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EUGENE THOMAS ALLEN

1864—1964

A Biographical Memoir by
CHARLES A. ANDERSON

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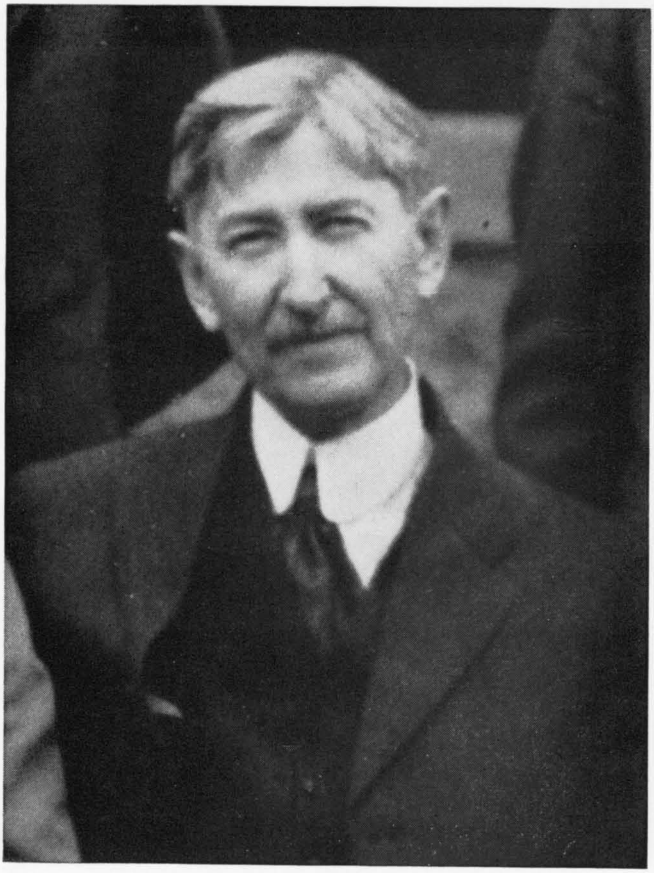

E. T. Allen

EUGENE THOMAS ALLEN

April 2, 1864–July 17, 1964

BY CHARLES A. ANDERSON

EUGENE THOMAS ALLEN was one of the pioneers in the field of geochemistry in the early part of this century, and much of his illustrious career was with the Geophysical Laboratory of the Carnegie Institution of Washington, from which he retired in 1933. He celebrated his centennial on April 2, 1964, and died on July 17, 1964, in Arlington, Massachusetts, where he had lived for many years following retirement. His last days were brightened by the greetings and flowers sent to him on the occasion of his 100th birthday. His death came rather suddenly and was quiet and peaceful, following a week of illness from which he appeared to be recovering.

Dr. Allen was born in Athol, Massachusetts, the son of Frederick and Harriet Augusta (Thomas) Allen, both descendants of old New England families. His father was engaged in a number of successive mercantile and manufacturing enterprises in Massachusetts. E. T. Allen was married in Arlington, Massachusetts, to Harriet Doughty of Arlington on August 26, 1896. Mrs. Allen had been born in Charlestown, Massachusetts, on January 8, 1865, and died in Arlington on February 11, 1945.

Dr. Allen received his A.B. degree from Amherst College in 1887, followed by graduate study in chemistry at The Johns

Hopkins University, where he received his Ph.D. degree in 1892. While working for his doctorate, he was Associate in Chemistry at the Women's College of Baltimore, now Goucher College. He spent the academic year 1892-1893 as Acting Professor of Chemistry at the University of Colorado, then studied at Harvard University for two years. For six years (1895-1901) he served as Professor of Chemistry at the Missouri School of Mines.

Allen's first contribution to geochemistry was made at Missouri. It involved a study of terrestrial native iron found in three localities in sedimentary rocks associated with coalbeds. Careful analytical work, coupled with concern for the geologic environment—qualities that persisted throughout Allen's career as a geochemist—proved that the iron was not meteoric or artificial but truly one of the rare natural occurrences of this element in sedimentary rocks.

