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Presentation of the 2018 Roebling Medal of the Mineralogical Society of America to E. Bruce Watson

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Given my great personal affection for Bruce Watson and equally great admiration for his many scientific contributions, it gives me great pleasure to have been asked to introduce Bruce as the 2018 recipient of the Roebling Medal of Mineralogical Society of America (MSA). This medal is the highest honor given by the MSA to recognize scientific eminence as represented primarily by scientific publication of outstanding original research in mineralogy, broadly defined. Mineralogy, broadly defined, has allowed the award to be given to many eminent experimental petrologists including Norman Bowen in 1950. I will come back to Bowen in a bit.

The Roebling medal, first given in 1937, was named in honor of Colonel Washington A. Roebling who developed his passion for minerals while a student at the Rensselaer Polytechnic Institute in Troy, New York. Bruce Watson also has a connection with RPI, indeed a very long connection, having joined the faculty in 1977 and remained there where he now holds the highest rank of Institute Professor. Some of what I have to say involves paths, so I'll begin by mentioning the path that brought Bruce here today. It starts on a dairy farm in New Hampshire, where I expect he developed the mechanical skills that have served him so well as an experimentalist. He attended Williams College for one year and then transferred to the University of New Hampshire where he received a B.A. in 1972. He went on to graduate school at MIT receiving a Ph.D. in geochemistry in 1976, which was followed by a year as a post-doctoral Fellow at the Carnegie Institution of Washington, and finally 41 years at RPI. It was a bit like a not-all-that-random a walk followed by a long state of institutional equilibrium.

I will use the work of Norman Bowen as the reference for putting Bruce Watson's contributions into the larger picture of the major developments leading to the modern approach and methods of petrology. Bowen is quite rightly regarded as the father of experimental petrology in that he transformed petrology from a descriptive, field-based subject into one where the understanding of igneous and metamorphic rocks became increasingly based on laboratory experiments, phase equilibria, and thermodynamics. Bowen used his experiments and physicochemical principals to rewrite, both figurative and literally, the book on *The Evolution of the Igneous Rocks*. Many subsequent experimental petrologists expanded Bowen's work with new pressure, temperature, and compositions, but the conceptual framework was still very much in the Bowen tradition. Bruce Watson, much like Bowen, used exquisite and ingenious experiments to take petrology on new paths strongly influenced by geochemistry, materials science, and an emphasis on physicochemical kinetic processes. In so doing he became, in my opinion, one of the most original and significant experimental petrologists since Norman Bowen.

Bruce's work in experimental petrology has been distinctive, one might go so far as to say revolutionary, in its strong focus on accessory minerals, how these determine trace element budgets in partially molten systems, and how their geochemical role depends not only on equilibrium considerations but also on kinetic processes such as dissolution rates and diffusive adjustment times. While the equilibrium studies by Bowen define the state that a system aspires to, once a system reaches equilibrium it erases the path by which a system reached that state. Bruce not only used departures from equilibrium to add the element of time and path to the interpretation of the evolution of igneous systems, but he also provided much of experimental data that quantified key kinetic parameters such as dissolution rates and diffusion coefficients for many different minerals over a broad range of pressure, temperature, and composition space.

A good example of how Bruce Watson's work in experiment-based petrology/geochemistry has affected our understanding of major issues of Earth evolution involves the mineral zircon. His 1983 paper "Zircon saturation revisited—temperature and composition effects in a variety of crustal magma types" with over 2100 Web of Science citations was a key experimental study demonstrating the remarkable ability of zircon to survive dissolution in melts of different composition, temperature, and pressure. The trace element budget of zircon is especially important because it includes radiogenic elements that allow for it to be dated and also other elements such as titanium that can be used to constrain environmental conditions at the time the zircons crystallized. Certain zircons are remarkable in that while the oldest rocks found on Earth are about 4.0 billion years old, some zircons are 4.35 billion years old (only about 200 million years younger than the formation of the Earth itself 4.57 billion years ago). These zircons are a unique repository of quantitative information regarding condition at or near the surface of the Earth in this earliest period. Bruce used laboratory experiments to calibrate a geothermometer based on the incorporation of the element titanium from melts into zircon and used it to show that the crystallization temperature of these oldest zircons is of the order of 700 °C. This clearly implies the existence of water on and near the surface of the early Earth and that the conditions on the early Earth only 200 million years after it formed were not much different from those of today. Bruce's 2005 paper with Mark Harrison "Zircon thermometer reveals minimum melting conditions on earliest Earth" argued that conditions at the surface of the Earth 200 million years after its formation were already similar to those of today rather

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than the "infernal" conditions that were previously assumed, for lack of any actual evidence, to have prevailed in those earliest days. As Yogi Berra might have said—Bruce Watson showed that the Hadean wasn't really Hadean after all.

The terms exquisite, ingenious, and surprising come to mind when thinking about Bruce's experiments. Examples of exquisite experiments are those that he and Daniel Cherniak have used to determine diffusion coefficients for many different elements in many different minerals. A good example of ingenuity is his spinel thermometer that he developed by calibrating the growth rate of spinel as a function of temperature and pressure at places where alumina and MgO are juxtaposed in high-pressure experimental assemblies. He then used this to measure the time-integrated spatial distribution of temperature in typical piston-cylinder and multi-anvil assemblies. His clever use of integrating monitors is also seen in his experiments with Jay Thomas quantifying the rate of diffusion of magnesium along grain boundaries in a quartzite. In this case, the integrating monitors were small fayalite grains (detector particles) that had been distributed throughout the quartzite and that recorded the flux along the grain boundaries by the increased magnesium in the original fayalite grains. This very clever detector particle method that Bruce conceived and developed into a quantitative flux monitor can be modified to study grain-boundary diffusion in numerous geologic systems.

Bruce, much as Bowen had done before, has impacted many aspects of petrology with his emphasis on accessory minerals and departures from equilibrium combined with quantitative kinetics. His publications are an extraordinary record of creativity, ingenuity, surprises, and novel experiments to explore processes of fundamental importance in petrology and geochemistry. Given my long-standing and well-founded admiration for what Bruce Watson has accomplished in the realm of mineralogy broadly conceived, I am delighted to join this celebration on the occasion of his being awarded the 2018 Roebling Medal of the Mineralogical Society of America.