ROCK STARS

Reginald Aldworth Daly, from the Harvard archives.

Reginald Aldworth Daly (1871–1957): Eclectic Theoretician of the Earth

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Reginald Aldworth Daly was an authority in igneous petrology, structural geology, physiography, geophysics, and marine geology who wrote cogent syntheses that considered Earth from several vantages. In his earliest book, he presented what he called an "eclectic theory" of volcanic action and magmatic differentiation, and thus I describe him as an "eclectic theoretician of the Earth."

The son of a tea merchant and a minister's daughter, Daly was born on a farm near Napanee, southeastern Ontario, the youngest of four sons and five daughters. Late in his career, he recalled the simple life of a small town, the high standards of conduct expected by his parents, and an early introduction to the importance of hard work and wide reading. He was educated in public schools and attended Victoria College in Ontario (B.A., 1891; S.B., 1892; instructor in mathematics, 1892). There, inspired by Professor A.P. Coleman's description of granite ("This is made of crystals."), he decided on a career in geology. Encouraged by interviews with Nathaniel Southgate Shaler and Josiah D. Whitney, Daly commenced graduate studies at Harvard under John E. Wolff, obtaining his Ph.D. in 1896.

Daly seemed always to absorb the better part of the knowledge of his mentors and associates. Of the Harvard faculty, Wolff's interests in ore mineralogy, petrography, and economic geology had the greatest influence on Daly at this time. Daly also was teaching assistant under Shaler and William Morris Davis, the latter attuning Daly to an understanding of physiography and planation surfaces. At the same time, Daly formed important lifelong friendships with two contemporaries, crystallographer Charles Palache and the future Hawaiian volcanologist, T.A. Jaggar. His closest friend, however, was Lionel Marks, soon to be a mechanical engineer in the physics department at Harvard, who introduced Daly to his future wife. These young men shared a community of mutually reinforcing interests that led them all to positions of leadership in their fields.

In 1893, Daly began his dissertation study of the geology and petrology of Ascutney Mountain, Vermont. The project culminated in the publication of a landmark paper (1903) that outlined his developing theory of the geological and petrological consequences of large-scale magmatic stoping and assimilation of roof rocks. The paper combined careful mapping, detailed petrographic descriptions, sophisticated treatment of chemical analyses of rocks, and analysis of the process of intrusion in light of contrasting densities of rocks and magma. The stoping hypothesis evidently came to Daly in a flash, while dropping off to sleep. Daly later wrote, "The solution then found still seems the best in sight, but its chief result has been the realization that geology must be based on geophysics."

Upon completing his degree, he obtained a superb postdoctoral overseas fellowship in Europe (1896–1897), where he became an expert at thin section analysis under the petrographers Harry Rosenbusch (1836–1914) and Alfred Lacroix (1863–1948), toured many famous field localities, and attended the 7th International Geological Congress in Russia (1897). Looking at photographs taken at this time, Francis Birch (1958) described the young Daly as "physically impressive, sartorially elegant, [and] conspicuous among the somewhat worn-down gathering of international geologists."

In 1903, Daly married Louise Porter Haskell, who was from a distinguished Southern family, a graduate of Radcliffe College, and the owner and headmistress of a girls' school in Boston where she taught history and literature. Two of his books are dedicated to her as "inspiring fellow worker," another as "comrade and wise counselor in the search for the meaning of things." In a letter, she in turn described him as "a genius who remembers his mineral stage as few others ever have, & so feels earth-secrets as few others do." After their marriage, she was his companion on journeys, field assistant, amanuensis, typist, manuscript critic, and editor. The Dalys had one child, a son named for his father and called Aldworth, who died of a fever from tubercular meningitis at the age of two.

In 1901, Daly left Harvard, where he had been teaching physiography and oceanography. Despite the Ascutney work and the amenities of his position, he had not, as he later wrote, "made much progress in the development of original thought." He joined the Canadian International Boundary Survey and undertook a monumental exploration of the Canadian–U.S. boundary from the Pacific coast through the wide belt of the Cascades and Rocky Mountains into the Great Plains. The survey was along the 49th parallel, the border between the United

States and Canada. Working with but one field assistant during five field seasons, Daly mapped a strip 5 to 10 miles wide and 400 miles long through some of the most rugged country in North America. He then was able to present his fully developed theory in five chapters of his final report (1910, reprinted as Memoir 38 of the Geological Survey of Canada in 1912) and his first book, *Igneous Rocks and Their Origin* (1914). In 1907, he returned to academic life, first taking a position at Massachusetts Institute of Technology, and then succeeding William Morris Davis as Sturgis-Hooper Professor at Harvard in 1912.

The maturity of Daly's thought and the scope of his scholarship are evident in the treatment of many topics in *Igneous Rocks and Their Origin*. Using Rosenbusch's petrographic classification of igneous rocks, he divided 2631 chemical analyses to give average analyses of 116 petrographic types. He presented not only distributions of rock types of different composition, but described and classified the many forms of extrusive and intrusive rocks and the links between intrusive and extrusive bodies of igneous rock. The central problem of petrology at that time was to understand the diversity of igneous rocks. To Daly, crystallization differentiation by itself was insufficient, and he instead argued that magmatic stoping and assimilation contribute fundamentally to diversity. He also saw that beneath all igneous action, injection of basaltic magma into the crust was the essential precursor. Basalt is present in all associations, in all provinces, and at all times in Earth's history. It is "the bringer of heat."