Because of Dr. Allen's long career with the Geophysical Laboratory, it seems appropriate to give some of the history leading to the establishment of this outstanding organization. Shortly after the creation of the U.S. Geological Survey in 1879, Dr. G. F. Becker, together with Dr. Carl Barus, began to make systematic physical and chemical studies of igneous rocks. Apparatus was developed for the measurement of high temperatures and other properties. Nearly ten years were consumed in the preparation of this equipment, but in 1892 appropriations were curtailed and the laboratory work was discontinued. Dr. Becker persisted in his efforts for restoration of funds, and in October 1900 he was able to bring Dr. Arthur L. Day from the Physikalische Technische Reichsanstalt to reactivate the program. In 1901 Dr. Allen joined the staff of the Geological Survey to begin his long association with Dr. Day.

Day and Allen started work on the feldspars—the most abundant of the rock-forming minerals. The first step was the development of equipment for accurate high-temperature thermometry and the measurement of the melting points and thermal properties of the plagioclase feldspars. The melting points of these feldspars were determined with an accuracy never obtained before, and these points, considered with reference to their composition and the series of specific-gravity determinations on chemically pure feldspars made by Allen and Day, settled beyond question that albite, the sodium feldspar, and anorthite, the calcium feldspar, form a continuous series of isomorphous crystals. A comparison of the data of Allen and Day with Roozeboom's classes of isomorphous mixtures shows that the plagioclase feldspars fit Type I of Roozeboom's classification. By analogy, Allen and Day were able to explain the zonal structure of plagioclase found in thin sections of most igneous rocks.

In order to keep the Geological Survey's Geophysical Laboratory working at a high level of efficiency, the Trustees of the Carnegie Institution of Washington supplemented the Congressional appropriations by awarding grants to Dr. Becker and to Dr. Day; the later stages of the feldspar program were completely financed by the Institution. In appreciation of the splendid financial support given this program, the Director of the Geological Survey authorized publication of the feldspar study by the Carnegie Institution of Washington in 1905 (Publication 31).

By this time it was apparent that Congressional appropriations were not sufficiently stable to encourage an expanded and vitally needed program in geophysics and geochemistry, and the Carnegie Institution of Washington established the Geophysical Laboratory in December 1905, with Arthur L. Day as Director. The wisdom of this step has been amply demonstrated by the brilliant record of the staff of physicists, chemists, and geologists working together in a concentrated attack on fundamental geological problems.

Dr. Allen transferred to the Geophysical Laboratory in 1906 and became a key member of several teams working in collaborative research. His career with the Laboratory can be divided into three parts. For several years he continued working on the preparation of artificial silicates and on their melting temperatures and stability fields. In the middle part of his career, he worked on various metal sulfides that are of importance in ore deposits. The last part of his career was devoted to the fundamental problems of volcanic activity, particularly as related to the source of the water and gases involved in volcanic eruptions, geysers, fumaroles, solfataras, and hot springs.

In the work on silicate minerals, Allen collaborated with F. E. Wright, J. K. Clement, and W. P. White—Dr. Wright performing most of the petrographic studies that aided in the determinations of the various crystals formed during crystallization. The first study in this program was on $MgSiO_3$, but only one crystalline form was obtained in definite crystals, clinoenstatite, with a melting point of 1521°. This magnesian pyroxene is found in certain meteorites and rarely in igneous rocks. In addition, three other different types of fibrous, crystalline aggregates were obtained, but modern X-ray diffraction techniques have proved necessary to determine their identity—techniques not available to Allen and his associates at the time.

Allen next studied the calcium silicates, wollastonite and pseudo-wollastonite. He was successful in synthesizing wollastonite by preparing a glass of the composition $CaSiO_3$ and heating the glass to 800°-1000°. Both natural and artificial wollastonite, on heating to 1180°, changed without melting to the hexagonal form, pseudo-wollastonite. The reverse change could not be brought about except by the addition of other substances to reduce viscosity. Pseudo-wollastonite is rarely found in rocks but is a common constituent of some furnace slags. This study is important in petrology because it gives limiting temperatures for the formation of wollastonite, a common metamorphic rock mineral.

Allen next turned to tremolite, chemically the simplest known amphibole, consisting of calcium and magnesium metasilicate. The attempts failed to crystallize tremolite by heating glass of tremolite composition below 1000-1100°, or by rapid cooling of the melt of the proper composition. This failure suggested to Allen that tremolite must be hydrous and that water is essential for its crystallization. He then carefully analyzed five natural tremolites and found that the H_2O content ranged from 1.72 to 2.5 percent. Dehydration studies on tremolite revealed only small losses in water until a temperature of 850° was reached, and Allen suggested that the H_2O, an essential constituent in the tremolite, was dissolved in solid solution. By modern techniques we now know that (OH) is an integral part of the tremolite structure; Allen's work was the first indication that tremolite requires more than Ca, Mg, and SiO_2 for its formation.

