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REGINALD ALDWORTH DALY

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A Biographical Memoir by

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REGINALD ALDWORTH DALY's first publication appeared in 1896; his last, a biographical memoir of his lifelong friend and colleague, Charles Palache, was published in the year of his death, 1957. His last scientific paper, "Origin of 'Land Hemisphere' and Continents," appeared in 1951, when he was eighty years old. During a marvelously productive lifetime, he wrote about one hundred and fifty papers and books. Probably no other American geologist has been more widely read abroad, nor more generously recognized by foreign scientific societies. Throughout his long career as field geologist, writer, teacher, and natural philosopher, his accomplishments, on a grand scale, were the expression of a personality of exceptional force and single-mindedness. The intensity of his devotion to geology is evident in all of his writings, and the many basic problems to which he repeatedly returned were never far from his mind. Even his private life was closely bound up with the professional one, Mrs. Daly participating in many of his expeditions and in the writing of his major works.

Daly's grandfather, Denis St. George Daly, a native of Ireland and a manufacturer of cotton cloth, emigrated to Ontario, Canada, early in the nineteenth century, bringing a family of six sons and two daughters to a farm near Napanee. One of the sons, Edward, born in Dublin, and educated at Trinity College, became a tea merchant in Napanee. Here he married Jane Maria Jeffers, daughter of an Ontario preacher, William Jeffers. Reginald Daly, born on May 19, 1871, on the farm, was the youngest of their family of four sons and five daughters. In 1876 the family moved into the town of Napanee, where Reginald attended the public schools. Of this period, Daly recalled "a simple life in a small town, under the direction of parents with high standards of conduct; [I was] taught early to assume responsibility and to take pleasure in hard work, and encouraged by uninterrupted schooling and opportunity for wide reading early in life." Though he did not enjoy Latin, "partly because of teacher's lack of skill," he seems to have had no particular preference in his studies; it was not until he reached Victoria College, then at Cobourg on Lake Ontario, that the interest was awakened which dominated the rest of his life.

At Victoria College, Daly won prizes in English literature and astronomy, a silver medal in science, a gold medal for general proficiency. He received the A.B. degree in 1891, the S.B. in 1892, and during the year 1891–1892 was also instructor in mathematics. According to his own account, his interest in geology dated from the moment Professor A. P. Coleman "held up a piece of granite and remarked, 'This is made of crystals.' His course prompted the gamble of entering geology as a livelihood—a field almost wholly unknown [to me] until 1891." (This suggests that ignorance of the existence of geology is not a recent development.) Encouraged by interviews with Shaler and Whitney, Daly undertook graduate studies in geology at Harvard; the M.A. degree was awarded in 1893, the Ph.D. degree in 1896. He held the Townsend scholarship in 1893–1894, also the post of assistant in geology (to Shaler) in 1894–1895. A Parker Traveling Fellowship enabled him to spend the next two years abroad; he then returned to Harvard as instructor in physiography from 1898 to 1901.

The academic year 1896–1897 was spent at Heidelberg, where Daly learned the techniques of thin-section analysis taught by Rosenbusch. The next year found him in Paris, studying with Alfred Lacroix.

In the vacations, his travels took him to most of the geologically interesting parts of Europe, including Finland and the Caucasus. Photographs of this period, taken during the leisurely progress of the Seventh Geological Congress through Russia, show the young Daly, physically impressive, sartorially elegant, conspicuous among the somewhat worn-down gathering of international geologists. The many associations formed during his European studies lasted throughout his life, to be many times renewed in the course of later travels.

At Harvard were N. S. Shaler, J. D. Whitney, W. M. Davis, J. E. Wolff, J. B. Woodworth, T. A. Jaggar, Charles Palache, and R. DeC. Ward. In the smaller academic circle of those days, departments were less self-sufficient than now, and Daly had many close friends who were not geologists, such as Lionel Marks, Albert Sauveur, and later, H. N. Davis and P. W. Bridgman. His enthusiasm for geology led to innumerable discussions of its problems with his friends among the engineers and physicists, and he frequently acknowledged their assistance in forming his views. In the summer of 1900, Daly accompanied a party of Harvard undergraduates (including Henry B. Bigelow) on a cruise along the Labrador coast; a lasting interest in shore-line physiography and marine geology may perhaps be dated from this experience. Noting the lack of exploration of Labrador, Daly called attention to the more important jobs to be done: "The Labrador should be mapped at least as carefully as the coast of northern Norway. With the mapping, detailed observations of value on the hydrography of the coastal waters could be carried on. The remarkable tides of Ungava Bay, the marine zoology of the coast, particularly the study of the jelly-fishes, the fixing of bench marks to show the rate of elevation on the coast, the study of the fossiliferous beds of the raised beaches,—these and many other subjects of research await the explorers of the future." This, with its view toward the next investigations, is a thoroughly characteristic passage.

