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Memorial of A. F. Buddington
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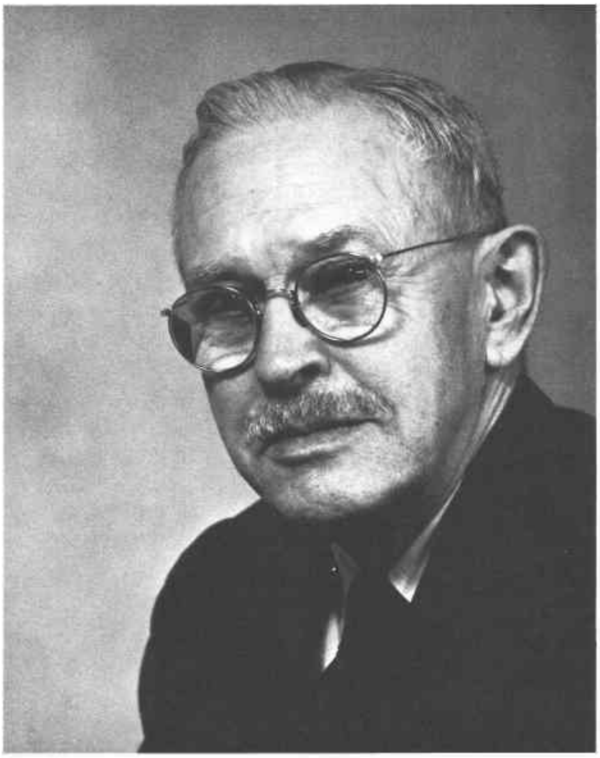
Arthur Francis Buddington was born in Wilmington, Delaware, on November 29, 1890. He died at Quincy, Massachusetts, on Christmas Day 1980, and was buried at Princeton, New Jersey.



Two people called him Arthur—his wife, Jene, and the late Professor R. M. Field. His brother called him Art. Everyone else who knew him well called him Bud, and Bud is the subject of this memorial.

Bud grew up in West Mystic, Connecticut. His mother, Mary S. Wheeler Buddington, died in 1895. His father later married Ella Turner, and she became Bud's very mother. Osmer G. Buddington, Bud's father, was a Baptist minister and part-time farmer. As a youngster, Bud peddled the farm's produce door to door. It taught him to know people, to eschew farming as well as peddling, and to find a more congenial way of earning a living. Aided by his savings and a small inheritance from his grandfather Wheeler, he went to Brown University, studied chemistry and botany, became interested in geology, combined his interest in botany and geology to write a Master's thesis on the Carboniferous flora of the Narragansett Basin, and then proceeded to devote his life to geology, chemistry, and geophysics. He did it with zeal. He was indeed Sigma Xi's "companion in zealous research," and the ways of Sigma Xi, not those of Phi Beta Kappa, governed his life. Nevertheless, Bud thought well enough of Phi Beta Kappa to wear its key in the field. He lost it somewhere in the Lake Bonaparte quadrangle, got another, lost it in the thickets of that or some other Adirondack quadrangle, and thereafter dressed without adornment.

The straightforward explanation for Bud's wearing a gold watch key in the field is that it was conventional. In those years a mineralogist such as A. H. Phillips wore a frock coat in the chemical laboratory. Bud was conventional, and he stuck to it as far as the second key. He was also practical. When he lost the second, he snorted, continued his bush traverse, and never looked back. Then and later, he made a clear distinction between symbol and substance. He was a scholar, though he disliked the term and its connotation and thought of himself as a research scientist. He remained conventional in small ways, yet he broke trail in his chosen field of chemical petrology.

When Bud was young, chemical petrology was just putting down roots in this country. Mineralogy and chemistry had long been inseparable, petrographers used rock analyses, economic geologists such as G. F. Becker did experimental work and applied the results, the Carnegie Geophysical Laboratory had men such as Allen and Day who put chemistry to work in mineralogy, volcanology, and ore petrology, but not much was done in combining analytical chemistry and physical chemistry to study ordinary rocks. One university man, C. H. Smyth, Jr., was doing it. Smyth had only recently moved from Hamilton College to Princeton University. By 1913 he already had two or three graduate students, and in that year Bud decided to join them.

