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Memorial of Arnulf Muan 1923-1990

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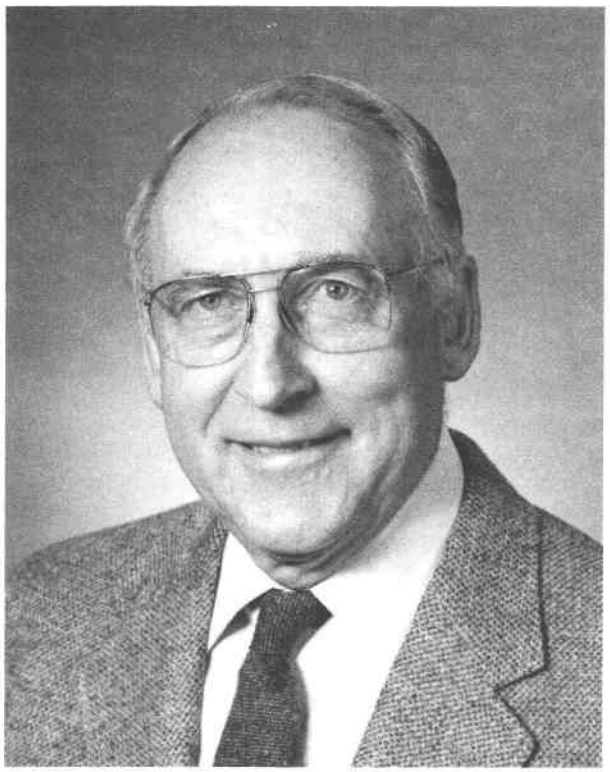
Arnulf Muan, professor of geochemistry and materials science at the Pennsylvania State University, died unexpectedly of an aortic aneurism on December 17, 1990, at the age of 67.

Arnulf Muan was born in Meldal, Norway, on April 19, 1923, the son of Anders and Ingeborg Muan. After graduating from high school in Orkdal, Norway, in 1943 he enrolled at the Technical University of Norway (NTH) in Trondheim, Norway, where he received the Diploma (master's degree) in inorganic chemistry in 1948. His thesis research, conducted under the supervision of Håkon Flood, focused on acid-base indicators in anhydrous silicate melts. After a year as an instructor at the same university, Arnulf moved to the Pennsylvania State University to pursue a Ph.D. degree under the supervision of E. F. Osborn. He received his Ph.D. in geochemistry from the Pennsylvania State University in 1955.

After graduation, Arnulf maintained a continuous association with both NTH and Penn State until his death. At Penn State he held faculty positions in geochemistry, materials science, metallurgy, and mineralogy. He was appointed assistant professor of metallurgy in 1955 and associate professor in 1957 and was promoted to professor of metallurgy in 1962. He served as professor of mineral sciences from 1966 to 1976 and as professor of geochemistry and materials science from 1976 to his death. From 1966 to 1971 Arnulf served as head of the department of geochemistry and mineralogy. Following the reorganization of that department into the department of geosciences in 1971, he became its first head and served in this capacity from 1971 to 1974. Arnulf was appointed associate dean for research in the College of Earth and Mineral Sciences from 1976 to 1985 and was acting dean of the college in 1985. During his long tenure at Penn State, Arnulf Muan was an important factor in the development of the Penn State program as one of the world's leading teaching and research institutions in experimental characterization of physical and chemical properties of rock-forming materials. Nearly all practitioners of this art at various universities either received their formal training or spent portions of their active career at Penn State.

Throughout his career, Arnulf maintained close contact with Norway and frequently visited his alma mater. Arnulf had a profound impact on the institutes of metallurgy and inorganic chemistry at NTH, and he is given credit for the formation in 1966 of a new institute of high-temperature chemistry there with Professor Flood as the director. In cooperation with Professor Flood, he developed principles of phase equilibria and phase diagrams into a required course for their graduate students. The course is still taught with the book *Phase Equilibria among Oxides in Steel Making* by Muan and Osborn as principal material. Such information, fundamental to our understanding of equilibrium relations among phases, presently is taught only at a handful of universities worldwide in the mistaken belief that principles of physics and chemistry can be superseded by advanced analytical and computation methods. A cursory reading of the literature should convince the reader of the inaccuracy of this notion, and Arnulf remained firmly convinced that no amount of computational power obviates the need to understand basic principles of thermodynamics. No graduate student in petrology at Penn State could leave that institution without having demonstrated to Arnulf a grasp of this material. Arnulf also recognized, however, that this material is not always easily accessible. Thus, he gave his time freely to publications of phase diagrams relevant to ceramics, steel making, and earth science. For this rea-



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son, he was a contributing editor for more than ten years to the series *Phase Diagrams for Ceramists* (published by the American Ceramic Society in a series currently consisting of eight volumes with nearly 10000 diagrams). More than 300 entries in this series carry his signature. Only another contributing editor may appreciate the work that goes into preparation of those entries. In 1960, the American Ceramic Society published ten large phase diagrams, *Phase Equilibrium Diagrams In Oxide Systems* with E. F. Osborn and Arnulf Muan as the authors. These diagrams represented the best possible summary of the data in these ternaries to date. His book *Phase Equilibria Among Oxides in Steelmaking* (Addison-Wesley), coauthored by E. F. Osborn, reflects his understanding of the need to employ phase equilibria quantitatively in steelmaking processes. For anybody with a need to understand the principles of phase equilibria, whether interested in steel making or rock-forming processes, this is the book to consult.

