

Memorial to Robert Leland Smith 1920–2016

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Robert L. Smith, renowned volcanologist and distinguished scientist with the U.S. Geological Survey (USGS), was a world authority on ash-flow tuffs, silicic volcanism, and caldera structures. Bob died peacefully in Sacramento, California, on 17 June 2016, a few days short of his ninety-sixth birthday. His publications on ash flows and their deposits brought about an international revolution in understanding explosive silicic volcanism and, in his fifty-year career, he profoundly influenced USGS programs and countless scientists.

Bob Smith was born in Sacramento, California, on 30 June 1920 and grew up on the family property nearby in rural Fair Oaks. His father, W. Leland Smith, raised exotic pheasants and other rare game birds and his mother, Elma A. Smith, was a florist. Young Bob acquired a keen interest in ornithology, botany, and nature in general, becoming a serious collector of natural objects, including insects, reptiles, wildflowers, native plant specimens, bird eggs, rocks and minerals, and artifacts. Boyhood exploits along the American River and family expeditions to Nevada deserts instilled in him an acute sensitivity to the beauties of nature and a love of outdoor life. Later in life, this true naturalist became a superb birder and horticulturalist who cultivated ferns, dwarf conifers, and other primitive species, including a large collection of cycads that he nurtured and raised primarily from seed.

Bob excelled at science in high school, then attended Sacramento Junior College where his interest in mineralogy grew, and subsequently transferred to the University of Nevada, Reno, to pursue geology, graduating in 1942. After a year at Columbia University, Bob joined the Mineralogy and Petrology Section of the USGS in Washington, D.C., in 1943 under the direction of Clarence S. Ross. Bob's USGS career was interrupted in 1944, when he began three years with the U.S. Navy, serving aboard the destroyer USS *Nelson*. Duty as a gunnery officer resulted in serious hearing impairment, a disability that Bob steadfastly shouldered and largely overcame one-on-one and in small groups through lip reading and a hearing aid, but that severely limited his ability to attain the personal visibility that could result from service on committees and participation in scientific meetings, particularly large forums such as the Geological Society of America and American Geophysical Union annual meetings.

During the summer of 1946, while awaiting final discharge from the Navy, Bob briefly visited C.S. Ross and E.S. Larsen Jr. in the Jemez Mountains, New Mexico, where they had begun systematic geologic mapping and petrologic studies. The following winter, he attended the University of California at Berkeley, where Howel Williams kindled his enthusiasm for volcanology and an interest in calderas. Upon returning to the USGS in 1947, Bob joined Ross in the Jemez Mountains and spent the next ten summers there while devoting office time to studying welded tuffs and providing mineralogical and petrological service for other Survey



projects. During this time, he and Ross concluded that perlite was the product of hydration of obsidian, likely containing magmatic water from the parent obsidian and a larger proportion of added meteoric water. Collaboration with Irving Friedman resulted in several papers (1958–1966) that presented isotopic proof of this concept, some of the first measurements of the high-temperature viscosity of hydrous rhyolitic glass, and development of obsidian hydration dating, a method based on diffusion of water into obsidian that could be rapidly applied to artifacts and source materials by measuring the thickness of the hydrated rim on natural glass surfaces using an optical microscope. The obsidian hydration dating method enabled chronological ordering of archaeological artifacts and assemblages, thereby opening up entirely new dimensions of archaeological research that might otherwise have remained inaccessible.

Modern concepts of ash flow emplacement, welding, cooling, crystallization, and chemical zonation were formulated by Smith and coworkers from study of the Bandelier Tuff in the Jemez Mountains. Bob's early work with Ross led to the iconic USGS Professional Paper 366, "Ash-flow tuffs: Their origin, geologic relations, and identification," begun in the early 1950s and published, after printing delays, in 1961. Growing out of study of the Bandelier Tuff in the Jemez project, Bob also wrote and published two seminal papers in 1960: "Ash flows" in the review series of the *GSA Bulletin*, and USGS Professional Paper 354-F, "Zones and zonal variations in welded ash flows." These three publications, rich with outcrop, hand specimen, and thin section photographs, and originating the cooling unit concept, enabled geologists to communicate and compare tuffs using a common language. Moreover, the review paper elucidated the violent eruption of vast amounts of gas-charged silicic magma, the intimate association with caldera collapse, and the emplacement mechanism, welding, cooling, and crystallization of ash-flow deposits. These papers ushered in a revolution in field and petrologic study of previously enigmatic ash-flow tuffs, the products of the largest explosive volcanic eruptions. Collectively, as of this writing, the three have been cited over 1,300 times. The Professional Papers proved so popular as guides and teaching tools that they were reprinted and are still made available by the New Mexico Geological Society.

