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Experimental Interactions Between Clay Minerals and Bacteria: A Review

Barbara MUELLER[1,2,*]

[1] *Clay Mineralogy Group, Institute for Geotechnical Engineering, ETH Zurich, Zurich 8093 (Switzerland)*
[2] *Plant Pathology, Institute of Integrative Biology, ETH Zurich, Zurich 8092 (Switzerland)*

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ABSTRACT

Interactions between microbes and minerals have the potential to contribute significantly to global cycles of various processes and serve as a link between the geosphere and life. Clays and clay minerals occur commonly in agriculturally utilized soils, are naturally grown underground (soil and rock) and are used in construction material. Clay minerals serve as natural, geological and technical barriers in geotechnics and environmental geotechnics. Bacteria in turn are ubiquitous in natural soils, subsoils and rocks and are in permanent contact with clay minerals. There are numerous ways in which bacteria can interact with clay minerals and alter them: dissolution, refinement and transformation, reduction of trace elements incorporated in the clay minerals and uptake of trace elements from these minerals, *e.g.*, by the production of siderophores and chelators and enhancement or reduction of adsorbance of trace elements on clay minerals. In addition, bacteria can influence layer charge, cation exchange capacity (CEC), exchangeable cations, Brunauer-Emmett-Teller surface, swelling and the rheological properties of clay minerals. The field of clay mineral-microorganism interaction is still wide open because of the large potential that the interactions of bacteria with clay minerals in soils and sediments may result in changes in clay mineral properties and behaviors. Further detailed studies on all these tentative changes and underlying mechanisms as well as broad surveys of quantifications of extents and rates of clay mineral-microorganism interactions, especially in mimicking natural systems, are highly required. This review summarizes the influences of various bacteria on the properties of different clay minerals as determined experimentally using viable bacteria.

Key Words: bacterium, dissolution, microbes, reduction, trace elements

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INTRODUCTION

Clay minerals, *i.e.*, layered aluminum silicates, are the most abundant minerals of sedimentation basins (both marine and continental), weathering crusts and soils. In soils and near subsurface environments, microorganisms play a fundamental role in the dissolution of geomaterials, thereby contributing to element cycling, distribution of contaminants, soil fertility and water quality (*e.g.*, Neher and Rohrer, 1959; Zeyer, 1993; Kretzschmar and Voegelin, 2001). Microbial-mediated weathering of minerals has been documented for a wide variety of rocks and mineral phases characterized by different surface properties and solubilities, including phyllosilicates. Moreover, bacteria are well known to accelerate mineral transformation (*e.g.*, Stucki *et al.*, 1992; Vandevivere *et al.*, 1994; Kostka *et al.*, 1996, 1999a, b; Lee and Fein, 2000).

In recent years, increased attention has been focused on various aspects regarding the role of microorganisms in altering clay minerals, *e.g.*, reduction of structural iron(II) (Fe(III)), aggregation, flocculation, dissolution, specific surface area, basal spacing, cation fixation, layer charge, cation exchange capacity (CEC), swelling in water, changes in clay structures and stability (*e.g.*, Maurice *et al.*, 2001a, b). The purpose of this review is, therefore, to summarize some of the recent findings related to the effects of bacteria on clay properties and behaviors in general. Only experimental work conducted with viable bacteria is considered in

*Corresponding author. E-mail: barbara.mueller@mus.ch.

this review.