In Cambridge, probably through his friends, Lionel Marks and

Thomas Jaggar, Daly met his future wife. Louise Porter Haskell, of a distinguished South Carolina family, graduated from Radcliffe College in 1897 with a *summa cum laude* degree in history. In 1898 she taught in Miss Ward's School in Boston, a fashionable school for young ladies, which she soon acquired and directed until her marriage to Reginald Daly, in Columbia, South Carolina, in 1903. The school was then taken over by Mrs. Daly's sister, Mary E. Haskell, who later moved it to Cambridge. Another Haskell sister married Harvey N. Davis, instructor in physics, later professor of mechanical engineering at Harvard and president of Stevens Institute of Technology. It was through this connection with Davis that the fruitful association was established with Bridgman after Daly returned to Harvard in 1912.

Mrs. Daly was a charming woman of exceptional character and intellect, and there is little doubt that her aid was vital in Daly's writing. Not only did she type his manuscripts; her criticism helped to clarify his ideas and expressions, as many warm dedications bear witness. She was able to stimulate her husband's interest in art and music. She accompanied him on many of his travels, even occasionally in the field. The Dalys first set up housekeeping in Ottawa, as this was the period of the studies for the Canadian Boundary Commission. In 1907 they returned to Cambridge, thenceforth their home. Daly became a citizen of the United States in 1920.

Besides her literary collaboration on the many papers and books of her husband, Mrs. Daly found time to edit for publication the Civil War letters and papers of her father. This work, published as *Alexander Cheves Haskell, the Portrait of a Man,* has found its place in the treasury of firsthand reports of the War between the States. Daly's admiration of his wife's abilities was profound; to his sister-in-law he once remarked: "She had the finest mind I ever knew, in a woman." When a joke was attempted on the qualification, he said severely: "You forget that I have also known Whitehead, Einstein, etc." In his response to the presentation of the Penrose Medal in 1935 he further details his debts to his wife, "who has shared the fatigues, perspiration and mosquitoes of mountain land, the mal de mer of ocean voyages, and the misery of preparing manuscripts for print."

At Harvard, Daly first assisted William Morris Davis in his course on physiography and later gave it himself; he also offered a course on oceanography. Though both of these subjects repeatedly engaged his attention at later times, and though he had completed his field studies at Mt. Ascutney, he had not, he felt, "made much progress in the development of original thought. Hence, in spite of the attraction of Harvard, resignation to undertake a prolonged program of field work as geologist for Canada along the 49th Parallel. The vast range of problems then opened up guided to a life work in research. However, perhaps the most significant problem in controlling work of later years was that of Mt. Ascutney, Vermont, where field work was begun in 1893. Only after nine years of more or less steady thought on the results of this mapping did a reasonable theory as to the origin of the Ascutney complex of rocks come to mind; this solution came as a flash of understanding, when its author, after another day of effort to find it, had retired for the night and was dropping off to sleep. It seems to have been a case of a draft from the unconscious. 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." These notes by Daly appear to have been written in the thirties.

Leaving Cambridge in 1901, Daly began his survey of the International Boundary, the 49th Parallel. In six field seasons, Daly mapped a belt from the Strait of Georgia to the Great Plains, 400 miles long, from 5 to 10 miles in width, with a total area of about 2,500 square miles. "No geologically trained assistant was employed in any part of the field. The work was, therefore, slow. Each traverse generally meant a more or less taxing mountain climb through brush or brulé. The geology could not be worked out in the detail which this mountain belt deserves." It seems, in fact, that this heroic geological reconnaissance was carried out by Daly with a single mountaineer as companion, though large parties of axemen were required to clear trails through the wooded regions for the topographers, greatly facilitating access. It was not until the fifth season that adequate topographic maps were available. Daly brought back some 1,500 rock specimens and studied 960 thin sections; 60 chemical analyses were made for him, and he had expert assistance with the relatively small number of fossils which he could find. He took some 1,300 photographs, sounded lakes, studied the stratigraphy, structure, petrology, economic geology, glacial geology, physiography. Some twenty papers and preliminary reports preceded the massive final report, in three large volumes, published by the Geological Survey of Canada in 1912. This work showed Daly's mastery of every geological technique; it brought him face to face with the problems of earth history on a grand scale.

A large portion of the report is necessarily descriptive, and this discussion of range after range for a distance of 400 miles might well have satisfied most geologists. But mere description did not satisfy Daly. His point of view is explained in one of the preliminary reports (1906): "As in former years the effort was made during the months in the office to clear up some of the theoretical and other major difficulties in the way of interpretations of the field observations in the boundary mountains. The experience of five seasons spent on the boundary work has convinced me more and more thoroughly that theoretical geology is the basis of practical geology, that economic or mining geology is unceasingly dependent on the healthy and vigorous growth of the theory of general physical geology. On the other hand, the data for intelligent geological theory must be found chiefly in sheet or areal mapping on the large scale. There is, therefore, one principal way in which the Government can best serve the interests of the mining public, and that is, by causing the active, thorough, interpreting geological survey of areas much larger than mining districts. That wider view of the rocks is absolutely indispensable to a full and rounded, and hence completely fruitful, knowledge of ore-bodies or other mineral deposits as to their origin, occurrence or exploitation. The mining companies are today showing an increasing demand for the services of those mining geologists who have completely assimilated the stable principles of rock-interpretation laid down by intelligent areal geologists. Both classes of geologists are dependent upon theory: without theory it is impossible to take a single long step in the evaluation of field phenomena whether those have a direct practical bearing or not. It is thus not of choice, merely, but of necessity, that I have had to spend much time on the theoretical side of the boundary geology." In fact, in the last five chapters of his report, Daly gives the essence of his theory of the origin of the igneous rocks, soon after to appear as a textbook in expanded and developed form.