Drawing from geophysical conceptions of shells of the Earth, Daly proposed the existence of a universal basaltic substratum beneath the crust that he argued was vitreous (a strongly viscous liquid; glass at high pressure) in its physical properties. Basalt was thus "primary" (a direct melt of the vitreous substratum). Gravitational accumulation of olivine then leads to formation of olivine gabbros seen as cumulates in so many intrusive bodies and the complementary olivine-free basalt so commonly found along the perimeter of the North Atlantic and in flood-basalt provinces. Ever since, discussion of basaltic petrogenesis has had to deal with concepts of primary magma and the question of the potential uniformity of composition of its mantle sources.

Daly's outer two shells of the Earth are a discontinuous layer of sediments and, beneath that, a silicic or *acid* crystalline layer, together comprising the upper part of the continental crust. He supposed that the acid shell is discontinuous beneath the oceans and viewed the continental crust as reworked by sediment melting, or *syntexis*, operating at and near basaltic intrusions. In this way, the crust becomes more strongly differentiated toward granite than its average protolith, which Daly considered to be sedimentary material derived from ancestral basaltic and andesitic terranes. His theory *required* that the field relations be considered along with any theoretical or experimental inferences about the behavior of magmatic fluids. From his study of rock distributions, Daly was able to declare (1914, p. 52), "The igneous rocks of the globe chiefly belong to two types, granite and basalt … one of these dominant types is intrusive, and the other is extrusive. To declare the meaning of this fact is to go a long way toward outlining petrogenesis as a whole."

Louise Porter Haskell, Daly's "inspiring fellow worker," Christmas 1901, a year before her engagement to Daly, from a family portrait.

Daly's subsequent career added layers of expertise to his core concepts in petrology and field geology. In 1909, before completion of his Boundary Survey report, he traveled to Hawaii with T.A. Jaggar, accompanied also by Louise (this was shortly after their son's death). There, the two scientists examined Kilauea volcano. The trip led directly to the establishment of the modern Hawaii Volcano Observatory, which Jaggar headed for nearly three decades. Daly's first publication on Hawaiian volcanism was in 1911. His observations of island subsidence and reef distribution convinced him that fluctuations in sea level were critical to the formation of the lagoons of barrier reefs and atolls. He published this as "The Glacial Control Theory of Modern Reefs," also in 1911. After the First World War, he traveled extensively to study other volcanic islands (Ascension, St. Helena, American Samoa), ore bodies in Sweden, and (with Charles Palache) the Bushveld intrusion in South Africa.

His interests came to include uplifted beach rock, the bearing of coral reefs on Pleistocene fluctuations in sea level, submarine canyons, isostasy and glacial rebound, and the great questions of continental geology, including continental drift. He sparred with experimental petrologist N.L. Bowen in attributing the origin of alkaline magmas to the effects of limestone assimilation by basaltic magma rather than crystallization differentiation (Daly, 1918). He endorsed continental drift in *Our Mobile Earth* (1926) and offered a mechanism for it: very low-angle continental landslides or detachments slipping over a medium of extremely low strength, his own vitreous basaltic substratum, and compressing sediments in geosynclines. The idea is not far removed from today's view of the geodynamics of accretionary prisms at subduction zones. In 1927, he favorably reviewed the evidence for drift summarized by Alexander du Toit in *The Geology of South Africa*, which put him in a small minority of North American geoscientists who favored drift.

In 1930, together with physicist Percy Bridgman and other Harvard colleagues, Daly initiated an interdepartmental committee on geophysics, hiring Francis Birch, who held a Harvard degree in physics, to undertake experimental study of the properties of rocks at high pressure. An early graduate student in this program was Norman A. Haskell (not related to Louise), whose work on post-glacial Scandinavian uplift,

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suggested by Daly, led to the first estimates of the viscosity of the upper mantle.

In 1933, Daly published a second edition of his 1914 book, this time calling it *Igneous Rocks and the Depths of the Earth*. In contrast to Bowen's advocacy that crystallization differentiation led to granites, Daly continued to stress the importance of syntexis in the formation of continental crust, of superheat driving that syntexis, and of transport of alkalis in magmatic volatiles. Daly also added a full chapter on the physical properties of igneous rocks, which incorporated results of laboratory measurements made in collaboration with Percy Bridgman.

In retirement, Daly presciently argued that the origin of the Moon involved collision of Earth with another planetoid (1946) and that the Vredevort structure in South Africa was produced by giant impact (1947). Daly became a U.S. citizen in 1920, was elected to the National Academy of Sciences in 1925, and received both the Penrose Medal of the Geological Society of America (1935) and the Bowie medal of the American Geophysical Union (1946). He published actively until 1952, and in 1957 he wrote a biographical memoir of his Harvard friend and colleague, mineralogist Charles Palache.

Daly was a gifted lecturer who made good use of his and others' drawings, diagrams, and photographs in both talks and published works. The title page of *Our Mobile Earth*, in which he endorsed continental drift, is wryly inscribed, following Galileo, "E pur si muove!" Daly's forte was clearly in selecting among disparate observations and lines of reasoning and then reinforcing or extending hypotheses into new and more powerful syntheses. He tried to view geological processes from as many angles as possible. Almost all of us today are specialists, but to read Daly is to be reminded that ours is a multidisciplinary enterprise, and that understanding Earth requires mastery of many arts.

Daly died in 1957 at the age of 86; Louise, his wife, predeceased him in 1947. Reginald, Louise, and Aldworth Daly are buried in the Haskell family plot at Elmwood Cemetery in Columbia, South Carolina.

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