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From Tailings to Oxygen Barriers: Sustainable Acid Mine Drainage Control via Biotite-to-Clay Conversion

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Aitik mine (Sweden), Europe's largest Cu mine, generates vast volumes of tailings dominated by feldspars and micas (biotite, muscovite) [1]. The tailings also contain ca. 1.5 % sulfides capable of producing acid mine drainage (AMD). Upon mine closure, these potential acid-generating tailings require engineered covers with low hydraulic conductivity ($k = 10^{-9}$ m/s) to limit oxygen ingress, typically by using bentonite/smectite-amended moraine. However, this bentonite demand represents a substantial economic and material burden. Therefore, reprocessing locally abundant biotite-rich tailings into swellable clay-like materials offers a potential in-situ low-cost alternative for sustainable mine waste control.

We investigated alteration of biotite driven by Fe^{2+} oxidation coupled with K^+-Na^+ interlayer exchange, aiming to reduce layer charge, promote K^+ release, and transform biotite towards smectite-like phases, such as oxybiotite. Experiments were conducted on well-characterized biotite [2] and Aitik mine tailings using NO_3^- and H_2O_2 as oxidants in Na^+-bearing solutions. Elemental release was quantified by ICP-OES, while structural expansion and evolution (oxidation states, coordination environments) were revealed by XRD and XAS, respectively. Additional characterization included XRF, SEM-EDS, FTIR, Raman, TGA, dynamic vapor sorption, cation exchange capacity, and hydraulic permeability measurements to bridge structural transformation with barrier performance.

Aitik tailings contain abundant biotite with a basal spacing d_{001} of 10 Å. After oxidative treatments, the interlayer of biotite expanded from 10 Å to 12.2 Å under dry conditions and up to 15 Å upon hydration. H_2O_2 promoted interlayer expansion across all particle sizes. In contrast, nitrate-driven alteration produced interlayer expansions of 18.8 Å in water and 15 Å after drying exclusively in fine-grained tailings (< 40 µm). ICP-OES confirmed significant interlayer K^+ release and mobilization of structural cations, indicating cation exchange and structural reorganization.

These results show that oxidative reprocessing of biotite-rich tailings can induce smectite-like swelling behavior, particularly in fine-grained fractions. By linking molecular-scale redox processes to bulk hydraulic functionality, this study outlines a mechanistically grounded pathway for transforming mine waste into an engineered oxygen barrier, advancing sustainable AMD mitigation and responsible mine closure strategies.

[1] Forsberg, Lovisa (2008), PhD thesis.

[2] Malmström, Maria, et al. (1996), Journal of Contaminant Hydrology, 21(1): p. 201-213.