Biologically-mediated weathering of minerals from nanometre scale to environmental systems

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The Weathering Science Consortium is a multi-disciplinary project that aims to create a step change in understanding how biota control mineral weathering and soil formation (http://www.wun.ac.uk/wsc). Our hypothesis is that rates of biotic weathering are driven by the energy supply to the organisms, controlling their biomass, surface area of contact with minerals and their capacity to interact chemically with minerals. Symbiotic fungal mycorrhiza of 90% of plant species are empowered with an available carbohydrate supply from plants that is unparalleled amongst soil microbes. They develop extensive mycelial networks that intimately contact minerals, which they weather aggressively. We hypothesise that mycorrhiza play a critical role through their focussing of photosynthate energy from plants into sub-surface weathering environments.

Our work identifies how these fungal cells, and their secretions, interact with mineral surfaces and affect the rates of nutrient transfer from minerals to the organism. Investigating these living systems allows us to create new concepts and mathematical models that can describe biological weathering and be used in computer simulations of soil weathering dynamics. We are studying these biochemical interactions at 3 levels of observation:

1. At the molecular scale to understand interactions between living cells and minerals and to quantify the chemistry that breaks down the mineral structure
2. At the soil grain scale to quantify the activity and spatial distribution of the fungi, roots and other organisms (e.g. bacteria) and their effects on the rates at which minerals are dissolved to release nutrients
3. At soil profile scale to test models for the spatial distribution of active fungi and carbon energy and their seasonal variability and impact on mineral dissolution rates.

A geochemist's view of environmental science at the molecular level

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Molecular Environmental and Interface Science (MEIS) has evolved over the past two decades in response to the need to understand the speciation and properties of environmental contaminants at the molecular level and the chemical and biological processes at environmental interfaces that control speciation and properties. This highly interdisciplinary field has grown rapidly and is making increasing use of a sophisticated array of instrumentation and major user facilities. Synchrotron radiation sources and the micro-structural, micro-compositional, surface-sensitive, and spectromicroscopy techniques they have enabled are having an increasing impact on our ability to determine the speciation, spatial distribution, and phase association of important heavy metal, metalloid, and xenobiotic organic contaminants in complex environmenal samples. In addition, studies of model systems under controlled laboratory conditions are providing fundamental insights about the factors controlling chemical reactivity at environmental interfaces, where much of chemistry of the natural environment occurs. In this talk I will review some of these factors, including defect density, cooperative effects among adsorbate molecules, surface structure, solid variables such as the isoelectric point, solution variables such as pH, and coatings of organic matter and microbial biofilms on mineral surfaces. I will also discuss recent synchrotron-based studies by members of my research group and members of the Stanford Environmental Molecular Science Institute of the structure of bulk water, uranium speciation in the vadose and groundwater zones at Hanford, WA, and the reactivity of nanoparticles of biogenic $UO_2(s)$ and hematite with respect to aqueous Zn(II). Finally, I will offer some thoughts on the future of MEIS following the introduction of hard x-ray free electron lasers.