Despite his commitment to teaching and training, Arnulf always had time to pursue his many research interests. He was recognized worldwide for his studies of the response of materials to high temperatures. In a 40-year career, he built a coherent and multifaceted body of research on heterogeneous equilibria and thermodynamics and the application of these principles to geosciences, materials science, and metallurgy. He emphasized that the same principles that govern equilibria among oxides and silicates in rock-forming processes also govern those of oxide ceramics and metallurgy, and he applied the results to these fields with equal success. Under his guidance, 19 students carried out thesis work for M.S. degrees in metallurgy or mineral science, and 22 students obtained their Ph.D. degrees in metallurgy or mineralogy.

His research was particularly concerned with equilibria and kinetic aspects of reactions involving oxide, silicate, and metal phases. Special attention was directed toward the high-temperature chemistry of transition-metal ions and the role of aliovalent transition metals under reducing conditions. He focused on the laws governing their crystal-chemical behavior in oxide and silicate phases, the thermodynamics of solid solutions, and the distribution of elements among coexisting phases. A principal objective, always evident in his lectures and his writing, was to decipher crystal-chemical and thermodynamic parameters and relationships to provide a better understanding of the high-temperature behavior of minerals and other inorganic materials. In recent years he focused on the oxides of Fe, Ni, Cr, Ti, and V over a large range of f_{O_2} with application to fields ranging from steel making to layered intrusions. Following the manned lunar landings of 1969, Arnulf Muan directed the work carried out at Penn State on lunar mineralogy and petrology. He and his students carried out phase equilibrium experiments aimed at obtaining a better understanding of the intensive and extensive variables that controlled the genesis of the rocks brought back by the lunar missions. Among the many important contributions to lunar petrology that derived from these phase equilibrium studies, perhaps the most important were the earliest clues as to the unusual reducing conditions during rock-forming processes on the moon compared with the Earth. Although the interest in silicate melts, initiated as a student at the Technological University of Norway, never faded, he did not return to this field of research until recent years, when he began several studies on the solubility behavior of transition metals (Ni and Cr) in silicate melts. Arnulf recognized that a study of solution behavior of elements, be it in crystalline or amorphous materials, requires proper structural characterization of the solvent. It is no surprise, therefore, that Arnulf returned to silicate melts at this late time as our understanding of the structure of amorphous silicate materials finally was being placed on a firm footing. The result of this work exists in 129 publications, the most important titles of which are summarized in the bibliography below, and in his many manuscripts that were not yet published at his untimely death.

Arnulf Muan's work was honored by the American Ceramic Society with the Ross Coffin Purdy Award in 1958 and the John Jeppson Award in 1978. He was an elected fellow of the Mineralogical Society of America and the Geological Society of America. In 1981 he was named a Foreign Member of the Royal Norwegian Academy of Sciences. Between 1970 and 1975 he served as secretary, vice president, and president of the Mineralogical Society of America. It is notable that the majority of his many awards were in the form of lectureships. Arnulf always felt that one of his principal duties was to serve society with training and education. He held the NORAD lectureship at the Technical University of Norway in 1971 and the Fulbright-Hays senior lectureship at Moscow State University in 1973. The Japan Society for the Promotion of Science lectureship was awarded in 1976 and was spent at Tokyo Technological Institute. In 1988 he served as the Honorary Lecturer of the Norwegian Chemical Society. During the same year he received the Alexander von Humboldt Senior Scientist Award and spent a research year during 1989–1990 at the Institute of Physical Chemistry, University of Hanover, Germany. A major part of that year was devoted to writing a number of manuscripts based on work by him, his students, and various research associates over the previous ten years. By the time of his death, at least 26 such papers were in preparation.

Arnulf Muan leaves behind his wife since 1960, Hildegard, and two children, Michael and Ingrid.

Selected bibliography of Arnulf Muan

Muan, Arnulf, with Flood, H. The influence of the cation composition on anion-equilibria in molten salt mixtures. Acta Chem. Scand., 4, 359–364 (1950).

