Experimental observations of the effects of bacteria on aluminosilicate weathering

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ABSTRACT

Mineral dissolution experiments using batch cultures of soil and groundwater bacteria were monitored with solution chemistry and various microscopic techniques to determine the effects of these organisms on weathering reactions. Several strains of bacteria produced organic and inorganic acids and extracellular polymers in culture, increasing the release of cations from biotite (Si, Fe, Al) and plagioclase feldspar (Si, Al) by up to two orders of magnitude compared to abiotic controls. Microbial colonies on mineral grains were examined by cryo-scanning electron microscopy (cryo-SEM), confocal scanning laser microscopy (CSLM), and epifluorescence microscopy. Bacteria colonized all mineral surfaces, often preferentially along cleavage steps and edges of mineral grains. Low-voltage high-resolution cryo-SEM of high-pressure cryofixed and partially freeze-dried colonized minerals showed many bacteria attached by extracellular polymers of unknown composition. These biofilms covered much larger areas of the mineral surfaces than bacterial cells alone. Mineral surfaces where bacteria and extracellular polymers occurred appeared more extensively etched than surrounding uncolonized surfaces. CSLM was used to observe microbial colonization of biotite and to measure pH in microenvironments surrounding living microcolonies using a ratiometric pH-sensitive fluorescent dye set. A strain of bacteria (B0693 from the U.S. Department of Energy Subsurface Microbial Culture Collection) formed large attached microcolonies, both on the outer (001) surface and within interlayer spaces as narrow as 1 \( \mu \)m. Solution pH decreased from near neutral at the mineral surface to 3–4 around microcolonies living within confined spaces of interior colonized cleavage planes. However, no evidence of pH microgradients surrounding exterior microcolonies was noted.

INTRODUCTION

Mineral weathering is arguably one of the most important geochemical phenomena occurring at and near the Earth’s surface. This process results in the formation of soils and maintenance of soil productivity; the evolution of ground, surface, and sea water composition; the denudation of continents; and regulation of atmospheric composition and global climate. Weathering is inextricably bound to biological processes, for organisms inhabit a wide range of niches in surface and subsurface environments and influence various mineral transformation reactions (Banfield and Nealson 1997; Huang and Schnitzer 1986).

Field observations and laboratory experiments demonstrate that microbes can accelerate aluminosilicate mineral weathering reactions, especially when in direct contact with mineral surfaces (see Barker et al. 1997 for a review), by producing organic and inorganic acids, producing metal-complexing ligands, changing redox conditions, or mediating formation of secondary mineral phases.

The physical size of pores exerts a primary control over distribution of microorganisms within rocks, soils, and sediments. Recent studies of the intact organic mineral interface of weathering silicates (Barker and Banfield 1998) in lithobiontic microbial communities have demonstrated a zonation defined by access of microorganisms to mineral surfaces. In the case of outcrop surfaces colonized by lichens, Barker and Banfield (1996, 1998) demonstrated that mineral weathering is accelerated beneath lichen thalli along fluid conduits such as cleavages and grain boundaries of insufficient size to permit microbial colonization (the indirect biochemilithic zone), presumably by soluble organic acids. Mineral reactions and textures approximate those seen in strictly physiochemical weathering, differing primarily in the extent to which they are developed. Where sufficient space exists to allow microbial access (the direct biochemilithic zone), all mineral surfaces, both primary and secondary phases, are coated in thick layers of microbial exopolymers, primarily acidic mucopolysaccharides. Assemblages of secondary miner-