Allen's last study on the synthesis of silicate minerals was on diopside, one of the simpler pyroxenes composed of calcium and magnesium silicate; this more complex system followed naturally after his studies on the $CaSiO_3$ and $MgSiO_3$ compounds. His experiments with these two end members demonstrated that each end member has dimorphous forms, each with a separate melting point. The inversion of $CaSiO_3$ at 1190° is to pseudo-wollastonite (in this paper Allen refers to it as β wollastonite in contrast to α wollastonite, the lower temperature form and the common mineral). The β form of $MgSiO_3$ is magnesium pyroxene (clinoenstatite), and below 1365° it is transformed to the lower temperature orthorhombic form which is distinct from enstatite, the naturally occurring mineral. The only stable form that appeared in the experiments was diopside ($CaSiO_3.MgSiO_3$), with a melting temperature of 1380°. A eutectic occurs between diopside and β wollastonite at the composition 60 percent diopside and 40 percent $CaSiO_3$, with a melting temperature of 1348°. This was one of the first experimental studies to demonstrate the complexity that may exist in a simple system of two end members.

About 1910, A. L. Day and R. B. Sosman of the Geophysical Laboratory were involved in perfecting improved high-temperature thermometry, and Allen contributed to this study by carefully analyzing a number of metals—Pb, Co, Ni, Cu, Ag, Al, Sb, Zn, and Cd—in order to determine their purity for use as fixed points. The high quality of these analyses is regarded as one of his finest contributions as a chemist.

Allen was attracted to the problem of ore deposition because of the scarcity of chemical data to help the geologist understand the complex processes of ore formation. In the early stages of this program, Allen was aided by John Johnston, J. L. Crenshaw, H. E. Merwin, and E. S. Larsen, Jr. The sulfides of iron were their first targets and Allen was able to demonstrate from his experimental work that the orthorhombic FeS_2, marcasite, forms only at low temperatures in association with free acid, and cannot exist above 450°. The isometric FeS_2, pyrite, forms in alkaline or nearly neutral solutions and is stable at low as well as high temperatures. The mineral pyrrhotite, $Fe_{1-x}S$, is of variable composition, the amount of sulfur in the mineral depending on the pressure of the sulfur vapor. Allen pointed out that the nonmagnetic FeS, troilite, is the end member of the pyrrhotite series and is not a distinct mineral species—a conclusion that is accepted today by mineralogists.

In Allen's next study on some of the metal sulfides, he emphasized that the geologic portion of the subject of mineral genesis should be left to the geologist, but that decided advantages can be derived from active consultation between the experimentalist and the field worker, a point of view that is just as valid today as when Allen made it in 1912. This second study involved the two forms of ZnS, isometric sphalerite and hexagonal wurtzite, and the comparable forms of HgS, hexagonal cinnabar and isometric metacinnabar. Experimental work on these sulfides brought out the same relations that were determined for pyrite and marcasite, namely, marcasite, wurtzite, and metacinnabar form only from acid solutions, whereas pyrite, sphalerite, and cinnabar are the common primary minerals in nature and crystallize from alkaline or nearly neutral solutions. This concept greatly advanced our understanding of the formation and stability of these important metal sulfides.

In 1913 L. C. Graton of Harvard University organized the so-called Secondary Enrichment Investigation under the joint auspices of copper companies, the Geophysical Laboratory, and Harvard University. The main emphasis was on the copper minerals. Allen, with his colleagues at the Geophysical Laboratory, Eugen Posnjak, H. E. Merwin, E. G. Zies, and R. H. Lombard, contributed the fundamental knowledge of the physical chemistry involved in the secondary enrichment.

The first paper concerned with this program was a systematic study of copper sulfides and dealt with two simple minerals, chalcocite (Cu_2S) and covellite (CuS). The dimorphic character of chalcocite was proven, the orthorhombic form being stable at low temperatures and the isometric form at higher temperatures. The inversion point of 91° was accepted, although coarsely ground chalcocite had an inversion point of 105°, which subsequent work has demonstrated to be the correct temperature. Solid solution of CuS in chalcocite was demonstrated up to 8 percent of covellite, causing darker colors and lower specific gravities of the chalcocite.

