ENVIRONMENTAL MICROBE-METAL INTERACTIONS
Environmental Microbe-Metal Interactions

EDITED BY

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ASM PRESS WASHINGTON, D.C.
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The importance of metals in the life of microorganisms is well known. Iron and other metals are key components in many proteins that are necessary for microbial respiration and metabolism. Less appreciated is the major impact that microorganisms can have on the fate of metals in the environment. Environmental science textbooks typically discuss the geochemical cycles of metals in terms of equilibrium thermodynamics and Eh-pH diagrams. However, research on microbe-metal interactions, much of it conducted within the last decade, has demonstrated that new models that take into account nonequilibrium biochemical processes are required in order to truly understand metal geochemistry. The purpose of this volume is to give an overview of the current understanding of environmental microbe-metal interactions and to provide the basis for improved models of metal cycling.

This book deals first with biogeochemical cycling of iron and manganese. These are the two most abundant redox-active metals in the Earth’s crust. As outlined in chapter 1, the origin of life may have been intimately connected to the ability of iron to readily cycle between the ferric [Fe(III)] and ferrous [Fe(II)] states. Some of the earliest geochemical signals of life on Earth are the conversion of the Fe(II) dissolved in the archaean seas to massive Fe(III) oxide deposits, possibly as the result of activity of Fe(II)-oxidizing phototrophs (chapter 2), and the conversion of this Fe(III) oxide to magnetite by Fe(III)-reducing microorganisms (chapter 1). In modern environments, microbial oxidation of organic matter to carbon dioxide, coupled to the reduction of Fe(III) or Mn(IV), is an important process for the degradation of both naturally occurring and contaminant organic compounds in a variety of sedimentary environments and the subsurface (chapter 1). Microbial oxidation of the Fe(II) produced from Fe(III) reduction provides a “ferrous wheel” to complete the iron cycle (chapter 2). Microbiologically catalyzed Fe(III) reduction and Fe(II) oxidation are also important processes in acidic environments, such as those that result from mine drainage. Recent studies have begun to elucidate which microorganisms might catalyze these reactions at low pH and the biochemical mechanisms for these reactions (chapter 3).

Iron is also an important nutrient for environmentally relevant microbes. Nowhere is this more apparent than in the dramatic effect that iron and other trace metals can have on primary productivity in the ocean (chapter 4). The study of this phenomenon is essential to understanding global carbon cycling and nutrient dynamics in marine systems.

An amazing impact of microorganisms on the iron cycle is the ability of magnetotactic bacteria to concentrate iron from the environment into intracellular chains of single-domain magnetite crystals (chapter 5). Magnetite from magnetotactic bacteria provides one of the best-characterized geological signatures of microbial activity on Earth and possibly other planets.
One of the most-studied forms of microbe-metal interactions is microbial acquisition of iron through the use of siderophores. Nearly all of the research on microbial siderophores has focused on iron uptake by microorganisms of medical interest. However, as described in chapter 6, siderophores may also have an impact on iron cycling and microbial metabolism in aerobic soils. Studies in this area are in their infancy, but it seems likely that this form of metal solubilization plays an important role in metal cycling.

Microbially influenced corrosion of metallic iron is of considerable economic concern and has been studied intensively for many years. Chapter 7 reviews the diverse concepts that have been developed in this area and presents a new model for the mechanisms by which microorganisms enhance iron corrosion.

A major factor driving recent increased interest in environmental microbe-metal interactions is the need to remediate extensive metal contamination of water and soils. Microorganisms are not alchemists and cannot change a toxic metal to a less-toxic element. However, microbially catalyzed precipitation or volatilization of metals can remove them from polluted environments. The most-studied form of microbial metal reduction is reduction of soluble Hg(II) to volatile Hg(0) (chapter 8). Hg(II) reduction is not linked to respiration but rather is a detoxification strategy which removes mercury from the cell and may also promote mercury volatilization from contaminated environments. The detailed information that is available on Hg(II) reduction serves as an excellent model for the study of microbial reduction of other metals.

Reductive precipitation of metal and metalloid contaminants from waters and waste streams also shows promise for environmental restoration. For example, microbes can use oxidized forms of the metalloids selenium and arsenic as terminal electron acceptors to support anaerobic growth (chapter 9). Reduction of soluble selenium in insoluble elemental selenium naturally removes this toxic metalloid from agricultural drainage waters and can be stimulated in order to promote selenium removal (chapter 9). The metalloid arsenic can also be microbially reduced, which, depending upon environmental conditions, can lead to solubilization or precipitation of arsenic (chapter 9). Microbial reduction of soluble, toxic Cr(VI) to less soluble, less toxic Cr(III) provides a potential mechanism for remediation of chromium-contaminated waters and soils (chapter 10). Microorganisms can even conserve energy to support growth from the reduction of uranium and other radioactive metals and in the process immobilize these metals in the environment (chapter 13).

Although most investigations of microbe-metal interactions have focused on prokaryotes, fungi have similar abilities to affect the fate of metals (chapter 11). Considering the vast biomass of fungi in many soils, fungus-metal interactions are certain to be a major area of future study on the biogeochemistry of metals.

A major environmental fate of toxic metals may be adsorption to microbial biomass. As outlined in chapters 12 and 14, there are numerous mechanisms by which metals can bind to cell surfaces. Microorganisms can also promote cell-associated precipitation of toxic metals by the release of phosphate, which can form insoluble metal phosphates (chapter 13). These various adsorption processes can lead to mineral formation in the environment (chapter 12), and they have
practical application for the removal of metals from contaminated waters and waste streams (chapters 13 and 14).

One of the most important factors promoting the solubility of contaminant metals, and hence their mobility in subsurface environments, is complexation of the metals to synthetic chelators (chapter 15). The discovery that microbes can degrade the organic portion of metal chelates, thus diminishing the mobility of the metals, has been a major advancement in the field of microbe-metal interactions.

A take-home message of many of the chapters in this book is the need for better understanding of many facets of environmental microbe-metal interactions. The level of inquiry into microbe-metal interactions has been modest in comparison with the intensive study of microbial carbon metabolism and microbial interactions with major, nonmetallic inorganic species such as oxygen, nitrogen, phosphorous, sulfur, and hydrogen. Hopefully, this book makes clear the significance of environmental microbe-metal interactions and provides some clues for fruitful areas of further investigation.

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