Graduate work was just then becoming a major part of the university's program. The Oxbridgian Graduate College, opening that year, provided elegant quarters in which students from the various departments were supposed to mingle. Surely they ate and slept there, and enough mingling took place by Dean Andrew West's design or by natural selection to make the likes of Bud in geology, Arthur Compton in physics, and Harold Dodds in politics friends for life. What Bud thought about his formal course work, I never heard him say. Smyth taught him petrography and petrology, Phillips mineralogy, and Gilbert van Ingen field work. I suppose he must have learned economic geology from Smyth, though he never said so. Wil-

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liam Berryman Scott, the vertebrate paleontologist, presided over the department with dignity, but I cannot think that Bud's aversion to paleontology and stratigraphy allowed him to spend more time than he had to with van Ingen's invertebrate collections and Scott's and Sinclair's giant vertebrates.

A long-standing co-operative arrangement between the geology department and the Geological Survey of Newfoundland encouraged Bud to do his thesis on pyrophyllite deposits in the altered rhyolites of Manuels (Buddington, 1916), instead of on the rocks of Smyth's stamping grounds in the Adirondacks. But in 1916, soon after graduation as a Ph.D. from Princeton, Bud began mapping the Lake Bonaparte quadrangle. After teaching a year at Brown, he was commissioned by the State of New York's Defense Council to investigate the pyrite and pyrrhotite deposits of the northwest Adirondacks as a wartime source of sulfur (Buddington, 1917). This formally began Bud's long career in Adirondack geology. His joint work with Smyth on the Lake Bonaparte quadrangle was not published until sometime later (1926). From this work he learned several things: to map and decipher metamorphic structures as Smyth had done meticulously in the Old Forge quadrangle; to weld together petrology, structure, and general geology; and to quit making his own rock analyses. "There's no way to be an analyst and get anything done in petrology." Having made that decision, he later became the chief client of analyst A. H. Phillips at Princeton and of F. F. Grout's Rock Analysis Laboratory at the University of Minnesota.

Smyth, by his example, taught Bud something else. Smyth's Old Forge map was never published. Bud said it was because Smyth thought the map lacking in perfection. Perfection, for Bud, was a commendable ideal but, for a scientist, not a practical goal. Bud also said that Smyth "wrecked his health in the Old Forge quadrangle." Health and infirmity were of enough concern to Bud to give him what Harry Hess labeled a mild case of hypochondria, saying, "He gets that from Smyth." An automobile accident that left Bud with an arthritic knee, two heart attacks suffered after he was 55, and shingles that for a time paralyzed his right hand were successfully overcome without diminishing Bud's passion for work, especially work in the field, so perhaps a little hypochondria, properly controlled, was not altogether a bad thing for him to live with.

The years of World War I were fractured ones for Bud. He left Brown early in 1918 to teach in the school of aerial observation at Princeton, then enlisted in the aviation section of the Army Signal Corps. He received training as a photo-interpreter and aerial observer but, owing to his background in chemistry, was soon reassigned to the Chemical Warfare Service in Washington for research on gas shells and gas candles under R. C. Tolman. The war ended before Sergeant Buddington saw service overseas, and he returned to Brown. Later, he had little to say of his military service except that he had learned a good deal about scientific method from Tolman.

A year, 1919, at the Geophysical Laboratory immersed Bud in experimental physical chemistry. Incidental to his study of the akermanite-gehlenite system ("I know you can call it okermanite, but it's ackermanite." Half the time he called it akermanite), published in 1920, he learned a lot of optical mineralogy from Merwin and formed lasting friendships with Ham Bowen and other members of the staff. He also learned that laboratory work kept him too much indoors. The year in Washington did several other things for him and for the science. He met Jene Muntz, married her in 1924, and lived happily with her for more than 50 years. When he returned to Princeton to teach petrology, he invited Bowen to lecture there. The lectures resulted in a small book of some impact, *The Evolution of the Igneous Rocks* (1928). When thermodynamics began to nudge out the phase rule during the 1950s, Bud sent to the laboratory two of his best students, Hugh Greenwood and Donald Lindsley. Thermodynamics may not have been Bud's dish of tea, but he encouraged them, as well as Baker, Holland, Kulp, and others to make good use of it.