In 1907 Daly was appointed Professor of Physical Geology at the Massachusetts Institute of Technology; his lectures were based largely on his theory of igneous rocks, born of the work at Mt. Ascutney and in the Cordillera. Two more field seasons were spent in the Rockies, along the route of the Canadian Pacific Railway; here he had as field assistant one of his students, a fellow Canadian, Norman L. Bowen, who was to accomplish more, perhaps, than any other single individual toward finding answers to the problems of rock differentiation. In 1909 Daly spent his summer in Hawaii, observing the volcanoes and collecting rocks; in 1911 he participated in a commission to investigate the danger of further landslides at Turtle Mountain, Alberta. Reports on all these studies were promptly published; the work of each summer usually appeared in print within the next year, a phenomenon not likely to be seen again in this country.

Daly succeeded William Morris Davis as Sturgis-Hooper Professor of Geology at Harvard in 1912. He became at the same time chairman of the department, continuing in this post for the unusually long term of thirteen years. He also took over the course in Elementary Physical Geology (Geology 4) originated by Shaler, and introduced a new one, Geology 9, on the igneous rocks. His travels and publications did not suffer. Nearly every summer saw a trip to some new area: to Sweden, where he studied the Kiruna ore body; to Butte, Crater Lake, the Grand Canyon; to Duluth, the Adirondacks, the New England mountains. In 1913 he was editor of the guide book for the 12th International Geological Congress, held in Victoria, B.C., and wrote large portions on the Cordilleran geology.

An interruption came with the entrance of the United States into the First World War. Daly went to France with the Y.M.C.A. in the post of chief librarian. In the notice of his death in the *Comptes Rendus* of the Académie des Sciences, of which he became a correspondent, we read that, as librarian, "ses interventions en faveur de nos compatriots furent innombrables."

The year after the war found him mapping the Samoan Islands, on an expedition supported by the Carnegie Institution of Washington. Having become interested in the consolidation of beach-sands, Daly prepared for the Samoan visit by studies at the Marine Laboratory directed by A. G. Mayor, at Tortugas, Florida. The impersonality of Daly's scientific writing is illustrated by a remark in the Samoan memoir: "To get some idea of the amount of carbonaceous material in the sand of the Tortugas shelf, a large sample was secured, with the use of a diving helmet, about 100 meters from the laboratory wharf, at a depth of about 2.5 meters. While digging up the bottom sample, some of each shovelful (perhaps one-fifth) was lost." Who wore the diving helmet? The syntax, which seems to have escaped the attention of Mrs. Daly, suggests that it was Daly. No doubt this detail was scientifically irrelevant, like the reports of "bad food in Manila" for which he somewhere takes geographers to task.

The expedition to Samoa brought new problems to the fore in Daly's mind, especially those connected with the contrast between oceanic and continental rocks. In 1921–1922, a protracted visit to the Southern Hemisphere was organized with support from the Shaler Memorial Fund, and the trip was known as the Shaler Memorial

Expedition. It began with the mapping of Saint Helena and Ascension islands by Daly, about one month to each. (He liked afterward to remark, "What a pity Napoleon was not a geologist; he would have found Saint Helena much more interesting.") He was then joined by Palache, G. A. F. Molengraaff, and F. E. Wright of the Geophysical Laboratory in an investigation of the Bushveld Complex of the Transvaal.

This party was well received in South Africa and is credited by A. L. Hall, in his memoir on the *Bushveld Igneous Complex of the Central Transvaal,* with important contributions, especially with respect to the stratigraphic position of the Waterberg sediments. Hall begins his introduction as follows: "In the history of geological research in South Africa, the year 1922 is a landmark, for it saw the visit of the Shaler Memorial Expedition, whose members were Professor R. A. Daly and Professor C. Palache. . . ." It was testimony not only to the high professional qualifications of Daly and Palache but to their personal qualities of tact, modesty, and devotion to science that they were able to participate so fruifully in the work of another country, already renowned for its own leaders in geology.

This was Daly's last field investigation. His travels had been prodigious. He records that he crossed America twenty-four times, the Atlantic fourteen. He had visited all of the states except South Dakota, all of the provinces of Canada except Prince Edward Island. He had seen a remarkably large fraction of the globe, and looked at it with unrivaled concentration.

