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Metal Enrichment in Secondary Mineral Cements Facilitated by Microbial Mineral Weathering and Precipitation

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The weathering of sulfidic mine tailings results in acid mine drainage (AMD), contaminating surface water and groundwater downstream of tailings storage sites. Hardpans develop when mineral weathering and secondary mineral precipitation causes cemented mineral crusts to form in the vadose zone of sediments or tailings. These horizons can reduce AMD generation by limiting water and gas permeability and immobilizing toxic metals through adsorption and coprecipitation within cements. Sulfur and iron oxidizing bacteria that accelerate both sulfide mineral dissolution and secondary oxyhydroxide mineral precipitation may contribute to metal cycling and hardpan formation processes. In this study, a laboratory hardpan formation experiment was conducted in columns using iron and sulfide rich tailings collected from a historic gold mine near Marmora, Ontario. Biotic columns were inoculated with a consortium of iron and sulfur oxidizing bacteria cultured from the same site. The biotic and abiotic columns were provided with acidic (<pH 2.3) basal salt solution and deionized water, respectively, with half of the columns receiving an elevated concentration of copper to track new cement formation. Solutions were added on a bi-weekly basis for 6 weeks, then allowed to dry out to stimulate mineral precipitation. Mineralogical characterization of consolidated surface material and centimeter-scale cores revealed that although the mineralogy was similar across all treatments (ilmenite, quartz, albite, gypsum, jarosite), the degree of consolidation and concentrations of water-soluble trace metals (Al, Cu, Zn, Mn, Co), were higher in the inoculated treatments. Scanning electron microscopy and energy dispersive spectroscopy revealed differences in mineral morphology between the biotic and abiotic columns. Metal enrichment was only observed in the biotic columns and was associated with the gypsum ($CaSO_4 \cdot 2H_2O$) cements and microcrystalline jarosite. Results of 16S rRNA amplicon sequencing of the inoculated column cements revealed the proliferation of acidophilic iron and sulfur oxidizing microbes, as well as metal ligand expressing and biofilm producing microbes. Collectively, this study provides a snapshot of early hardpan precipitation in tailings and demonstrates the role of microbial communities in accelerating mineral dissolution and enriching metals in biogenic secondary precipitates, with implications for the cycling and potential stabilization of trace metals at historic mine sites.