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Heavy metal release suppression in coarse mine tailings rock by ambient-pressure mineral carbonation: Insights from multi-batch leaching experiments

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This study investigates the geochemical evolution of mine tailings subjected to carbonate mineralization treatment under bench-scale and ambient pressure conditions, with particular focus on heavy metal release behavior during repeated wetting–drying cycles. Coarse waste rock samples (centimeter scale) were reacted with CO_2 under atmospheric pressure without additional grinding, aiming to simulate practical field-applicable conditions.

Batch leaching experiments were conducted to compare CO_2-treated and untreated samples over multiple reaction cycles. In the initial batch, untreated samples exhibited a pronounced decrease in ORP, indicating active sulfide oxidation and oxygen consumption. In contrast, CO_2-treated samples showed moderated ORP evolution and systematically lower dissolved concentrations of Zn, Cu, Pb, and Fe. These observations suggest that carbonate mineralization treatment modifies the early-stage redox-driven dissolution processes.

In subsequent batches, redox conditions became comparatively stable, and leaching behavior shifted toward a more surface-controlled regime. For several elements (e.g., Zn and Fe), lower dissolved concentrations were consistently observed in CO_2-treated samples. However, in later batches, element-specific divergence emerged: while Fe release remained suppressed, Cu and Pb showed reduced or diminishing suppression effects. This indicates that the influence of carbonate mineralization evolves over time and depends on reactive surface restructuring and secondary phase development.

Our results demonstrate that even under ambient-pressure, coarse-grained conditions, carbonate mineralization can significantly influence heavy metal release pathways in mine waste. At the same time, the effectiveness of suppression is temporally dynamic and element-dependent, highlighting the importance of understanding reaction-field evolution in predicting long-term geochemical behavior.

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