Microbial Metal and Metalloid Metabolism

ADVANCES AND APPLICATIONS

Edited by
John F. Stolz and
Ronald S. Oremland
DEDICATION

This volume begins with a tribute to Dr. Terry Beveridge as we felt it very appropriate to dedicate this volume to him (Chapter 1). Terry, who passed away in 2007, was a major contributor to the field of microbe/metal interactions and one who touched many of our lives, either directly or through his seminal work on microbe/mineral interactions.
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The impact of microbial activity in shaping the composition of the soil, water, and atmosphere of the Earth over the millennia is now well recognized. Moreover, in a remarkable feat of biological evolution, over a third of the elements in the periodic table have found some use in the chemistry of life. Of the 114 elements typically listed in the table, fewer than half are inert or have no known biological function (Wackett et al., 2004). Over 60 elements (in elemental form or as compounds) are involved in some form of microbial structure or activity (Color Plate 1). Those who grow organisms in culture recognize the major (i.e., carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur), minor (calcium, potassium, magnesium, sodium, and chlorine), and trace (cobalt, copper, iron, manganese, molybdenum, nickel, selenium, tungsten, vanadium, and zinc) elements as typical constituents of a defined medium. But there are other elements that are necessary for cellular processes, such as quorum sensing (e.g., boron), and in the active sites of metalloenzymes. Even toxic metals and metalloids can be involved in energy generation and carbon fixation. For example, tellurate can serve as an electron acceptor in anaerobic respiration (Chapter 16) and arsenite can serve as an electron donor in photoautotrophy (Chapter 11). The latter speaks directly to the fact that photosynthesis can be distilled down to the microbe having sufficient quanta of light of the appropriate wavelength for which its photosystem has been tuned (e.g., light harvesting and reaction center pigments), a source of electrons [e.g., H₂O, H₂S, Fe(II), or As(III)], and carbon.

The recent discovery that arsenate may replace some of the cellular phosphate to allow for growth under phosphate-limited conditions suggests that crafty organisms may substitute for other essential elements (Wolfe-Simon et al., 2010), such as selenium substituting for sulfur. For those elements that do not have a direct biological function (e.g., uranium), their chemical form, toxicity, and mobility can nonetheless be influenced by microbes because they may be bound to the cell, transported out of the cell, oxidized, reduced, or...
methylated (Chapters 7 and 8). Iron continues to provide surprises with anaerobic iron oxidation (Chapter 9) and iron reduction by gram-positive bacteria (Chapter 10). Microbe-metal interactions are regulated by mineralogical (Chapter 6) and genetic (Chapter 12) controls. The net results of these activities and interactions are robust biogeochemical cycles.

A more practical ramification of microbe-mineral interactions is the realization that one cannot assume that an element will remain in a given chemical form or oxidation state once it has been released into the environment and exposed to microbial activity. Despite this revelation, we continue to introduce new chemicals and compounds into the environment with only rudimentary toxicology studies. Case in point, the organoarsenical roxarsone (3-nitro-4-hydroxy-benzene arsonic acid) has been used extensively in the production of broiler chickens in the United States as a prophylactic against coccidiosis and as a growth stimulant (Chapter 15). The compound passes through the chicken unmetabolized and into the litter. The litter is then applied to fields as fertilizer, whereupon soil microbes and those associated with the chicken frass degrade the roxarsone, releasing inorganic arsenic. Given that a sizeable percentage of the 9 billion chickens raised each year are given the feed additive and each chicken releases about 150 mg of roxarsone in its lifetime, poultry farming can be a significant non-point source of arsenic.

Many major discoveries and innovations have been made since the publication of the first volume of *Environmental Microbe-Mineral Interactions* ten years ago (Lovley, 2000). Recent advances in microbial ecology have been the result of employing both reductionist and holistic methodologies in an integrated approach, “from genes to geocycles” (Chapter 2). No longer dependent on culture, the geomicrobiologist has been free to investigate extreme environments where the microbial transformation of metals and metalloids is essential for survival, such as hydrothermal systems (Chapter 3), seafloor basalts (Chapter 4), and the subsurface (Chapter 5). Advances in technology such as pyrosequencing, microarrays, and mass spectrometry have resulted in a proliferation of the “−omics”: genomics, metagenomics, transcriptomics, proteomics, metabolomics, and metallomics. The number of annotated microbial genomes is now over 1200 with more than four times as many in production. The latter has facilitated advanced proteomic, genomic, and metagenomic studies of microbe-metal interactions in pure culture and natural environments using transcriptomics (Chapter 12), proteomics (Chapter 13), and geochip (Chapter 14) as well as functional biochemical and molecular probes (Chapter 15). The discovery of pili that function as “nanowires” and the development of microbial fuel cells (Chapter 17) are particularly noteworthy, because they have resulted in a fundamental advancement in our understanding of microbial energy generation. Metal-reducing bacteria, such as *Geobacter sulfurreducens*, immobilized on an electrode can literally generate free electrons and be used to power small electronics.

The purpose of this volume is to provide an overview of the current state of the field as well as some prognostication for future directions. It covers a wide range of topics and approaches with contributions by both established leaders in the field and by up-and-coming new investigators. There are both general introductory chapters and more focused contributions; thus, this volume
should be appropriate for advanced students, researchers, and professionals. We see its primary use as a reference, but it could be adopted for a graduate-level course (e.g., Applied and Environmental Microbiology, Biotechnology and Bioremediation). While we regret that we may be missing a few things, it does leave the door open for the next edition.

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COLOR PLATE 1 (PREFACE) Periodic table of the elements highlighting the currently known major, minor, trace, and biologically active elements. Updated from Wackett et al. (2004).
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