Most of Daly's books were yet to appear. He now turned his still abundant energies to writing and lecturing. The numerous occasions on which he delivered a series of lectures promptly resulted in books. *Our Mobile Earth* (1926) developed from lectures at the Lowell Institute; *The Changing World of the Ice Age* (1934) contains the substance of his Silliman lectures at Yale; the Harris lectures at Northwestern University (1937) became *The Architecture of the Earth; The Floor of the Ocean* (1942) is based on three Page-Barbour lectures at the University of Virginia. Besides these, he published in 1933 a revision of his textbook, now entitled *Igneous Rocks and the Depths of the Earth,* and in 1940, *Strength and Structure of the Earth,* largely devoted to summarizing and interpreting the geophysical, especially gravitational, evidence concerning the earth's interior. Daly never deviated from his purpose of relating the field evidence of geology to the latest research in seismology, gravimetry, and experimental petrology and geophysics. Several of his books were intended for the educated general reader, and set a high standard for "semipopular" scientific literature. Copiously illustrated, packed with numerical data, and written with contagious enthusiasm, they all bear the imprint of Daly's imagination and intellectual force, and his extraordinary familiarity with the geological terranes and the geological literature of the world.

At Harvard, Daly was relieved of Geology 4 in 1923 and of the departmental chairmanship in 1925 by Kirtley F. Mather; in 1926, Geology 9 was replaced by Geology 8, "Principles of Geology." The subject matter of this course, renumbered Geology 21b in 1933, varied with Daly's current interest, turning increasingly toward geophysical topics.

During the twenties and thirties, honors accumulated. The University of Toronto (which now embraced Victoria College) presented Daly with his first honorary degree in 1923. Heidelberg followed in 1936, Chicago in 1941, Harvard in 1942, on his retirement. In 1932 he was elected President of the Geological Society of America, and in 1935 received the Penrose Medal of that Society. Other recognition included the Hayden Medal of the Academy of Sciences of Philadelphia, the Wollaston Medal of palladium of the Geological Society of London, and the Bowie Medal of the American Geophysical Union. He was elected to the American Academy of Arts and Sciences in 1909, the National Academy of Sciences in 1925, the American Philosophical Society in 1913, to honorary membership in Phi Beta Kappa in 1934. Daly was elected member or correspondent of nearly every European geological society, as well as the Geological Society of South Africa and the Indian Academy of Science. Until his death he was an associate editor of the *American Journal of Science,* and before the Second World War, of *Gerland's Beiträge zur Geophysik* and of the *Mineralogische und Petrographische Mitteilungen* (Leipzig).

As a member of an Interdivisional Committee on Borderlands in Science of the National Research Council in 1936, Daly advocated a project for the compilation of physical data of significance for geologists; his own works contained the embryo of this compilation, which was later realized as the "Handbook of Physical Constants," Special Paper No. 36 of the Geological Society of America.

From his earliest papers, Daly showed an interest in the physical properties of rocks and rock melts. His major thesis concerning the origin of the igneous rocks depended upon differences of density, and he was exceptional in recording the density of every rock which he had analyzed. He soon found that many other kinds of data were required, especially the extension of the physical measurements to conditions of pressure and temperature resembling those of the interior of the earth. Daly's path from 23 Hawthorne Street to the Geological Museum took him past the Jefferson Physical Laboratory, where Percy W. Bridgman was giving physical measurements a new domain, that of high pressures. Bridgman, as a physicist, was primarily concerned to find the effects of pressure for the simplest materials, elements, simple chemical compounds, for which conceivably there might be theoretical explanations. Daly interested Bridgman in the geological applications of his work and supplied minerals for various kinds of measurements. He resorted to Bridgman for discussion of the many frustrating problems relating to the behavior of materials under the unfamiliar conditions of the inner earth, and a close friendship and scientific collaboration developed.

In the meantime, the high-pressure program of the Geophysical Laboratory in Washington developed independently and began to show the value of a steady application of physical and chemical methods to geological problems. In 1932 Daly, seconded by Bridgman, Harlow Shapley, L. C. Graton, and D. H. McLaughlin, was able to obtain financial support from the Rockefeller Foundation for launching a long-range program of experimental geophysics and seismology at Harvard. This involved the creation of a modern seismological station at Harvard, Massachusetts, on the grounds of the Agassiz Astronomical Observatory, replacing the station long operated by Woodworth in the Geological Museum, and the beginning of a program of physical measurements exploiting Bridgman's development of the high-pressure field. A few years later, the Rockefeller Foundation decided to withdraw from the physical sciences, and the large support which had been confidently anticipated did not materialize. This was a critical period for the new program, but it was rescued by generous aid from an anonymous benefactor, to Daly's great satisfaction and relief. Except for a period of standstill during the war, this work has continued under the administration of an interdepartmental committee, like the original group including representatives of other sciences than geology. Daly's part in this development was aptly recognized in J. B. Conant's citation on presenting the honorary D.Sc. degree: "A geologist of rare imagination and wide vision, his enthusiasm has aroused physicists, chemists and astronomers to cooperate in the advancement of his science."