The composition of bornite (Cu_5FeS_4) was in doubt, and Allen selected five samples of unquestioned purity for chemical analysis, confirming the composition given above. The data of four of these samples are given in the Seventh Edition of Dana's *System of Mineralogy*.

Probably the most significant paper from the Geophysical

Laboratory resulting from the Secondary Enrichment Investigation was published in 1916 based on work by Allen and his two associates, E. G. Zies and H. E. Merwin. The reactions of a number of natural sulfides with copper sulfate solutions were investigated quantitatively, special attention being given to chalcocite (Cu_2S), covellite (CuS), bornite (Cu_5FeS_4), chalcopyrite ($CuFeS_2$), pyrrhotite ($Fe_{1-x}S$), pyrite (FeS_2), sphalerite (ZnS), and galena (PbS). In all of these experiments, a copper enrichment product was formed—either a sulfide or, in special cases, metallic copper and cuprite. It was demonstrated that cuprous sulfate acts more quickly than cupric sulfate in replacing the original sulfide by chalcocite, the most important copper mineral found in supergene enriched deposits. It was emphasized that the quantities of ferrous iron and cuprous copper that can exist in solution are very small as compared with the quantities of ferric iron and cupric copper, but if the ferric iron could be removed *pari passu* with the precipitation of the cuprous copper, the reduction of cupric copper by ferrous iron could proceed unhindered. Geologically, this is extremely important, because it implies that if limonite (hydrated ferric oxide) is present with supergene chalcocite, the chemical reaction took place above the water table; but if limonite is absent, the formation of supergene chalcocite took place below the water table—an implication that is substantiated by abundant field evidence.

In 1917 Allen and R. H. Lombard devised a new method for the determination of dissociation pressures at comparatively high temperatures for use in the study of sulfide minerals. The dissociation pressure curves of covellite (CuS) and pyrite (FeS_2) were determined from 1 mm to 500 mm pressure. This method supplies a convenient means for the synthesis of sulfides in cases where the dissociation of the sulfides causes difficulty. The study was the last that Allen made under the auspices of the Secondary Enrichment Investigation.

During World War I the United States was forced to develop its own supply of optical glass, and Allen with his associate, E. G. Zies, contributed greatly to the methods of analysis and made studies on the condition and role of arsenic in optical glass. Here, as in all of his research, Allen demonstrated the skill that made him one of the great analysts of his time.

Lassen Peak erupted in June of 1914, the first outbreak in this century of an active volcano within the boundaries of the United States (Alaska was still a territory). Dr. Allen and A. L. Day visited the volcano in 1915 to start a program of physical and chemical measurements of its activity, to be followed in 1922 and 1923 by extensive studies of the hot springs in the area. This marked the beginning of Dr. Allen's third major interest with the Geophysical Laboratory, volcanic phenomena, which continued throughout the remainder of his career. Allen's excellent review of volcanic-gas analyses became a standard reference. In addition, he made some preliminary tests of gases at Sulphur Banks at Kilauea Volcano and joined with E. G. Zies in a classic chemical study of the fumaroles in the Valley of Ten Thousand Smokes near Katmai. This last study showed that by 1919 the fumarolic activity was declining and that steam was the predominant constituent of all gases, the remaining gases consisting of HCl, CO_2, H_2S, N_2, HF, associated with minor amounts of O_2, CO, A, and NH_3. It was concluded that the water was largely of surface origin that was heated and vaporized by the still-hot rocks before it entered the fumaroles.

The studies of Lassen Peak and its hot springs were published in the admirable memoir by Allen and Day. The eruptions at Lassen Peak culminated in May 1915 when the crater was filled with viscous dacite; then mud flows followed, and a horizontal hot blast devastated the northeastern flank of Lassen Peak. Careful studies of the hot springs proved that the alteration of the surrounding lavas was caused by sulfuric acid. Two types of alteration were observed, one producing kaolin and some opal, and the other producing opal with alunite (K-aluminum sulfate). Kaolin provides the key as to the type of alteration, because it is decomposed by strong sulfuric acid. The sulfuric acid forms near the surface by oxidation of the H_2S contained in the rising gases. If sufficient water percolates through the rocks, the concentration of the acid will be kept low, permitting the kaolin to form. However, if the sulfuric acid forms in nearly dry ground, the acid may reach such high concentration that kaolin will be unstable.

