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Probing the Dynamic Nanoscale World at the Interface Between Micro-Organism and Minerals

Steven Lower (slower@vt.edu), **Christopher Tadanier** & **Michael Hochella** (hochella@vt.edu)

Dept of Geological Sciences, Virginia Tech; 4044 Derring Hall, Blacksburg, VA 24061, USA

Biological force microscopy has been developed to directly probe interfacial and adhesion forces between living micro-organisms and mineral surfaces, *in-situ*. The interactions between *Escherichia coli* and the surfaces of muscovite, goethite, and graphite were studied with this technique (Lower et al., in press). Native cells were attached to a force-sensing cantilever with a polycationic or silane linker molecule thereby creating a biologically-active-force-probe, which was then used in a force microscope to characterize interfacial forces as a mineral approached bacteria on the probe, and adhesion forces upon contact and subsequent retraction of a mineral from bacteria on the probe. Attractive and repulsive interfacial forces were detected at ranges up to 400 nanometers separation, the magnitude and sign depending on the ionic strength of the intervening solution and the mineral surface charge and hydrophobicity. Adhesion forces, up to several nanoNewtons in magnitude and exhibiting various fibrillation dynamics, were also measured and reflect the complex interactions of structural and chemical functionalities on the bacteria and mineral surfaces.

In the case of the muscovite-*E. coli* system, for example, repulsive interfacial forces were detected as the mineral approached the bacteria (Fig. 1 approach). This is consistent with electrostatic interactions as both muscovite and *E. coli* are negatively charged at the pH of the experiments. The decreased magnitude and range of repulsion with increased ionic strength is consistent with a compression of the electrostatic double-layers around the bacteria and mineral under these conditions. Attractive adhesion forces observed upon retraction at high ionic strength (Fig. 1; retraction) are likely due to solution sensitive conformation changes of biomolecules on the bacteria surface. At high ionic strength, negatively charged polymers on *E. coli* withdraw from solution and compress onto the bacteria surface. This in turn would enable uncharged polymers, which are less affected by changes in ionic strength, to form attractive hydrogen bonds with hydroxyls or water molecules on the muscovite surface.

The fundamental forces between micro-organisms and minerals are central to understanding the intricacies of phenomena within the realm of biological geochemistry. We are currently using biological force microscopy to study: electron transfer at the interface between *Shewanella* and iron-oxy(hydroxides); mineral recognition between *Thiobacillus* and sulfides; intermolecular forces between *Pseudomonas* and silicates; and inter- and intra-species signaling of micro-organisms within a community. Biological force microscopy provides the means of obtaining a truly fundamental appreciation of the nanoscale world that exists at the microbe-microbe and mineral-microbe interface.

Lower SK, Tadanier CJ & Hochella MF Jr, *Geochim. Cosmochim. Acta,* **(In press).**

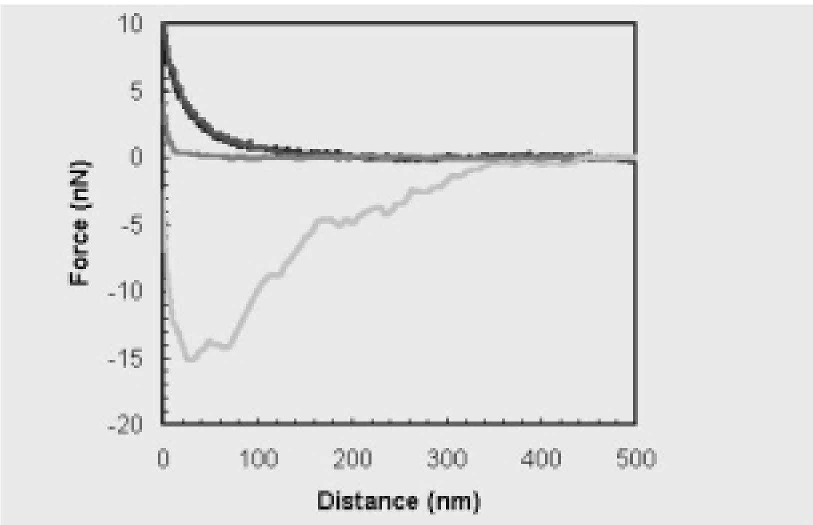

Figure 1. Force-distance curve describing the interaction between *Escherichia coli* and the (001) surface of muscovite at pH 6, 25ºC and varying ionic strengths. Curve convention: (blue) ionic strength = 10^{-5} M, approach; (green) ionic strength = 10^{-5} M, retraction (attractive adhesion forces were not detected at low ionic strength); (orange) ionic strength = 10^{-1} M, approach; (gold) ionic strength = 10^{-1} M, retraction. Force sign convention: (+) repulsive; (-) attractive.