A lifelong teetotaler, Daly was at one time sufficiently ardent in his convictions to march in temperance parades. In a long letter to the New York *Times* in 1917, entitled "Beer and Brutality," he argued, with characteristic thoroughness, the alcoholic origin of German brutalities; allowances must be made for the excitement of the times. In the twenties, traveling in France with his wife and sister-in-law, he was amused to announce to the waiters, "Nous sommes secs." Fundamentally sober and serious-minded, he was not above an occasional pun, and his rich experience of places and people gave him an inexhaustible supply of anecdotes and reminiscences. A touch of fantasy occasionally appeared, as in his memorable dream of lowering a French clock down a borehole in order to find the time down there.

Daly suffered a penalty of longevity in surviving many colleagues and friends. He wrote biographical memoirs on R. DeC. Ward, W. M. Davis, J. B. Woodworth, John Joly, John Horne, J. L. Vogt, Albert Sauveur, and Charles Palache. He outlived his brothers and sisters: his last trans-Atlantic passage in 1947, this time by air, was to visit a sister living on the island of Jersey. His only child, a son, died at the age of three. Mrs. Daly died in 1947; the loss of this ally and companion of more than forty years produced a visible change in his usually buoyant bearing, and he began to set his affairs in order. Much of the material now available for his biographer was prepared in the last few years, but, as always, it remained impersonal, almost exclusively devoted to the scientific aspect of the travels and studies to which his life had been dedicated. Until the last year, Daly retained a remarkable degree of physical energy, and his mental facilities were never clouded, though he reproached himself with forgetfulness of names. His interest in departmental affairs and in the latest research remained lively until the final failure of strength. The generous bequest which he made to Harvard in the name of Mrs. Daly was earmarked for meeting field expenses of graduate students.

The growth of the Department of Geology at Harvard in the 1890s and the early years of this century was largely a consequence of the personal qualities of N. S. Shaler as lecturer, teacher, and administrator. The introductory course, Geology 4, was for years the most popular course in college, though a sharp reduction in enrollment took place when required laboratory exercises were introduced; at its peak, 500 students were enrolled, in a college of 2,000. The chapter on the Department of Geology and Geography, written by Davis and Daly for *The Development of Harvard University, 1869–1929,* says with reference to Shaler (p. 319): "It was his happy boast that few Harvard men took their degree without coming under his instruction; also that he had lectured to seven thousand enrolled, and no one knew how many non-enrolled students; probably a greater number than had ever before been taught geology by any one man. His lectures were spontaneous revelations of a life-long familiarity with his subject, illuminated with an inexhaustible fund of apposite illustrations, derived from his many contacts with the actual world. His teaching was seldom analytical or argumentative; it was as a rule more broadening and inspiring than minutely systematic and instructive." "The Department of Geology was thrown on its beam-ends by Shaler's death in 1906, and righted itself with difficulty" (p. 321). The elementary course was given by Wolff and Woodworth to classes usually numbering fewer than 100 students for the next six years. W. M. Davis, appointed Sturgis-Hooper Professor in 1898, spent much of his time away from Cambridge, in the western states, Turkestan, Mexico, South Africa, and elsewhere. When he resigned this chair in 1912, he was succeeded by Daly.

Daly was superbly equipped to take over Shaler's old course. Though his experience of life had been more limited, he had seen much more of the geology of the world, and had thought more intensely about it. An excellent speaker, capable of extracting the essentials from masses of details, he could not fail to impress and inspire his classes. At the end of class, his lectures were frequently applauded, an unusual event in Harvard College. His standards, however, were high; he insisted upon rigor and clarity, so that his course never regained the relatively easy popularity of Shaler's, though the enrollment gradually returned to about 200 by 1921. His advanced courses were taken by most of the graduate students, and their rosters show a remarkable proportion of names now well known to geologists.

Daly seems to have directed few doctoral theses himself, though the influence of his ideas certainly permeated the department. His influence was thus exerted principally through his published writings, his lectures, and his participation in the discussions and questions excited by visiting lecturers.

The specific conclusions of many of Daly's scientific studies have passed into the geological currency; some are still debatable, a few have proved untenable. Of the tentative nature of the speculative theory, Daly was well aware; many of his papers begin disarmingly with a warning of the incompleteness of the data and the unavoidable uncertainties of the conclusions; but his discussion is usually so thorough, so copious, and so warm that little doubt is left in the mind of the reader about what Daly, at any rate, suspects the truth to be. With the same untiring energy with which he confronted the mountains on the 49th Parallel, Daly systematically ransacked the literature of the world for examples, data, ideas, arguments; his *Igneous Rocks* contains about a thousand references to the literature. The range of his contributions is amazing, and includes almost every branch of geological science.