Steam wells and associated hot springs at "The Geysers" in the northern Coast Ranges of California were studied by Allen and Day in 1924 and 1925. This was the pioneer scientific study of the hydrothermal areas that have since become important for geothermal energy. The excellent temperature-pressure data gathered by Allen and Day, plus the fact that several of the wells were allowed to "blow" for thirty years, were major reasons for renewed interest in "The Geysers" and culminated in 1960 in the construction of the first geothermal power plant in North America. At the present time, geothermal energy as a source of power is utilized in Italy, New Zealand, Iceland, the United States, Japan, the USSR, and the Congo, and is becoming of increasing world-wide interest.

In 1925 Allen and Day started a five-year study of the hot springs and geysers of Yellowstone National Park—a fitting climax to their joint attack on the hot spring problems. The result is a beautiful and monumental monograph, copiously illustrated with pertinent photographs, filled with a wealth of data, and spiced with their interpretations. This monograph is a vital reference for all students of geysers, hot springs, and fumaroles.

The highlights of the research on the hot spring problems are succinctly stated by Allen in his papers "Neglected Factors in the Development of Thermal Springs" and "Geyser Basins and Igneous Emanations." Geological factors such as topography, water supply, and character of the local rocks are of fundamental importance. Hot springs depositing travertine ($CaCO_3$) exclusively are probably always associated with limestones. Allen was one of the first geochemists to recognize that alkali chlorides form a considerable proportion of the mineral matter in hot waters of the alkaline type. He suggested that the halides were transported from a magma, but the actual means of transport were in doubt because the physical chemistry of this problem was not understood. A pioneering effort was made in Yellowstone to take physical measurements of the discharge of hot water from different areas; these were the first quantitative heat flow measurements from a large hot spring area.

The career of E. T. Allen illustrates the point that great advances can be made in complex subjects like geochemistry and geophysics by working in a favorable environment and joining in collaborative research with other specialists. There must also be insistence on carefully controlled experimentation and lucid presentation of results. Allen's writings bring out these qualities and also indicate the inherent honesty of the man.

Allen was a very modest man, and the last to boast about his "Mayflower" background. He was kindly, with a smiling face, and always helpful to the younger men around him. In the early days of the Geophysical Laboratory, the Petrology Club met regularly in Whitman Cross's home, near the Laboratory. Whitman Cross, J. P. Iddings, Henry S. Washington, Arthur L. Day, and E. T. Allen were regular members, plus younger men from the Geophysical Laboratory and the U.S. Geological Survey. One might say the "giants of petrology" were the leaders of the group, and discussions were frequently acrimonious. In these episodes, E. T. Allen would break in to make a point in his quiet, friendly manner, always bringing a more peaceful atmosphere to the meeting.

Allen never lost his interest in geochemistry, and when his old colleague and friend, George W. Morey, sent him a Christmas note in 1960 saying that he was planning to study the hot springs at Yellowstone the following summer, Dr. Morey received a three-page handwritten letter outlining in some detail the work that Allen thought should be done, concluding with the following statement: "I would love to go out there with you, but I am afraid that my doctor would take a dim view of this. Perhaps he is right; I will be 97 in April."

Dr. Allen was elected to the National Academy of Sciences in 1930. He was a member of the American Chemical Society and President of the Washington Section in 1904. He was a Fellow of The Geological Society of America and of the American Geophysical Union.

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THE WRITER of this biographical memoir has been a great admirer of E. T. Allen because much of Allen's work has dealt with topics in his own professional line of interest. It has been a matter of deep regret that he never had the opportunity to know Dr. Allen personally. Because of his high regard for Dr. Allen and warm appreciation for his help and guidance at a critical stage in his career, the writer is delighted to have had the opportunity to prepare this biographical memoir.

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KEY TO ABBREVIATIONS

Am. Chem. J. = American Chemical Journal
Am. J. Sci. = American Journal of Science
Am. Mineral. = The American Mineralogist
Carnegie Inst. Wash. Publ. = Carnegie Institution of Washington Publication
Chem. News = Chemical News and Journal of Industrial Science
Econ. Geol. = Economic Geology
J. Am. Ceram. Soc. = Journal of the American Ceramic Society
J. Am. Chem. Soc. = Journal of the American Chemical Society
J. Geol. = Journal of Geology
Z. anorg. Chem. = Zeitschrift für anorganische und allgemeine Chemie

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