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Microbial Response to Mineral Surface Microtopography

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Microorganisms mediate many Earth processes, such as mineral dissolution and precipitation, impacting elemental cycling at various scales. While some microbial cells are free living, most exist attached to surfaces (Hazen et al., 1991). Because bacteria affect mineral surface chemistry at their local attachment sites (Silverman and Ehrlich, 1964), these sites are extremely relevant to mineral dissolution. However, the distribution of micro-organisms in the environment is heterogeneous, and much of what controls the observed variability (between differing mineral substrata, and differing surface sites on a single mineral) is poorly understood.

In this paper we focus on interactions between cells and surface microtopography. We present theoretical calculations and experimental studies that indicate that microtopography can affect where and how cells attach to mineral surfaces.

Experimental data show that the alignment of rod-shaped (gram-negative) bacterial cells *(Thiobacillus caldus)* strongly correlate with principal crystallographic axes of pyrite [100] and [110]. Alignment preference relative to <100> increases with time over a period of several days. While bacteria often adhere to visible surface features such as scratches and steps, in many cases no surface features are visible (by light or electron microscopy). Additionally, the size of the surface feature does not unambiguously determine its effect in localizing and aligning bacterial cells. In order to theoretically model cell response to surfaces, it is first necessary to determine to what degree cells may elastically deform to achieve stronger adhesion to irregular surface microtopography. In principle, elastic deformation may increase the cell-mineral contact area, thereby increasing binding energy. However, deformation costs elastic energy, which offsets enhanced surface interaction energies. We find that based on the elasticity parameters of a common gram-negative bacterium, cells respond essentially as a rigid objects, hence, from the bacterial and surface geometry alone, we can quantitatively model anisotropy and specificity with respect mineral microtopography. We model adhesion energies as a function of size and shape of linear surface features. Figure 1 shows binding energies for a cell aligned along a "V"-shaped linear groove (with a 45-degree slope) vs. alignment along a "U"-shaped linear groove (circular cross-section), as a function of groove radius. In both cases, binding strength is reduced by the small grooves, but increased when the groove exceeds a critical radius that is close to the bacterial size. A semi-circular "U" groove in particular can dramatically enhance the binding strength of bacteria with the same or slightly smaller radius. This suggests that the size of the surface feature is much less important than its cross-sectional shape. Surface features that conform to the bacterial shape are found to very strongly alter local bacterial adhesion energies, pit depth of only 10nm. Because of the significant binding enhancement for these features, we suggest that subtle alterations in surface microtopography that may result in the vicinity of a cell due to metabolism could strongly bias adhesion and may in part account for observed patterns of attachment. We discuss and present examples for two types of chemo-autotrophic bacteria (iron- and sulfur-oxidizers) that may locally alter surface microtopography and consequently adhesion alignment in this manner.

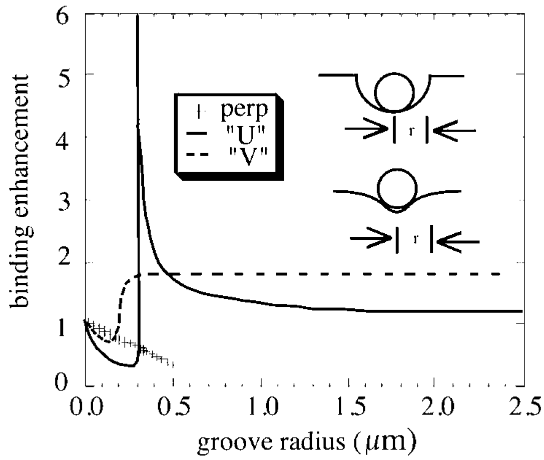

Figure 1: The enhancement factor over a flat surface as a function of groove radius r for "U" shaped and "V" shaped grooves (as shown). The binding strength is the enhancement factor times the binding strength on a flat substrate. The bacterial radius is 0.32 μm, which coincides with the discontinuous increase in binding strength at that radius for "U" shaped grooves. No such discontinuous increase is seen with "V" shaped grooves, though both exhibit a reduced binding below the bacterial radius and enhanced binding above. Also shown is the binding strength for bacteria aligned perpendicular to the groove, which applies to either groove profile. Bacteria will preferentially align perpendicular to the groove if the groove radius is much less than the bacterial radius.

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Silverman, MP, Ehrlich, HL, *Adv Appl Microbiol*, **6**, 153-206, (1964).