In 1920, Bud was called to teach at Princeton. He took the assignment seriously. When I was his student, he yearly taught one undergraduate course and one graduate course, supervised thesis work at both levels, carried forward his own research, reviewed manuscripts for his colleagues and the journals, served on university and society committees and councils, and helped establish the American Geophysical Union and the American Geological Institute. He shunned high office in the societies, though in 1942 he accepted the presidency of the Mineralogical Society of America and in 1956 became its Roebling medalist. From 1936 to 1948, he was chairman of the university's Department of Geology. Under his leadership, the department became one of the foremost in the country. He thought the tour of administrative duty overlong and groused that he carried it after World War II only because Harold Dodds, then president of the university, conned him into it. Teaching and research were to him the primary duties of a professor. When he reached 68, the mandatory retirement age, he taught an additional year by invitation, taught a year more at Penn State, and filled in for a year at Columbia after Arie Poldervaart's death. Then concluding his formal teaching, he continued his productive research for another decade. This research included the application of sulfur-isotope data (Buddington et al., 1969) to re-interpret the origin of the pyrite-pyrrhotite deposits that he had examined in 1917. In the last year of his life, Bud was still consuming the geologic literature and commenting on it in letters to his former students.

Bud's graduate courses changed names almost with the seasons. So did his lecture notes and reading lists. Whatever the names, one course dealt with chemical petrology (in my student days, essentially experimental petrology), the other with the observational and interpretive aspects of igneous and metamorphic petrology, including structural petrology (granite tectonics, microscopic petrofabrics, and what later came to be called the analysis of mesoscopic fabrics). Chemical sedimentation in seawater? The fine structure of minerals? The classification of silicates? The genesis of ore deposits or the interior of the earth? Stylolites? Weathering? If it had to do with rocks, Bud knew about it. He had not only read about it, digested it, and reorganized it to make better sense; he expected us to do the same. Obviously some subjects and some papers were more important than others; they deserved a star on the reading list. As the literature increased, so did the stars. By 1947, we were up to four stars. The papers to be read were the originals, not condensations of them, and the languages were as likely to be foreign as English. This, then, from a man who claimed not to be a scholar. Erudition, no. It never emerged in his lectures, which were no-nonsense affairs, thoroughly prepared, lucidly delivered, and punctuated with remarks (anent questions we raised) such as "Absolutely and unequivocally no!" Pause. "Well, maybe," followed by a judicious examination of the new hypothesis, an examination conducted with us as if he were one of us. Indeed, the essence of graduate education was that "we" were one of "them," colleagues whose opinions were treated with undeserved respect. How could even the meanest of us help but grow?

Research, another essential of teaching at Princeton, was difficult for a geologist to sustain before the days of government grants. Bud used his extracurricular knowledge of coasts and small boats to get a summer job with the Alaskan Branch of the U.S. Geological Survey, first under A. H. Brooks and then under P. S. Smith. From 1921 to 1925 Bud worked on the regional geology and ore deposits of southeast Alaska. Ostensibly he was finishing work begun by Theodore Chapin; actually he was bearing down on the petrology of batholiths and their wall rocks while creating the bible of southeast Alaskan geology. Support for the field work was good, but for years Bud fumed over the Survey's delay in publishing the results. The bulletin was not printed till 1929, only short chapters of it having appeared earlier. Journal papers, including one still cited on the distinction between violarite and bravoite (1924), filled the gap. That mineralogical paper convinced him to avoid mineralogy per se, he said. "I sat down one afternoon to straighten out violarite and bravoite. It was six months before I wound up the work. Don't do it; mineralogy will eat up all your time." The advice was sound, and my bosses at the Survey have often wished that I had taken it.