Also begun in the 1950s was Bob's association with Roy A. Bailey. Bob had become convinced that Redondo, the central domical mass within the Valles Caldera was the result of postsubsidence structural uplift rather than differential collapse of the caldera. Bob and Roy set out in 1957 to remap Redondo in greater detail in order to document the evidence. Soon thereafter, visits to calderas of the San Juan Mountains of Colorado convinced the pair that the uplift process, and its relationship to magma chambers and ring complexes, was a general phenomenon. First presented at the Geological Society of America meeting in Denver in 1960, then in 1962 at the International Association of Volcanology meeting in Tokyo, their concept of resurgent cauldrons saw print in the classic 1968 paper of the same name in *GSA Memoir 116* in honor of Howel Williams. This paper has so impacted volcanology and related fields of igneous petrology and mineral deposit geology that it currently has nearly 700 citations. The pioneering 1960, 1961, and 1968 papers led the way to discovery of many other calderas in the western United States and worldwide.

Bob's Jemez work with Roy Bailey netted additional exceptional products. Compositional zonation of ash-flow tuff and evidence for zonation of its source magma chamber was meticulously documented in the pioneering 1966 *Bulletin Volcanologique* paper on the Bandelier Tuff. *The Geologic Map of the Jemez Mountains, New Mexico* (Smith, Bailey, and Ross, 1970) compiled the results of years of geologic mapping onto one sheet that portrays the now-classic Valles Caldera and the Bandelier Tuff, along with precursory and postcaldera volcanics. It has served as a foundation for extensive later research by geologists from universities and the Los Alamos National Laboratory. Lastly, Smith and Bailey's collaboration with

Richard Doell and Brent Dalrymple resulted in discovery of the Jaramillo paleomagnetic event that became a key piece of evidence in the proof of sea-floor spreading early in the formulation of plate tectonics.

In the 1970s, the Survey's Geothermal Research Program was ramping up, and Bob became one of its senior advisors. Under that umbrella, he collaborated with Herbert Shaw on the cornerstone paper for assessing igneous-related resources on the basis of composition, size, and lifetimes of volcanic systems (Smith and Shaw, 1975; updated 1979). At the same time, he worked with Bob Luedke on compilation of a series of nine maps of late Cenozoic volcanic rocks in the western United States, Alaska, and Hawaii. Bob contributed a synthesis paper (Smith and Luedke, 1984) to the National Research Council–National Academy of Sciences book *Explosive Volcanism: Inception, Evolution and Hazards* based on the accompanying Luedke and Smith (1985) USGS map. The seventies also brought fruitful collaboration with Thomas P. Miller on the volcanoes of the Alaska Peninsula and eastern Aleutians. From this came important papers that demonstrated the ability of pyroclastic flows from a caldera-forming eruption to surmount topographic barriers (Miller and Smith, 1977) and that identified, dated, and characterized the many Holocene and late Pleistocene calderas of the eastern Aleutian arc (Miller and Smith, 1987). Additionally, Bob worked with Donald Richter on reconnaissance geologic mapping of the immense Wrangell volcanoes in 1971–1974, resulting in three fifteen-minute geologic quadrangle maps.

The GSA Rocky Mountain Section meeting in Albuquerque, New Mexico, in May of 1976 featured the symposium “Ash-Flow Tuffs—16 Years after Smith (1960)” and resulted in GSA Special Paper 180 in Bob's honor (1979). The lead paper in that symposium volume is “Ash-flow magmatism” by Robert L. Smith. This landmark paper (over 700 citations by 2016) laid out the systematic relation of caldera size to ejecta volume, argued for nonerupted magma volumes as much as ten times those erupted, stated that magma chambers grow by accretion of repeated inputs of relatively primitive magma, illustrated the concept of a shadow zone created by low-density differentiated magma through which denser less-differentiated magma cannot penetrate, proposed that the production rate of differentiated magma is typically $10^{-3}\text{km}^3/\text{yr}$, suggested that potential for ore deposit formation can be related to specific stages of volcanic histories, and culminated in the synthesis presented in “Figure 12. Model showing relationships among volume, depth, periodicity, and composition” for igneous systems that erupt silicic magma. Implicit in Bob's model is that nonerupted crystal-rich magma solidifies as plutons and batholiths, what has come to be known as the popular “mush” model. The fundamental principles set forth by Bob in 1979 remain essentially intact after nearly forty years.

