed at odds with his quiet speech and manner, it was nonetheless entirely genuine. These personal characteristics, coupled with a complete lack of pomp and ceremony, endeared Buddington to students. That his influence was lasting can be illustrated by a passage in Harry Hess's touching tribute in the 1962 Buddington Volume (Hess 1962). The words are from a letter sent to Harry by a former student—unnamed, but at the time of writing a distinguished professor in his own right:

> He always has been the greatest man I know in science, and I don't lead an isolated life. To me he is, to use his expression, "the pure quill." If I ever do anything worth a damn, it will be largely due to his influence on me. There is nothing like Bud on the market—and I go shopping every day.

IN PREPARING THIS MEMOIR I have had the advantage of access to autobiographical notes prepared by Buddington in his later years and to a draft of a memorial being prepared by B. F. Leonard. I have drawn freely from both sources, generally without attribution. I have also incorporated, again without specific credit, thoughts and comments received from others—notably, P. E. Hotz, A. E. J. Engel, P. K. Sims, J. C. Maxwell, and M. P. Foose—all of whom shared my good fortune in having had Bud as a teacher and as a friend.

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