Bud accepted two additional assignments with the Survey, one with Pat (Eugene) Callaghan in the Cascades in 1930 and one in the northeastern states from 1943 to the mid-1950s. Nevertheless, Alaska remained a fundamental part of Bud. From Alaska came some of his favorite stories: the bear, the fog, and the high-bush huckleberries ("When the fog lifted, both the bear and I left with alacrity"); the wolf about to attack Bud's assistant, Bill Jewell; the no. 12 skillet, the glacier, and the Survey's disapproval of the skillet as a means of rapid transportation on ice. And from Alaska came Bud's form for introducing a junior member of his field party: "This is my pardner ———."

On a foggy night in Princeton in 1926, Bud was hit behind the knee by an automobile. It changed the course of his field work. He could no longer climb steep slopes, so he returned to the Adirondacks, first to the lowlands and much later to the Whiteface–Mount Marcy block of high terrain. The New York State Museum paid for gasoline for the Buddington car; Bud paid all the rest of the field expenses. Mrs. Bud drove the car, Bud traversed the bush on foot, and Mrs. Bud picked him up at the end of the day. In this way he mapped about a dozen 15-minute quadrangles and produced the Adirondack memoir (1939).

Bud never drove a car. Herb Hawkes asked him why, as we drove toward the Adirondacks one day in 1943. With unwonted hesitation attended by embarrassment, Bud replied, "Well, Ben-I-mean-Herb, the method of multiple working hypotheses kind of got in my way. When I had to make a decision, I had too many choices and not enough time." Months later, gripping the gunwales of an outboard motor boat during a torrential rain, I turned my head to see him cruising serenely but at full throttle up the drowned arm ("flow") of Cranberry Lake. The flow was studded with standing dead trees, waterweeds, and flotsam, none of which bothered him. After we dried out back at camp, I commented that his performance in the boat didn't jibe with his avoidance of driving a car. "Oh, I don't know," he said, "I just never saw any problem with boats."

The year 1943 set Bud on a new course, one that determined much of what he was to do for the next 20 years. In 1943, graduate work in Princeton's Department of Geology was recessed and continued so for three years. Students from the Army Student Training Program and the Navy's ROTC took over the campus, and Bud and his colleagues found themselves teaching "baby courses" in geography, map reading, and air-photo interpretation. Thus, when C. F. Park, Jr., asked Bud to take leave from the university and head up a long-term study of iron ores in the northeastern states as part of the U.S. Geological Survey's Strategic Minerals program, Bud leapt at the chance. Years earlier, the New York State Museum had asked him to make a regional study of Adirondack magnetite deposits in order to amplify and bring up to date the local study finished by Newland in 1908. For the proposed study, the Museum offered no pay, only the recompense to which Bud, as a petrologist, was already accustomed: gasoline for the Buddington car and eventual publication of the report. Bud said that, as the purpose of the work was economic, the State could pay him as an economic geologist. This expression of crass commercialism astonished the gentlemen in Albany, they chided him for it, and the matter was dropped. In contrast, Charley Park's offer brought Bud a salary, three assistants the first year, and a crack at the iron ores of New Jersey and Pennsylvania as well as New York.

The three junior members of the party were Herbert E. Hawkes, a well-trained geologist and geophysicist; Preston

E. Hotz, a well-trained geologist; and I, a greenhorn with but one field season's experience. Luckily, that season had been spent on magnetite deposits in Newfoundland as field aide to Allen V. Heyl. Magnetite got me my job with the USGS, and I have been grateful ever since to that undistinguished mineral. A. Williams Postel was added to the Northeast Iron project in 1944, Paul K. Sims in 1947, and Donald R. Baker in 1951. Cleaves L. Rogers worked with us whenever he could be spared from assignments on zinc. Characteristically, Bud soon had all of us, himself included, working independently. He and Charley were determined that the work should have continuity, even during the difficult war years, and that it should contribute to the science, as well as to the economy. The principal and direct results were the papers by Buddington and Baker (1970), Buddington and Leonard (1962), Hawkes and Hotz (1947), Hotz (1950, 1953, 1954), Leonard and Buddington (1964), Postel (1952), and Sims (1953). Bud's stamp, if not his name, is on every paper.