Persistent elements of Daly's thinking about igneous intrusion are already present in his first major study, begun as a graduate student at the suggestion of Professor Wolff, of the composite stock constituting Mt. Ascutney, Vermont. This well-exposed and readily accessible monadnock presented in small compass an assortment of irruptive rocks, divisible into related but recognizably different mineral assemblages, cross-cutting a schistose country rock with a clear metamorphic aureole. By what means had this new material come to occupy the space in which it is now found? What had become of the original country rock? What process could account for the "differentiation" into granite, syenite, diorite, gabbro, all represented in the intrusive mass? To these problems Daly returned in papers and books throughout the next fifty years. The idea of "magmatic stoping" was vividly supported by the field evidence at Ascutney. Daly later found that others had also reached this conception, based on similar evidence elsewhere. The discussion of this idea, essentially the sinking of detached blocks of the original rock into underlying liquid magma, led Daly to assemble the measurements then available on the densities of rocks and rock melts, only the first of such compilations of physical data with which he sought to render quantitative the elusive problems of geology. The question then naturally arose as to the fate of blocks so engulfed; the concept of "abyssal assimilation" supposed that they were incorporated into the magma, perhaps at great depths, and gradually altered its composition. The idea of "differentiation" was then current, but vague; Daly followed his teacher Rosenbusch in supposing that the magma might "split" into acid and basic fractions, both still liquid, with the lighter acid portion rising to the top. The concept of a universal magma, everywhere present not far below the surface, of a composition close to that of common basalt, was also reached in this study; difficulties with geophysical evidence began to be serious in later years.

In 1901 Daly began the formidable reconnaissance of the geology of the 49th Parallel. The dimensions of this undertaking have already been mentioned. In this relatively unexplored region, it was first necessary to organize the nomenclature and to correlate the sometimes conflicting interpretations of geologists who had approached the Cordillera on opposite sides of the border. The stratigraphic correlations proved difficult, as fossils were almost nonexistent in many of the formations; though the Purcell lava provided a reliable marker over much of the eastern part, there were immense thicknesses of unfossiliferous formations both above and below this horizon. The western part was intensely deformed, with many igneous intrusions of mammoth scale. Daly singlehandedly studied the stratigraphy, structure, physiography, including the glacial history, and of course the petrology. The descriptive geology alone fills twenty-two chapters. In the last five chapters appears in brief the core of his discussion of igneous rocks which soon after was expanded and generalized in his first textbook, *Igneous Rocks and Their Origin.* In these chapters, Daly first demonstrated his exceptional ability to assemble and discuss voluminous quantities of information and concepts: the average chemical compositions of the numerous types of rocks distinguished by the petrographer; their physical properties; the classification of intrusive bodies. The mechanism of intrusion was now discussed in greater detail, with reference to the many exposures of the descriptive portion; the possible modes of differentiation were thoroughly canvassed. Much of this is now obsolete, but it served as a stimulus to the petrologists of the day, and one of the cardinal assumptions, that of the primary nature of basaltic magma, became also the starting point for Bowen's theory of the igneous rocks which forms so large a part of modern petrology.

Igneous Rocks and Their Origin appeared in 1914; based on lectures prepared for courses, first at the Massachusetts Institute of Technology and then at Harvard, it is a systematic treatment of the general problems of igneous geology with application to all of the major classifications of igneous rocks. Daly adopts the Rosenbusch system of classification according to mineralogy, and one of his first tasks, already begun in the 49th Parallel memoir, is to compute the average chemical composition, based on analyses, of the rocks assigned to each classification. These averages, to which he added in later work, have long been gospel for many problems of geochemistry and petrology. Daly then went on to consider the relative abundances of the various types by measuring the areas assigned to each type on the folios of the U.S. Geological Survey for the Appalachian and Cordilleran areas, which showed about 25,000 square miles of exposed igneous rocks. Taking these as a fair sample, Daly arrived at a conclusion, not indeed novel, but supported by more quantitative evidence than ever before: "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."

Daly's petrological theory was, as he said, eclectic: he took the elements he required from numerous sources, and he recognized the independent conception by other authors of many ideas which he made peculiarly his own. The basic assumption was an eruptible substratum of basaltic composition, available nearly everywhere and throughout all time; under favorable conditions, this could be injected at the base of the crust along abyssal fissures, and moving upward, might surround large blocks of the crust, which then foundered into the depths (magmatic stoping); these blocks might then be dissolved in the magma (abyssal assimilation), changing its composition. "Both the primary basalt and each of its solutions with crust-rock is, under certain conditions, subject to magmatic differentiation," thus giving rise to the varieties of igneous rocks.

The discussion of these processes continually raised the need for knowledge of physical properties, since Daly was not satisfied with mere enunciation of principles but whenever possible attempted quantitative treatments. Unavoidably these have had to be revised, but they have been of immense value in showing what information was needed and what could be done with it. Daly's illustrations were excellent; his mechanical sense was good, and the processes which he postulated are usually plausible and vividly described. It is worth remembering that no one has ever seen or will ever see the emplacement of a batholith; we see only the eroded remnant, millions of years later, after the removal of thousands of feet of cover; imagination is called for, and this Daly had in superlative degree.

