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Acid Mine Drainage Treatment Wetlands as Model Systems for Understanding Rare Earth Element Dynamics along Biogeochemical Gradients

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Acidic mine waters, such as those leaching from coal mine sites in Northern Appalachia of the United States, are enriched in rare earth elements (REE), cobalt, and other metals essential for modern technologies. The resourcing of these wastes can augment the U.S. domestic supply for critical metals while also incentivize the treatment of AMD discharges. Solids that are produced during the treatment of AMD are enriched with REE and are highly diverse in composition. Knowledge of these matrix features is essential for the development of scalable extraction processes for metal recovery. Here, we focus on vertical flow ponds, a nature-based AMD treatment system comprising shallow wetland basins filled with organic compost and limestone as the soil substrate. AMD water percolates from the surface through the wetland soil, resulting in deposition fronts of metals corresponding to pH and redox gradients with depth into the wetland soils. We employed scanning electron microscopy to demonstrate the compositional variety of potential solid phase hosts for critical metals. REEs are co-enriched with aluminum in these soils (likely as Al-hydroxy sulfates), while transition metals such as Co are coenriched with Al and Mn-rich solids. Yttrium X-ray Absorption Spectroscopy analyses indicate REE adsorption with host minerals (oxides, hydroxides) and possibly organic matter, rather than deposition as discrete Y-oxide minerals. However, more detailed analysis of potential host phases is needed to better resolve spectral features. With the pH gradients that develop vertically in the wetland media, the stratification of REE and other metals in the solid phases is analogous to engineered processes designed to recover REE from acidic feedstocks via pH-controlled staged precipitation. Moreover, these wetland systems are habitats for microbial communities adapted to acidic water and high levels of REE. As such, they can be model systems for the discovery of microbiomes and biomolecular systems that utilize these metals for key functions.