The 1979 paper also contained a section on geochemical evolution of the Bandelier–Valles system, an indication of Bob's fascination with trace-element chemistry of silicic magmas and its potential relation to metallic ore deposits. He had amassed detailed chemical analyses of natural glasses, mainly obsidians, that he obtained not only from the Jemez Mountains, but from around the world, through closely working with colleague David Gottfried and USGS chemists. Collaboration with Ray Macdonald and John E. Thomas of the U.K. Universities of Lancaster and Reading, respectively, resulted in Professional Paper 1523 (1992), “Chemistry of the subalkalic silicic obsidians.” His lifelong interest in obsidian chemistry and hydration processes also led to collaboration with Richard Hughes, focusing on archaeological applications (Hughes and Smith, 1993).

The papers on hydration of obsidian launched a career-long parade of invitations for Bob to speak at conferences and symposia in Latin America, Italy, Japan, New Zealand, and the United States. Topics, of course, included ash-flow tuffs and resurgent calderas but also granitic magma origins, magma-hydrothermal systems, ore deposits, magma chambers, and potential

lunar analogs of terrestrial calderas. The Society of Economic Geologists selected Bob for its Distinguished Lecturer–Research for the 1983 SEG–GSA Annual Meeting. He was editor for North America for *Bulletin Volcanologique*, now the *Bulletin of Volcanology*, from 1967 to 1975. Bob’s broad knowledge of volcanism led to his participation in field training of the Apollo astronauts and on the Preliminary Examination Team for the first lunar sample returns, and on high-level panels on international cooperation in volcano studies, on explosive volcanism for the National Research Council, and on hot dry rock geothermal assessment for the Department of Energy. His impact on USGS science programs in volcano hazards, geothermal research, and mineral resources was profound. He served as chief of the USGS Branch of Field Geochemistry and Petrology during its first years, 1960–1966.

Beyond the published record, Bob’s indelible influence boosted the careers of generations of geologists. As teacher and mentor, Bob made countless excursions with Survey and other, often foreign, geologists to their field areas (notably in later years, to Bolivia). The beneficiaries reaped immense benefit from his knowledge, enthusiasm, and encouragement. For example, Roy Bailey wrote that Bob’s “recognition of the Timber Mountain structure as a caldera and his continuing interest in [geologic] mapping problems at the Nevada Test Site, not only accelerated the progress of mapping there, but had a profound influence on the morale and enthusiasm of colleagues working in that vast desert purgatory.”

Bob was a Fellow of GSA, AAAS, and the Mineralogical Society of America, a member of the International Association for Volcanology and Chemistry of the Earth’s Interior (IAVCEI), the Mineralogical Societies of Great Britain and Italy, the American Ornithologists Union, the American Fern Society, and the Cycad Society, as well as a Charter Member of the Geochemical Society. He received the Department of Interior Meritorious (1974) and Distinguished (1983) Service Awards, an honorary D.Sc. from Lancaster University, U.K. (1989), and the inaugural IAVCEI Thorarinsson Medal (1987). Bob was promoted to senior scientist, one of a small number of “supergrade” USGS positions, in 1983. Subsequently, his office was moved from Reston, Virginia, to Sacramento, California, and the Smiths took up residence on the family property in Fair Oaks. Bob retired from the USGS in 1993, and continued working with geochemical data and interacting with colleagues by correspondence and with academic geologists in the Sacramento area until his health declined twenty years later. Over this time, honors and recognition continued, including Honorary Fellow of the Geological Society of London (1996) and the Martin A. Baumhoff Special Achievement Award of the Society for California Archaeology (2005). Bob Smith was predeceased by son Michael and is survived by Barbara M. Smith, his wife of 64 years, sons Leland and David, and three grandsons.

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