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Fractionation of Rare Earth Elements (REEs) in Stratified Cyanobacteria-Sulfate Reducing Bacteria Biofilms via Biogenic Mineralization

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Rare Earth Elements (REEs) are metals essential for use in green energy technologies; however, their supply remains difficult, with global demand still largely met through re-cycling and primary mineral extraction. Traditional methods for separating or fractionating REEs from solutions via crystallisation ponds are challenging and resource intensive due to similar ionic properties between the different lanthanide metals in aqueous systems and frequent co-precipitation of impurities. In contrast, microbially mediated secondary precipitation of REE minerals and/or REE-organic complexes offers a sustainable, low-impact alternative, potentially producing biologically induced fractionation.

The mine tailings from the Mary Kathleen (MK) uranium mine (Queensland, Australia) are rich in water soluble REEs, specifically, Ce (~400 ppm), La (~270 ppm), Nd (~70 ppm), and Pr (~31 ppm). Extensive washing of these tailings with ultra-pure water produced a REE-rich leachate, which was used in laboratory experiments to investigate the potential of microbial systems to immobilize REEs from complex, metal-rich solutions. Bioreactors consisting of cyanobacteria-sulfate reducing bacteria biofilms sourced from the MK mine site were established and were fed with the REE-impregnated, acidic leachate (pH 4.3) every 30 days over a 180-day experimental period. Similarly, the control reactors were fed with a simple mineral solution without REEs. Samples of reactor fluids and/or biofilms were collected every two months for ICP-OES, imaging (SEM-SE, SEM-EDS, FTIR, XFM), metagenomics, transcriptomics, and proteomics analyses.

Preliminary water chemistry data indicated ~98-99% removal of REEs in the REE-fed experiments, consistent with microbially mediated mineral precipitation and/or organo-metal complex formation. FTIR analysis revealed functional groups corresponding to carbonate, sulfate, phosphate, and acetate, while SEM-EDS revealed spatially distinct Ce- and La-enriched regions within the composite biofilm, suggesting microbially mediated REE fractionation. Ongoing analyses aim to identify bacterial genes and proteins associated with selective REE binding.

Overall, targeted biogeochemical processing may offer novel pathways for biologically mediated REE recovery and fractionation, transforming mine waste into a valuable resource.