Differentiation by crystallization had been postulated as one of the modes of differentiation by Loewinson-Lessing, the other being the splitting of liquid magma into fractions, of different compositions. Daly originally favored the idea of separation of liquids in the gravitational field ("liquation"), though recognizing the possibility of fractional crystallization under special circumstances. The appearance of Bowen's work, beginning in 1913 and culminating in his classic *Evolution of the Igneous Rocks* in 1928, established the process of fractional crystallization as the principal agency of differentiation. Accepting Daly's postulate of a primary basaltic magma as the parent of the igneous rocks, Bowen was able, with the aid of the experimental study of the crystallization of silicate melts, largely his own, and a systematic application of the principles of phase equilibrium, to show that fractional crystallization could account for the observed sequences of rock types. Though not accepting Bowen's work without reserve, Daly realized the transformation it had produced, and in the revised *Igneous Rocks and the Depths of the Earth*

(1933) Bowen's work is given a prominent place. On the separation of liquid magmas Daly still keeps an open mind, though recognizing that the weight of evidence had turned against this hypothesis. The experimental work has, of course, always dealt with systems much simpler than those of nature, and it has been difficult to be certain that important elements are not omitted from the experiments. By 1933 the seismological and gravitational evidence concerning the earth's crust had become more definite, and Daly sought to reconcile this with his general theory, which required a layer of vitreous basalt as the source of magma, and with the experimental evidence concerning basaltic glass. Though this postulate was still tenable in 1933, later experimental work, undertaken at his suggestion, eventually showed that the discrepancy between the properties of basaltic glass and those required for the material below the crust was too great to permit the identification of the one with the other; in 1946 Daly recognized the difficulty and courageously undertook to find a new model which might serve as a starting point for his theory. The problem of the constitution of crust and subcrust and of the locus of origin of magmas is still very much with us. Nevertheless, this magnificent attempt to bring together all of the evidence in a complete theory of the igneous rocks has been a source of ideas and inspiration for several generations of geologists and geophysicists, and the wealth of material assembled on actual occurrences will have a permanent value.

In his search for evidence of the petrological difference between continental and oceanic rocks, Daly studied the islands of Ascension, Saint Helena, Tutuila, and Hawaii. He rejected the concept of distinctly different "Atlantic" and "Pacific" rock types or compositions, and emphasized the uniformity of the basaltic rocks, wherever found. But oceanic problems of a nonpetrological character also occupied his attention. His early expeditions to Newfoundland and Labrador had acquainted him with raised beaches and other shoreline phenomena. In 1910 he proposed his widely known "glacial-control" theory of coral reefs, around which controversy long raged.

Darwin and Dana had postulated the continuous growth of corals around the shores of a slowly subsiding volcanic base, with the corollary of a gradually deepening ocean. But looking at the charts and at the shore-lines, Daly found a remarkable accordance of lagoon depths for dozens of atolls and continental banks, at roughly 30 fathoms. The Darwin-Dana hypothesis gave no explanations for this circumstance. Furthermore, this depth is of the same order as the lowering of sea level to be expected at the time of maximum glaciation. Daly inferred that the platform on which living coral reefs are growing was truncated at wave base at the time of lowest sea level, and that the present corals then grew upward as the sea rose to its present level.

There are many facets to this theory which cannot be dealt with here, but among others was the inference that the many coral atolls had not subsided appreciably during the glacial period, and Daly was interested in this in connection with the question of the earth's mechanical properties.

The amount of simple misunderstanding which appears in the discussion of this theory is remarkable: Daly had to reply in 1916, 1917, and 1934 to what he considered fallacious criticism, some from his teacher and colleague, Davis. Daly did not deny the possibility of subsidence, but he made it clear that it could not alone account for the topography of modern atolls and barrier reefs, whereas the lowering and subsequent rise of sea level very naturally accounts for the salient facts of the lagoonal flatness and depth. Since the discovery of seamounts, the fact of subsidence by thousands of feet seems incontestable; on the other hand, not all seamounts are crowned by atolls. Daly does not appear to have known about the seamounts; his last comments on the coral reef problem in 1948 are directed toward criticisms by Umbgrove and Kuenen, based on studies of corals in the East Indies. Kuenen's theory retains much of Daly's, especially the kernel of glacial control of the present topography.

Another proposal having to do with the ocean was inspired by the vast thicknesses of carbonate rocks in the Cordillera, of pre-Silurian age. The absence of recognizable animal forms and the fine and relatively uniform grain size throughout great thicknesses of pre-Cambrian as well as early Paleozoic rocks, persisting over large horizontal distances, were interpreted by Daly in terms of a biochemical precipitation of carbonates on the open ocean floor. A corollary, that the oceans of Eozoic time contained essentially no lime, since it was precipitated about as fast as it was brought in by erosion of the land, was held to account for the lack of calcareous fossils until the supply of lime was greatly increased by extensive emergence of the continent in late pre-Cambrian time.