MICROORGANISMS AND CLAY MINERALS USED IN STUDIES ON INTERACTIONS BETWEEN THEM

A wide variety of microorganisms and clay minerals have been used for all the studies mentioned in Table I. By far, the most common clay minerals (Table I) employed in the studies are minerals from the smectite group (tetrahedral-octahedral-tetrahedral (TOT) layers, 2:1 clay minerals): montmorillonite (dioctahedral, chemical formula $M^{+}_{0.4}(Al_{1.5}Fe^{3+}_{0.1}Mg_{0.4})_{2.0}[Si_{2.0}$-$O_{10}$-$(OH)_2]$, where M stands for monovalent cations like Na and K); nontronite (dioctahedral, chemical formula $M^{+}_{0.4}(Fe^{3+}_{1.6}Al_{0.2}Mg_{0.3})_{2.1}[Al_{0.4}Si_{3.6}O_{10}(OH)_2]$); lithium-based hectorite (trioctahedral, chemical formula $(Ca,Na)_{0.33}(Mg_{2.66}Li_{0.33})[Si_4O_{10}(F,OH)_2]$) (Jasmund and Lagaly, 1993).

In more recent works, the following clay minerals were included: illite (TOT layers, dioctahedral, general chemical formula $K_{0.65}Al_{2.0}[Al_{0.65}Si_{3.35}O_{10}(OH)_2]$; chlorite (TOT layers, trioctahedral, general chemical formula $(Mg,Al)_6[Al_{0.8}Si_{3.2}O_{10}(OH)_8]$); mixed-layer illite-smectite, palygorskite (TOT layers, mixed dioctahedral-trioctahedral, general chemical formula $(Mg,Al)_2[Si_4O_{10}(OH)]\cdot 4H_2O$); vermiculite (TOT layers, trioctahedral, general chemical formula $M^{+}_{0.71}$-$(Mg_{2.4}\,Fe^{2+}_{0.09}\,Fe^{3+}_{0.34}\,Al_{0.14})_{2.97}\,[Al_{1.13}\,Si_{2.87}O_{10}(OH)_2]$); kaolinite (TOT layers, dioctahedral, general chemical formula $Al_3[Si_2O_5(OH)_4]$) (Jasmund and Lagaly, 1993).

TABLE I

Summary of microorganisms and clay minerals used for the studies on microbial interactions with clay minerals

Bacteria used	Clay mineral(s) used	Property(ies) studied	Reference
Pseudomonads, Bacillus licheniformis, Bacillus cereus, Bacillus lentus, Bacillus polymixa, Bacillus megaterium	Vermiculite, chlorite within a granitic rock	Dissolution, chelation	Berthelin and Belgy (1979)
Bacterial strain P1	Smectite (SWa-1, API 25 (montmorillonite), and API 33 (nontronite)) (< 2 μm)	Fe(III) reduction	Stucki *et al.* (1987)
Enrichment culture	Garfield nontronite (< 2 μm)	Fe(III) reduction, swelling	Wu *et al.* (1988)
Xanthomonas campestris	Wyoming montmorillonite, StAustell kaolinite	Aggregation, formation of biofilm	Dorioz *et al.* (1993)
Pure and mixed cultures of *Pseudomonas* spp.	Smectite (SWa-1) (0.5–2 μm)	Fe(III) reduction, swelling	Gates *et al.* (1993)
Bacillus megatherium	Kaolinite (< 20 μm)	Rheology, dehydroxylation temperature	Mörtel and Schmelzer (1993)
Various bacteria	Ceramics	Rheology	Mörtel and Heimstädt (1994)
Zooglea ramigera ATCC 19623, *Pseudomonas* NCIB 11264	Kaolinite (125–250 μm)	Dissolution, chelation	Vandevivere *et al.* (1994)
Alteromonas atlantica	Kaolinite (1.5 μm)	Rheology	Dade *et al.* (1996)
Shewanella oneidensis MR-1	Smectite (SWa-1) (0.5–2 μm)	Fe(III) reduction, layer charge, CEC[a)]	Kostka *et al.* (1996)
Mixed culture of *Pseudomonas* spp.	Danish clayey till (< 0.2 and 0.2–2 μm)	Fe(III) reduction	Ernstsen *et al.* (1998)
Mixed culture of *Pseudomonas* spp.	Smectite (SWa-1, SWy-1, API 25 (montmorillonite) and API 34 (hectorite)) (< 2 μm)	Fe(III) reduction, swelling	Gates *et al.* (1998)

(to be continued)