Phase equilibria in the system FeO-Fe_2O_3-SiO_2. Trans. AIME, 203, 965–976 (1955).

with Osborn, E.F., Phase equilibria at liquidus temperatures in the systems MgO-FeO-Fe_2O_3-SiO_2. J. Am. Ceram. Soc., 39, 121–140 (1956).
Muan, A. Phase equilibrium relationships at liquidus temperatures in the system FeO-Fe_2O_3-Al_2O_3-SiO_2. J. Am. Ceram. Soc., 40, 420–431 (1957).
Muan, A. Phase equilibria at high temperatures in oxide systems involving changes in oxidation states. Am. J. Sci., 256, 171–207 (1958).
Muan, A. On the stability of the phase $Fe_2O_3 \cdot Al_2O_3$. Am. J. Sci., 256, 413–422 (1958).
with Phillips, Bert. Phase equilibria in the system CaO-iron oxide-SiO_2 in air. J. Am. Ceram. Soc., 42, 413–423 (1959).
with Somiya, Shigeyuki. Phase equilibrium studies in the system iron oxide-Al_2O_3-Cr_2O_3. J. Am. Ceram. Soc., 42, 603–613 (1959).
with Hahn, W.C., Jr. Some energy relations in solid state reactions involving crystalline phases of variable compositions. J. Phys. Chem., 63, 1826–1830 (1959).
with Osborn, E.F. Phase equilibrium diagrams of oxide systems. The Am. Ceram. Soc. (1960).
with MacChesney, J.B. The system iron oxide-TiO_2-SiO_2 in air. J. Am. Ceram. Soc. 43, 586–591 (1960).
with Phillips, Bert. Stability relations of calcium ferrites: Phase equilibria in the system $2CaO \cdot Fe_2O_3$-$FeO \cdot Fe_2O_3$ above 1135°C. Trans. AIME, 218, 1112–1118 (1960).
with MacChesney, J.B. Phase equilibria at liquidus temperatures in the system iron oxide-titanium oxide at low oxygen pressures. Am. Mineral., 46, 572–582 (1961).
with Hahn, W.C., Jr. Activity measurements in oxide solid solutions: The systems NiO-MgO and NiO-MnO in the temperature interval 1100–1300°C. Int. J. Phys. Chem. Sol., 19, 338–348 (1961).
Muan, A. The miscibility gap in the system Ag-Fe-Pd at 1000°, 1100°, and 1200°C. Trans. AIME, 224, 1080–1081 (1962).
with Ranganathan, T., and MacKean, B. The system manganese oxide-alumina in air. J. Am. Ceram. Soc., 45, 279–281 (1962).
Muan, A. Silver-palladium alloys as crucible material in studies of low melting iron silicates. Bull. Am. Ceram. Soc., 42, 344–347 (1963).
with Katsura, T. Experimental study of equilibria in the system FeO-Fe_2O_3-Cr_2O_3 at 1300°C. Trans. AIME, 230, 77–84 (1964).
with Osborn, E.F. Phase equilibria among oxides in steelmaking. Addison-Wesley Publishing Company, Reading, Mass. (1965).
with Schwerdtfeger, Klaus. Activities in olivine and pyroxenoid solid solutions in the system Fe-Mn-Si-O at 1150°C. Trans. AIME, 236, 201–211 (1966).
with Rosen, Erik. Stability of $MgAl_2O_4$ at 1400°C as derived from equilibrium measurements in $CoAl_2O_4$-$MgAl_2O_4$ solid solutions. J. Am. Ceram. Soc., 49, 107–108 (1966).
Determination of thermodynamic properties of silicates from locations of conjugation lines in ternary systems. Am. Mineral., 52, 797–804 (1967).
with Nafziger, R.H. Equilibrium phase compositions and thermodynamic properties of olivines and pyroxenes in the system MgO″FeO″-SiO_2. Am. Mineral., 52, 1364–1385 (1967).
with Woermann, E., and Brezny, B. Phase equilibria in the system MgO-iron oxide-TiO_2 in air. Am. J. Sci. (Schairer Volume), 267-A, 463–479 (1969).
with Brezny, B. Activity-composition relations of solid solutions and stabilities of Mg_2TiO_4, $MgTiO_3$ and $MgTi_2O_5$ as determined from equilibria in the system MgO-CoO-TiO_2 at 1300°C. Thermochim. Acta, 2, 107–119 (1971).
with Lipin, B.R. Equilibria bearing on the behavior of titanate phases during crystallization of iron silicate melts under strongly reducing conditions. Proc. 5th Lunar Sci. Conf., Geochim. Cosmochim. Acta Suppl. 5, 1, 535–548 (1974).
Muan, A. Phase relations in chromium oxide-containing systems at elevated temperatures. Geochim. Cosmochim. Acta, 39, 781–802 (1975).
Muan, A. Mineral equilibria in an interdisciplinary perspective. Amer. Mineral., 61, 355–365 (1976).
with deVilliers, J.P.R., and Mathias, J. Phase relations in the system CaO-chromium oxide-SiO_2 in air and solid-solution relations along the Ca_2SiO_4-$Ca_3(CrO_4)_2$ join. Trans. Inst. Mining and Metal., Sect. C, 96, C55–C62 (1987).