MICROBES IN THE ENVIRONMENT

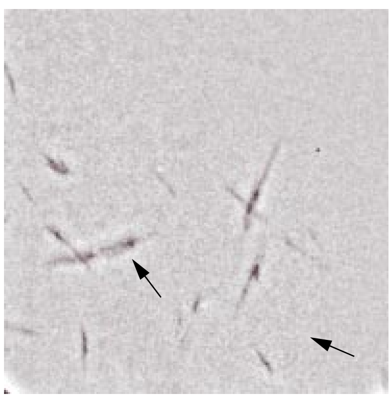
Examining Bioremediation of Contaminants

Cleaning up the environment is a monumental task, now consuming many billions of dollars annually. Based on the belief that effective waste-remediation treatments will come by scrutinizing, at a molecular level, the various chemical compounds that enter the environment as the result of human activity, the new field of molecular environmental science (MES) is emerging. Practitioners of MES investigate the route contaminants take to their final destinations in the environment, including formation of new compounds due to interaction with their surroundings, transport through soils and groundwater, uptake in plant and animal life, and possible immobilization in benign forms. It turns out that bacteria are potentially key players with the ability to purify contaminated soils and water supplies (bioremediation).

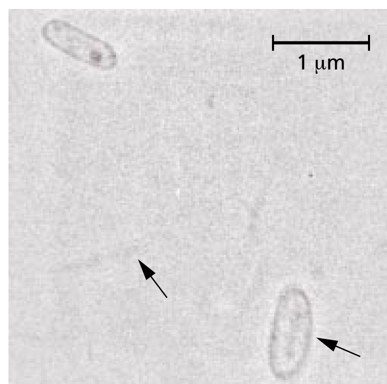
Where the Action Is

The complex chemistry taking place in the environment is dominated by reactions in the presence of water. Among other functions, water serves as a medium to transport metal atoms to and from microbes and chemical compounds in the soil. It is known that bacteria can oxidize (remove electrons from) or reduce (add electrons to) metal atoms, such as iron and manganese. Oxidation of iron or manganese that is dissolved in water creates insoluble oxide compounds, such as goethite or manganite (FeOOH or MnOOH), resulting in solid mineral deposits (biomineralization). Conversely, reduction of the metals already in mineral particles causes them to dissolve in the surrounding water.

There are at least two ways biomineralization could help in environmental cleanup. If bacteria



646 eV



517 eV

Depending on their species, bacteria can either oxidize metals dissolved in water, thereby causing the formation of metal-oxide particles, or reduce the metal in solid particles, thereby causing it to dissolve. These x-ray microscope images were taken in the same area of a sample, (left) at x-ray wavelengths (photon energies) absorbed by the manganese atoms in needle-shaped particles of manganite (MnOOH), and (right) at wavelengths absorbed by the carbon atoms in microbes. The two arrows in each image indicate the locations of a manganite needle and a bacterium.

could directly mineralize contaminants such as plutonium, uranium, and chromium, this bacterial digestion would immobilize them as insoluble sediment. Alternatively, biomineralized deposits of other metals, manganese for example, could attract contaminants, which would then form insoluble compounds on the surfaces of the mineral deposits. Learning which, if either, of these mechanisms is a potential route to bioremediation involves analyzing the chemical reactions, their products, and where they occur relative to the bacteria and the particle surfaces.

GETTING THE PICTURE

X-ray absorption spectra offer researchers much of the information they want because the wavelengths at which a metal atom in a molecule absorbs x rays identify its oxidation state. Owing to the small size of both bacteria and mineral particles, spatial resolution is also necessary to map the distribution of metals and their oxidation states and to probe their local properties rather than averaging over wide areas. At the ALS, the combination of spectroscopy with imaging in an x-ray microscope (spectromicroscopy) fills the bill. However, the watery nature of environmental systems creates a challenge, since water also absorbs many x rays. To work with wet samples, therefore, researchers have had to develop specially designed sample holders that minimize the distance the x rays must travel through water.

The first step in the investigation—now accomplished—is demonstrating the ability to image bacteria and mineral particles in the same wet-sample cell with high resolution. For example, manganese minerals occur as needle-shaped crystals about 1 μm long and 0.1 μm wide. Bacteria that metabolize manganese have a similar length but are a little more rotund. Since the manganese and carbon atoms in the bacteria absorb x rays at different wavelengths, the mineral particles and microbes are easily distinguished by making separate images at the appropriate wavelengths. Because water influences the wavelengths and shapes of x-ray absorption peaks, future absorption measurements to identify chemical species will require detailed examination of model compounds in wet cells to establish characteristic spectral signatures.

Research conducted by B.P. Tonner (principal investigator) and K. Nealson (University of Wisconsin–Milwaukee), and W. Meyer-Ilse and J. Brown (Berkeley Lab's Center for X-Ray Optics), using the x-ray microscope (XM-1) at Beamline 6.1.2.
Funding: Office of Biological and Environmental Research of the U.S. Department of Energy, Laboratory for Surface Studies and Center for Great Lakes Studies (University of Wisconsin–Milwaukee), and Office of Basic Energy Sciences of the U.S. Department of Energy.