

Presentation of the Mineralogical Society of America Award for 2009

GORDON E. BROWN, JR.

Department of Geological and Environmental Sciences, Stanford University, Stanford, California 94305, U.S.A.

Madam President, Officers, and Councilors of MSA, Members and Fellows of the Mineralogical Society of America and the Geological Society of America, Ladies, and Gentlemen, it is a great pleasure for me to present my former Ph.D. student, Thomas Patrick Trainor, to receive the 2009 MSA Award. Tom's work at Stanford University as a graduate student, at GSECARS (University of Chicago) as a post-doctoral fellow, and in the Department of Chemistry and Biochemistry at the University of Alaska, Fairbanks, as a young faculty member has led to a new understanding of mineral surfaces and their interactions with aqueous environments. I nominated Tom for this prestigious award because of his groundbreaking contributions to the emerging field of mineral surface geochemistry, including first-of-their-kind non-specular crystal truncation rod (CTR) diffraction studies of hydrated mineral surfaces, which provided us with the first three-dimensional structures of environmentally important mineral surfaces on which many important chemical reactions in the environment occur. The results of these studies have led to fundamental understanding of the differences in chemical reactivity of different crystallographic surfaces of the same phase as well as the same crystallographic surfaces on isomorphous phases. Such reactions have a profound influence on many important mineralogical processes including crystal growth and dissolution, incorporation of trace elements in minerals grown from aqueous solutions, and sorption reactions that can effectively sequester aqueous contaminants and pollutants on mineral surfaces.

Tom's undergraduate studies were at the Colorado School of Mines, where he majored in chemistry with a minor in environmental science and engineering. Tom also earned an A.S. degree in Aviation Science from the University of New Haven in 1992 and was instrument rated. Tom spent summers in 1992, 1993, and 1994 working for the U.S. Forest Service and five months in 1994 working for the U.S. Geological Survey during which he carried out a geochemical study of acid mine drainage associated with an abandoned gold mining district in south-central Alaska. His background prior to graduate school showed that he is a chemist who loves the natural world—a combination that suggested to me that Tom would be a perfect match for my research group, which was becoming increasingly involved in environmental mineralogy and geochemistry. Tom's Alaska experience clearly had an impact on Tom, as he later decided to accept a faculty position at the University of Alaska, Fairbanks. When I met Tom during his first interview visit to Stanford, I was struck by his maturity, his keen interest in applications of chemistry to

environmental problems, his incredible appetite for food, and his fondness of plaid shirts. It took me about a minute to decide to admit Tom to Stanford and about an hour to convince him to join my research group.

When Tom first arrived at Stanford University in September 1995, it quickly became clear to me that he had the intellectual horsepower and work ethic for a very challenging thesis project that would break new ground. In the early 1990s, several seminal papers by Mike Bedzyk and co-workers at Northwestern University showed the potential of using X-ray standing waves to determine the distribution of metal ions in the electrical double layer (EDL) at a complex interface between a dilute $ZnCl_2$ electrolyte solution and a thin, charged phospholipid membrane on a Si-W multilayer substrate as a function of solution pH. Based on this work, I suggested to Tom that he try to map out the electrical double layer at a metal oxide-electrolyte solution interface use synchrotron-based X-ray standing wave methods. The plan was to use the fluorescence yield intensity generated from aqueous Zn^{2+} ions near the interface as the antinodes of the standing wave were swept through the EDL region. Tom's first experiments at the Stanford Synchrotron Radiation Laboratory showed that we could not achieve sufficient resolution using long-period standing waves to map out the Zn^{2+} ion distribution in the EDL, so Tom was forced to modify his original thesis plan. He handled this situation with great aplomb and very quickly chose another set of experiments in which he measured the extended X-ray absorption fine structure (EXAFS) spectra of Zn(II) sorption complexes in grazing-incidence geometry to determine the structure of these surface complexes at the $\alpha\text{-Al}_2\text{O}_3(0001)$ -aqueous solution interface as a function of surface coverage. Tom's discovery that Zn-Al hydrotalcite precipitated in the Zn(II)/ $\alpha\text{-Al}_2\text{O}_3$ /water system at higher Zn surface coverages was key to unraveling the speciation of Zn in smelter-impacted soils in northern France in a collaborative study with Georges Calas' group at the University of Paris VI-VII that was subsequently published in *American Mineralogist*.

