Investigation of the Spatial Distributions and Concentrations of Biologically and Environmentally Relevant Elements at the Mineral–Microbe Interface

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Understanding the fate of heavy-metal contaminants in the environment is of fundamental importance in the development and evaluation of effective remediation and sequestration strategies. Bacteria and the extracellular material associated with them are thought to play a key role in determining a contaminant's speciation and thus its mobility in the environment. Additionally, the metabolism and surface properties of bacteria can be quite different depending upon whether the bacteria exhibit a planktonic (free-floating) or biofilm (surface-adhered) habit. The microenvironment at and adjacent to actively metabolizing cells also can be significantly different from the bulk environment. Thus, to understand the microscopic physical, geological, chemical, and biological interfaces that determine a contaminant's macroscopic fate, the spatial distribution and chemical speciation of contaminants and elements that are key to biological processes must be characterized at micron and submicron length scales for bacteria in both planktonic and adhered states. Hard x-ray microimaging is a powerful technique for the element-specific investigation of complex environmental samples at the needed micron and submicron resolution. An important advantage of these techniques results from the large penetration depth of hard x-rays in water. This advantage minimizes the requirements for sample preparation and allows the detailed study of hydrated samples. The objectives of the studies presented here are (1) to determine the spatial distribution, concentration, and chemical speciation of metals at, in, and near bacteria and bacteria-geosurface interfaces; (2) to use this information to identify the metabolic processes occurring within the microbes; and (3) to identify the interactions occurring near these interfaces among the metals, mineral surfaces, and bacterially produced extracellular materials under a variety of conditions.

We have used x-ray fluorescence microscopy to investigate the spatial distribution of 3*d* elements in single *Shewanella oneidensis* cells grown with oxygen and fumarate as electron acceptors. Measurements were made on subsamples of cells taken at varying times during a five-day growth period. Cells analyzed were either in a surface-adhered or planktonic state. The zone plate used in these microscopy experiments produced a focused beam with a cross section (and hence spatial resolution) of 0.15–0.30 μm. The samples (both planktonic and biofilm) were all grown in a consistent manner in a defined minimal salts medium.

Results from x-ray fluorescence imaging experiments indicate that the distribution of P, S, Cl, Ca, Fe, Ni, Cu, and Zn can define the location of the microbe. Additionally, quantitative elemental analysis of individual microbes identified significant changes in concentration of 3*d* transition elements depending on the age of the culture and the type of electron acceptor presented to the microbes. These results and a discussion of the use of this technique for identifying metabolic states of individual microbes within communities will be presented.