The Fe-Ti-O geothermometer–oxygen barometer of Buddington and Lindsley (1964) is well known to every petrologist who reads this journal. I believe that in 20 years it has been applied or referred to in more papers in igneous and metamorphic petrology than existed in the whole field of ore microscopy before 1964. Only recently has it needed minor revision, by Spencer and Lindsley (1981). What young petrologists may not know, or aging petrologists have forgotten, is that the geothermometer is an outgrowth of economic geology, the need to interpret the aeromagnetic surveys of the northwest Adirondacks. The root of the idea is deeper still. I think that, for Bud, it lay in observations made during the 1930s by Edward Sampson, Bud's longtime friend and Princeton colleague. Ed had assembled a large collection of Fe-Ti oxide intergrowths from ore deposits. Impressed by their variety and complexity, he asked Bud what, besides exsolution, they meant petrologically. Bud took a look, threw up his hands, and stalked away, muttering something about their being great geothermometers, totally devoid of an experimental base for interpretation (Edward Sampson, oral comm., 1943). Years later, while struggling to interpret the Adirondack aeromagnetic data and write a paper (Buddington, 1948) for Gilluly's Granite Symposium, he came to me, thrust some rocks at me, and said, "Here. I've got to have some polished sections." "Of rocks?" "Yes, rocks. I want to look at the accessory oxides. This afternoon." Disgusted, I made the sections. Elated, we found on examining them that different granitic rocks, carefully selected by Bud, had different suites of accessory oxide minerals. Of course, you say; any fool would know that, but in 1947 two fools were only hoping it might be so. Shortly Bud was ransacking the literature. Finding nothing useful, he persuaded J. J. Fahey, a Survey chemist, to separate the oxides and analyze them by wet chemical methods (the electron microprobe had not been invented) while he tried to correlate the oxide phases with experimental and observational data on the crystallization temperature of various kinds of rock. The first excursion into a crudely calibrated kind of oxide geothermometry (Buddington, Fahey, and Vlisidis, 1955) received support from thermodynamic work done by Donald R. Baker for a Princeton thesis (1955) and culminated in the paper by Buddington and Lindsley (1964), with essential contributions en route from the discovery of ulvöspinel by Mogensen (1946) and an investigation of it by Ramdohr (1953). Don Lindsley (oral comm., 1984) says that Bud presented a prepublication version of the Fe-Ti oxide geothermometer in the last lecture to his undergraduate petrology class in 1955. The lecture so engaged undergraduate Lindsley's attention that he credits it for setting him off on his own career on the oxides and their physicochemical relations.

Scientists are best remembered for their direct, and published, contributions. I have mentioned some of Bud's, but other major contributions come to mind. They include the systematic description and interpretation of massif-type anorthosites and their distinction from the anorthosites of layered complexes (Buddington, 1939, 1969, 1972); the recognition and demonstration that many complexes of saturated syenites and granites are gravity-stratified sheets (Buddington, 1936, 1939, 1948, 1952); the systematic change in the fabric and mineralogy of igneous rocks during regional dynamothermal metamorphism (Buddington, 1939), a contribution that still seems to me a full generation ahead of its time, and one that he enriched in a series of papers published during the next 30 years; Adirondack and Alaskan regional geology (many contributions); the nature of batholiths (Buddington, 1959); the chemical character of rock-forming minerals, of which the mafic minerals are one example (Buddington, 1952) and the Fe-Ti oxides, noted earlier, another; the persistent use of modal and chemical data; and the application of physics and chemistry to the petrology of igneous and metamorphic rocks. That last contribution, which he began to make in his earliest papers, was the ripple that grew into a flood. In his autobiography, Bud cites two additional contributions: demonstration of zonation in the Coast Range Batholith (1927) and establishment of the xenothermal class of hypogene ore deposit (1935). I had overlooked these contributions, the first because he seldom mentioned it, and the second because I thought the term xenothermal was useful to me but not much favored by other workers. Bud the anticlassicist was fond of it, and so am I.

