Goldschmidt 2026 Abstract
https://doi.org/10.46427/gold2026.33998

From Prediction to Precipitation: Unraveling the Kinetics of Critical Metal Removal in Acid Mine Drainage from Coal Mines in Southern Brazil

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Coal mining in Southern Brazil poses a critical environmental challenge due to the generation of acid mine drainage (AMD). Effective AMD remediation relies on the strategic selection of neutralizing materials. This study evaluated limestone (CM), basalt (BBJ), and diabase (DU) for the neutralization of a synthetic AMD formulated at an extreme pH of 2.0, lower than the typical local drainage (pH ≈ 3.5) from coal mines in Southern Brazil. PHREEQC modeling using a solid-to-liquid (S/L) ratio of 1:50 predicted that Ni and Co would remain dissolved across all treatments at pH values below 9. A critical performance gap was identified for Zn, only limestone was predicted to increase pH above 4.5, enabling Zn removal via adsorption onto hydrobasaluminite, whereas BBJ and DU were not expected to exceed pH 4.0. To validate these simulations, batch experiments were conducted over two weeks using S/L ratios of 1:50 and 1:100 under stirred and non-stirred conditions, with materials pulverized to <200 mesh. The experimental results corroborated the modeling predictions since BBJ and DU failed to reach the pH threshold required for hydrobasaluminite precipitation (SI>0). In contrast, limestone promoted rapid neutralization, particularly under stirred conditions at 1:50 samples, inducing hydrobasaluminite formation within the first hour and effectively sequestering Al and Zn.Furthermore, contrary to initial predictions, Ni and Co were also removed in limestone treatments once pH exceeded 7.0, likely due to late-stage competitive adsorption processes. A marked increase in dissolved metal concentrations during the final week was observed exclusively in BBJ and DU treatments. Although mineralogical and geochemical characterization revealed high endogenous metal contents in these volcanic rocks, prior geochemical modeling confirmed chemical stability and negligible leaching potential. Therefore, the observed concentration increase is attributed to evapotranspiration effects rather than mineral weathering. In limestone experiments, this physical effect was masked by strong metal adsorption. We conclude that while Al-hydroxysulfate precipitation plays a key role in metal sequestration, the rapid formation of these secondaryphases may promote surface armoring and clogging, compromising long-term reactivity. Consequently, a staged treatment strategy that promotes Al-phase precipitation prior to limestone contact is recommended, to preserve neutralization efficiency over time.



