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Presentation of the Mineralogical Society of America Award for 2022 to Benjamin M. Tutolo

W.E. Seyfried Jr.[1,*] and Nicholas J. Tosca[2]

[1]Department of Earth and Environmental Sciences, University of Minnesota, Minneapolis, Minnesota 55455, U.S.A.
[2]Department of Earth Science, University of Cambridge, Cambridge CB2 3EQ, U.K.

Benjamin M. Tutolo, the 2022 recipient of the MSA Award, fulfills in every way the high standards in mineralogical research that this prestigious award symbolizes. As a doctoral student at the University of Minnesota, it was clear from the outset that Ben had an uncommon ability to master the more challenging aspects of thermodynamics and kinetics needed to accurately predict heat and mass transfer processes in geological systems. Thus, while still in graduate school, Ben successfully developed fully coupled reactive transport models that he used to shed light on the temporal evolution of mineral-fluid reactions in the Earth's crust, with both scientific and societal applications. The rate and impact of his publications during this early stage in his career development was nothing short of phenomenal, and the record shows this has not ceased and, if anything, accelerated. One important reason for this is the knowledge and confidence gained while a post-doctoral fellow at the University of Oxford. It was here that Ben further enhanced his skills in computational geochemistry while acquiring new awareness of the chemical evolution of sedimentary environments throughout Earth's history and that of other planetary bodies, such as Mars. Ben Tutolo is now an Associate Professor at the University of Calgary, where his research program continues to evolve and excel, especially with the support of colleagues and the participation of outstanding students and post-doctoral researchers that he has so effectively advised and mentored.

Ben's success in research can be linked to the innovative and integrated approach he uses to determine rates and mechanisms of mineral transformations in complex aqueous fluids. Supplementing available theoretical data for mineral solubility and aqueous speciation with novel analytical and experimental data, Ben has been able to better understand reactive transport processes in new and insightful ways. For example, Ben and co-workers have pioneered the use of X-ray computed tomography (XRCT) and (ultra) small-angle neutron scattering (uSANS) techniques to investigate the feedback between time series changes in fluid chemistry and mineralogy during fluid flow through intact 3D rock cores. Thus, taking full advantage of the insight afforded by the application of these novel analytical facilities, Ben was able to better constrain reactive surface area, something that has long plagued kinetic studies of mineral fluid systems. The combination of innovative analytical and experimental approaches, together with available thermodynamic data for minerals and fluids, permitted the upscaling necessary to allow fully coupled reactive transport models to achieve their full potential for predicting changes in mineral and fluid chemistry in complex geochemical systems in time and space.

* E-mail: wes@umn.edu

Ben's development of quantitatively based tools to better constrain the temporal and spatial evolution of geochemical systems is particularly well suited for the study of serpentinization, an alteration process that has long attracted Ben's attention. Serpentinization plays a fundamental role in the biogeochemical and tectonic evolution of the Earth and perhaps many other rocky planetary bodies, underscoring the need to better understand mass transfer processes intrinsic to serpentinization in modern and ancient systems. Thus, using serpentine-bearing assemblages from ancient subaerial deposits and modern seafloor vents (ultramafic-hosted Lost City hydrothermal system at 30°N on the Mid-Atlantic Ridge), Ben was able to apply reactive transport models and show that serpentinization reactions occur through a coupled process of fluid infiltration and reaction-driven fracturing. In the case of the modern Lost City vent fluids, calculations show that both brucite and Si are remarkably persistent in serpentinizing environments, leading to elevated Si concentrations in fluids that can be transported over comparatively large distances without equilibrating with brucite. These results are in excellent agreement with Lost City vent fluid composition and the constructional deposits through which the silica-bearing fluids pass prior to venting at the seafloor.

Redox reactions during serpentinization have been difficult to assess quantitatively owing to the lack of chemical data for ferric iron-bearing serpentine minerals in natural systems from which requisite thermodynamic data for such minerals could be regressed. Part of this simply results from the relatively rare occurrence of olivine with sufficient iron to stabilize Fe-rich serpentine phases, such that the coordination chemistry of the ferric component of the mineral could be satisfactorily examined. Motivated by this challenge, Ben searched for Fe-bearing ultramafic rocks at a number of localities and discovered altered ferroan peridotite with fayalitic olivine in lithologies from Minnesota and Wyoming. As expected, these rocks contained hisingerite (ferric-rich serpentine), which was confirmed by Ben and co-workers using Mössbauer spectroscopy. Using these data and available correlation algorithms for generalized thermodynamic properties, internally consistent thermodynamic data for hisingerite and other Fe (Fe^{3+}/Fe^{2+})-bearing serpentine minerals were determined. Thus, for the first time, redox-dependent phase equilibria during serpentinization could be accurately assessed at a wide range of temperature and pressure conditions and included in reactive transport and other thermodynamic and kinetically based models. This was a major accomplishment and an important advance in the study of serpentinization processes for which Ben Tutolo deserves enormous credit.

Using the revised thermodynamic database for serpentine minerals, Tutolo and co-workers were able to predict linkages be-

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tween redox species and other components during the transformation of primary olivine to serpentine phases. Calculations show a surprising inverse correlation between dissolved silica and H_2 concentrations owing to crystallographic constraints imposed by the relative stability of Fe-bearing serpentine polymorphs at a fixed temperature. These relationships take on added importance in light of secular changes in dissolved silica in seawater that are known to have existed. Accordingly, in the Precambrian, in advance of the existence of silica-secreting organisms, high dissolved silica concentrations in the ancient ocean would limit H_2 production by serpentinization, with implications for metabolic strategies for microbial life. In the absence of the thermodynamic data for ferric-serpentine minerals, these inferences would have been impossible to imagine.

Ben Tutolo's innovative and multifaceted approach to research has resulted in important breakthroughs in cause and effect understanding of some of the more challenging problems in aqueous geochemistry. This approach has led to a new understanding of the thermodynamic stability of Fe (ferric)-bearing serpentine minerals, which has provided critical data for assessing the role of serpentinization in controlling redox reactions in modern hydrothermal systems and ancient oceans and potentially in shaping the history of early life on Earth. His experimentally based research involving permeability and fluid flow and reaction in 3D rock cores has provided new knowledge of the reactive surface area at the pore scale, with implications for mineral dissolution rates and rates of diagenesis in sedimentary systems. Results of these experiments have also elucidated processes controlling the magnitude of CO_2 sequestration in sediments and sedimentary and igneous rocks, targeting new approaches of dealing with the challenges of CO_2-induced global climate change. Most importantly, Ben's contributions have enhanced the application of reactive transport models, such that ever more complex chemical and physical systems on Earth and other worlds can be assessed with higher levels of confidence than heretofore possible.

There can be no question that Ben Tutolo is a gifted young scientist. His novel and creative research efforts have had a transformative effect on mineralogy and geochemistry. He is highly deserving of the 2022 MSA Award.