The microbiology and biogeochemistry of sulfidic mine dumps

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The microbiology and the relevant biogeochemical processes in the dumps and heaps are reviewed and have to be understood for improving copper heap leaching operations and to develop and control countermeasures for the formation of acid mine drainage (AMD). Pyrite or pyrrhotite oxidation is the most relevant biogeochemical process in sulfidic mine waste dumps and heaps and different techniques have been applied to measure reaction rates: column experiments, humidity cells, heat flow measurements, or oxygen consumption measurements. Acidophilic Fe(II)-and sulfur-oxidizing microorganisms are most relevant for metal sulfide oxidation. Anaerobic biogeochemical processes in sulfidic mine dumps and heaps are Fe(III)- and sulfate reduction, but little is known about the reaction rates. Fe(III)-reducing microorganisms dissolve Fe(III)(hydr)oxides and may thereby release adsorbed or precipitated metals. Sulfate-reducing microorganisms precipitate and immobilize many metals. Mainly culturing approaches were used to study the microbial communities in sulfidic mine dumps and heaps. More recently, molecular biological techniques have been applied to investigate the microbial diversity and to quantify and monitor particular microorganisms.

[1] Schippers, A. *et al*. (2010) *Hydromet*. **104**, 342–350.

Bioremediation strategies to inhibit salt-enhanced stone weathering

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Salt weathering is an important mechanism contributing to the degradation and loss of carved stone and historic stone buildings. Stone monuments in the presence of salt and water, suffer from salt-enhanced physical and chemical weathering. It has been observed that weathering rates of rocks in nature, as well as building stones, are slowed down by naturally occurring or artificially produced patinas. These tend to be bacterially produced, durable mineralized coatings that lend some degree of protection to the underlying stone surface [1].

Our research shows that bacterially produced carbonate coatings can be quite effective at reducing both physical and chemical weathering of stone by soluble salts. The calcite-producing-bacteria used in this study were isolated from stone monuments in Granada, Spain [2] and cultivated in an organic-rich culture medium on a variety of artificial and natural substrates (including limestone, marble, sandstone, quartz, calcite single crystals, glass cover-slips, and sintered porous glass). Scanning electron microscopy (FESEM) was used to image bacterial calcite growth and biofilm formation. *In situ* atomic force microscopy (AFM) enabled calculation of dissolution rates of untreated and treated surfaces. 2D-XRD showed the mineralogy and crystallographic orientation of bacterial calcium carbonate.

Results indicate that bacterially produced calcite crystals form a coherent, mechanically resistant surface layer in perfect crystallographic continuity with the calcite substrate (self-epitaxy). These calcite biominerals are more resistant to chemical weathering by salt-enhanced dissolution, apparently due to the incorporation of organics (bacterial exopolymeric substances, EPS). Conversely, on silicate substrates, non-oriented vaterite forms, leading to limited protection. Organic films formed on treated substrates appear to promote salt crystallization at reduced supersaturation [3], thus reducing salt crystallization pressure and minimizing physical damage. These preliminary results indicate that bacterial treatments have tremendous potential to protect built cultural heritage.

[1] De Muynck *et al*. (2010) *Ecol. Eng*. **36**, 118–136.
[2] Jimenez-Lopez *et al*. (2007) *Chemosphere* **68**, 1929–1936.
[3] Ruiz-Agudo *et al*. (2006) *Cryst. Growth Des*. **6**, 1575–1583.