Bud's own record of his publications shows 77, including one abstract and five memorials. The first of his papers appeared when he was 26, the last when he was 82. Not much for looks, as he might have said, but hell for strong.

Bud received many honors and awards: fellow, American Philosophical Society, 1931; Sc. D. (Hon.), Brown University, 1942; member, National Academy of Sciences, 1943; fellow, American Academy of Arts and Sciences, 1947; Grant Memorial Lecturer, Northwestern University, 1952; Penrose medal, Geological Society of America, 1954; Roebling medal, Mineralogical Society of America, 1956; guest, India Science Congress, and guest lecturer, Geological Survey of India, 1957; L.L.D., Franklin and Marshall College, 1958; André H. Dumont medal, Geological Society of Belgium, 1960; Distinguished Service Award, U.S. Department of the Interior, Geological Survey, 1963; honorary foreign member, Mineralogical Society of Great Britain, 1966; Docteur Honoris Causa, Applied Geology, University of Liege, 1967; honorary fellow, Geological Society of Belgium, 1968. Two volumes were dedicated to his honor: *Petrologic Studies,* Geological Society of America, 1962; and *The Origin of Anorthosite and Related Rocks,* New York State Museum and Science Service Memoir 18, 1969. The mineral buddingtonite was named for him by his former student Don White (Erd et al., 1964).

Bud was an ordinary member or fellow of the following societies, in several of which he served as an officer: member, American Geophysical Union; fellow, Geological Society of America; fellow, Mineralogical Society of America (president, 1942); member, Society of Economic Geologists.

Bud accomplished much, deserved much, was honored much. Both Harry Hess (1962) and I have tried to show the man chiefly by his works. It is not enough; you cannot know the man from his works or through us. But by antithesis, perhaps you can catch a glimpse of him as he hurries along, soberly dressed, shoulders slightly hunched, outwardly composed, turbulent within. His likes or loves, in no special order: work, family, rocks, southeast Alaska, boats, the Adirondacks, Brown, Princeton, the Geological Survey, youngsters, the approach to truth, the New York *Times,* the walk down Prospect Street, the microscope, whist or bridge, trilium, Verplanck Colvin, Hills Brothers coffee, frost on the bracken, travel. His pet peeves: paleontology, formal geologic names, Latin and Greek, Republicans, editors, administrative authority, philosophers and philosophic geologists, things arty, things not feasible, opinions not based on fact, dirty novels, blackflies, esthetes, his own temper.

Mrs. Bud died in 1975. Surviving Bud are his daughter, Elizabeth (Mrs. Lyle E. Branagan), of Cohasset, Massachusetts; his four grandchildren, Lyle Arthur, Peter Buddington, James Hammer, and Katherine E. Branagan; his half-brother, Weston T. Buddington, M.D., of Middletown, Rhode Island, and Weston's children; and his half-sister, Mrs. Carlene H. List, of Magnolia, Massachusetts, and her two children.

I thank Elizabeth Branagan for lending me her copy of the autobiography of A. F. Buddington. I have used it to verify dates, honors, contributions, and bits of family information. For the rest, I have relied on standard sources and on memory—memory of what Bud said and did during our nine years of almost daily association from 1942 to 1951. I have turned rarely to Harry Hess's beautiful tribute to Bud (Hess, 1962) for the same reason that I largely avoided the autobiography: I had from Bud himself virtually all that I needed and more than I could compress into a memorial. I have, for example, said nothing about Bud's short, infrequent periods of activity as a consultant to government and industry. Bud was not distracted by them, and the reader need not be. I thank Donald H. Lindsley for the perfect illustration of the effect of Bud's teaching on one Princeton undergraduate. Sheldon Judson kindly tracked down the photograph that illustrates this memorial. I thank him and the photographer, Ulli Steltzer, for their work.

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