During the course of this work, we realized that the surface structure of $\alpha\text{-Al}_2\text{O}_3$ in contact with an aqueous solution was unlikely to be the same as the bulk structure, so Tom began exploring ways to determine the surface structure of hydrated $\alpha\text{-Al}_2\text{O}_3$. In collaboration with Peter Eng of GSECARS, Glenn Waychunas of LBNL, me, and others, Tom carried out the first crystal truncation rod (CTR) diffraction study of the hydrated surface of $\alpha\text{-Al}_2\text{O}_3(0001)$ at the Advanced Photon Source, which was published in *Science* in 2000. This seminal study

showed that the surface structure of hydrated $\alpha\text{-Al}_2\text{O}_3(0001)$ was significantly different from a simple termination of the bulk crystal structure and from the UHV clean surface. This study was quickly followed by a second CTR study of the $\alpha\text{-Al}_2\text{O}_3(1\text{-}102)$ surface, which showed that it reconstructed on exposure to aqueous solutions and was quite different from the structure of the hydrated $\alpha\text{-Al}_2\text{O}_3(0001)$ surface. Both of these studies were pioneering because they provided the first definitive information on the three-dimensional structure of metal oxide surfaces in contact with water.

As Tom was completing his unsuccessful XSW measurements on the EDL described earlier, another one of my graduate students (Alexis Templeton, now an Assistant Professor of Geological Sciences at the University of Colorado, Boulder) was beginning studies of the effects of microbial biofilms on metal oxide surfaces on sorption reactions of heavy metals such as Pb^{2+} and metalloids such as Se. It became clear to us that the same XSW methods used in grazing-incidence geometry could provide unique information about the position of these species at the metal oxide-biofilm interface with sufficient resolution to determine if these ions were dominantly at the interface or in the biofilm. These unique measurements were carried out by Tom and Alexis and showed that the presence of a monolayer biofilm of *Burkholderia cepacia* had essentially no effect on the intrinsic reactivity of the metal oxide surface. These first-of-their-kind results were published in *PNAS* in 2001 and quickly drew the attention of microbiologists, environmental mineralogists, low-temperature geochemists, and surface chemists because of the novelty of the approach and the insights this study provided on the impact of biofilm coatings on mineral surface reactivity. Tom's expertise in XSW measurements and the computer code he wrote for analyzing the XSW fluorescence yield data were essential to the success of this project. The impact of this work and several related studies in which Tom played a key role is illustrated by several major awards to Alexis Templeton including the inaugural Rosalind Franklin Young Investigator Award from Argonne National Laboratory in 2004 and the 2006 Clark Medal of the Geochemical Society. In a related study, Tom was able to use similar methods to study the distribution of Pb^{2+} and selenate ions at the $\alpha\text{-Al}_2\text{O}_3(0001)$ -water interface, which provided the first direct information on competitive adsorption effects of an aqueous cation and anion at a mineral surface.

After moving from Stanford to GSECARS at the Advanced Photon Source, Argonne National Laboratory, Tom continued his pioneering synchrotron radiation-based studies of mineral surfaces and mineral surface reactivity. His most important contribution made during this period was a seminal study of the

structure and reactivity of the hydrated hematite (0001) surface. This work was the first to combine a CTR diffraction study of a metal oxide-water interface with a density functional theoretical study of the most energetically favorable surface termination. Anne Chaka of the National Institute for Standards and Technology carried out the DFT ab initio thermodynamic calculations in this study. The agreement between experiment and theory was astounding. This pioneering study helps explain the much greater reactivity of the hydrated $\alpha\text{-Fe}_2\text{O}_3(0001)$ surface than the hydrated $\alpha\text{-Al}_2\text{O}_3(0001)$ surface in terms of significant differences in surface structure. This study was one of many that Tom carried out while at GSECARS. His research at Stanford and GSECARS resulted in about 30 publications in peer-reviewed journals, which is a remarkable level of productivity during the Ph.D. and post-doc periods.

Tom moved from GSECARS to the Department of Chemistry and Biochemistry at the University of Alaska, Fairbanks as an Assistant Professor in August 2003 and began building his lab and research group. He continued his CTR diffraction studies of hydrated metal oxide surfaces and began environmental mineralogy and geochemistry studies of various heavy metal contaminated mining sites in Alaska with his graduate students and post-docs as well as undergraduates. It was no surprise to me and others who know Tom well that he was promoted to tenured Associate Professor of chemistry after only 4 years.

During the past six years, Tom has been a key member of the NSF-funded Stanford Environmental Molecular Science Institute. In addition, Tom headed up an NSF-funded research team including me, Anne Chaka, and Peter Eng that focused on the structure and reactivity of iron oxide nanoparticles. These collaborative research experiences with Tom have been very productive, have broken new ground on mineral surface structure and reactivity, and have clearly demonstrated to me and all involved that Tom is a natural scientific leader who has astounding experimental talents. I have learned a great deal from Tom and have greatly enjoyed working with him for the past 15 years.

In summary, the body of Tom Trainor's work on mineral surface structure and reactivity provides much of the basis for our current understanding of some of the most important mineral surfaces in the biosphere, where chemical and biological reactions at environmental interfaces impact the biogeochemical cycling of elements as well as many other geochemical and mineralogical processes.

The MSA Award is very fitting recognition of this innovative young scientist's research accomplishments to date. President Ross and fellow mineralogists, I am extremely proud to present Tom Trainor for the 2009 MSA Award.