The discovery by Vening Meinesz of the great Indonesian belt of gravity anomalies probably drew Daly's attention to the significance of these geophysical measurements for general geological theory. He had in 1933 argued from the generally accepted idea of isostatic equilibrium that the substratum, where compensation was supposed to take place, must be mechanically weak, and this conclusion he found in harmony with his conception of an earth-shell of hot glassy basalt. The large anomalies in the East Indies, and indeed elsewhere, showed that considerable portions of the crust could remain appreciably out of floating equilibrium for times of the order of geological periods; this meant appreciable mechanical strength for the underlying material. There was always some confusion in Daly's thinking on this matter; he could not reconcile mechanical weakness with crystallinity, though the ductility of hot crystalline materials is one of the most familiar of technological phenomena. The question of just what strength is implied by gravitational anomalies cannot, however, be given a unique answer, and the discussions of the matter remain long and inconclusive. With his usual energy, Daly plunged into the literature of this subject, producing in his *Strength and Structure of the Earth* a useful compendium of the gravitational data and of the various interpretations based upon it.

Another set of observations, which led to a contrasting view of the mechanical behavior of the earth's interior, was based on the recoil of the glaciated regions of Fennoscandia and Labrador since the melting of the icecaps. Daly had noted the raised and tilted terraces along the Labrador coast in his early expeditions. The oscillations of sea level associated with the growth and decrease of the glaciers formed the basis of his glacial-control theory of coral reefs. He now saw that the delayed response to the removal of the ice load threw further light on the properties of the underlying medium. In a fascinating book, *The Changing World of the Ice Age,* Daly assembled much of the material relating to Pleistocene glaciation, especially that touching the many problems of his own direct interest.

A related matter to which his imagination brought clarification was the origin of submarine valleys. Though many geologists had been content with the theory of drowned river channels, Daly rejected this because of the extreme depth of these valleys (several thousand feet); it was implausible either that the coasts of the world had all come up so far, only to be returned to a lower level, or that so much water could be stored on land as ice. Daly's theory, thought by many to be highly improbable at first, was that these valleys had been excavated by submarine currents of silt-laden water, pouring down the continental shelf. Experiments by Kuenen have lent this theory a high degree of plausibilty, and in recent years the concept of turbidity currents has become indispensable to marine geologists. This theory, with much other material on oceanic topography and geology, is set forth in his book *The Floor of the Ocean.*

Although a complete review of Daly's many-sided achievements is hardly possible here, perhaps enough has been given to illustrate his versatility, imagination, and untiring industry. His rare personal qualities have been imperfectly portrayed. Perhaps the most enduring elements of his work will be the many contributions toward the quantification of the geological sciences, a transformation now conspicuously in process, in which large infusions of physics and chemistry have given geology new methods of observation and new powers of interpretation.

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KEY TO ABBREVIATIONS

Amer. Acad. Arts Sci. Proc. = American Academy of Arts and Sciences Proceedings

Amer. Geol. = American Geologist

Amer. Geol. Soc. Bull. = American Geological Society Bulletin

Amer. Geophys. Union Trans. = American Geophysical Union Transactions

Amer. Jour. Sci. = American Journal of Science

Amer. Nat. = American Naturalist

Amer. Phil. Soc. Proc. = American Philosophical Society Proceedings

Biogr. Mem., Nat. Acad. Sci. = Biographical Memoirs of the National Academy of Sciences

Boston Soc. Nat. Hist. Bull. = Boston Society of Natural History Bulletin

Carnegie Inst. Wash. Publ. = Carnegie Institution of Washington Publications

Dir. Geol. Surv. Canada Ann. Rep. = Director, Geological Survey of Canada, Annual Reports

Econ. Geol. = Economic Geology

Geog. Soc. Phila. Bull. = Geographical Society of Philadelphia Bulletin

Geol. Jour. = Geological Journal

Geol. Mag. = Geological Magazine

Geol. Soc. Amer. Bull. = Geological Society of America Bulletin

Geol. Soc. Amer. Proc. = Geological Society of America Proceedings

Geol. Surv. Canada Mem. = Geological Survey of Canada Memoirs

Jour. Assoc. Amer. Geogr. = Journal of the Association of American Geographers

Jour. Geol. = Journal of Geology

Jour. School Geogr. = Journal of School Geography

Jour. Washington Acad. Sci. = Journal of the Washington Academy of Sciences

Mus. Comp. Zool. Bull. = Museum of Comparative Zoology Bulletin

Nat. Res. Council = National Research Council

Proc. Nat. Acad. Sci. = Proceedings of the National Academy of Sciences

Proc. Washington Acad. Sci. = Proceedings of the Washington Academy of Sciences

Rep. Brit. Assoc. Adv. Sci. = Report of the British Association for the Advancement of Science

Sci. Mo. = Scientific Monthly

Seis. Soc. Amer. Bull. = Seismological Society of America Bulletin

Trans. Geol. Soc. South Africa = Transactions of the Geological Society of South Africa

U.S. Geol. Surv. Bull. = United States Geological Survey Bulletin

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