Marriage of X-ray Spectroscopy and Microscopy for Trace Element Analysis in Environmental and Biological Systems

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Bulk x-ray spectroscopy is a powerful tool for understanding oxidation state, speciation and coordination environment of elements under probe. X-ray microscopy, on the other hand, provides unparalleled information regarding the distribution and localization of the key species driving the reaction dynamics. Integration of the two results in what is often called \textit{x-ray spectromicroscopy}, which embodies the strengths of both x-ray spectroscopy and microscopy techniques.

Taking advantage of some of the recent developments in synchrotron x-ray science, our research combines x-ray microscopy (\(\mu\)-XRF, imaging, and STXM) and x-ray spectroscopy (NEXAFS, XANES, and EXAFS) techniques to understand the mechanisms of coupled (biological and inorganic) reaction pathways in order to integrate molecular constraints with modeling efforts. Lack of molecular-level insight hinders the development of accurate reaction networks in models, which in turn limits the predictive ability of the global elemental cycles.

There is an increasing evidence that reactions occurring at the surfaces and interfaces of biological and inorganic colloids are central to many, perhaps most, processes of environmental and biological importance – understandably so because the microenvironment at and adjacent to cell surfaces and clay/mineral particulates can be significantly different from the bulk environment. We have elucidated the role of cell surfaces, diatoms, and inorganic nano-particulates in a range of natural processes, from the fate and transport of contaminant metals to nitrogen and phosphorous cycle in terrestrial and aquatic ecosystems. In another investigation, we have shown synergistic uptake and co-localization of metals by edible plants. Our studies of metal speciation and homeostasis in edible plants have demonstrated the onset of defense mechanisms similar to those exhibited by microbes.

Examples presented in this talk would demonstrate that an in-depth understanding of molecular-scale processes affecting elemental speciation is a critical research need for modeling the global cycling of elements in order to advance fundamental understanding of coupled reaction processes in complex natural environments and enable system-level environmental prediction and decision support.