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Expanding our knowledge base to support sustainable mine waste management

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The extraction and processing of mineral resources generates billions of tons of mine waste globally, predominantly waste rock and tailings. These materials can have negative effects on downstream environments via poor-quality drainage generated by mineral weathering reactions, particularly sulfide oxidation, and associated release of acidity, metal(oid)s and other contaminants. Mine waste storage facilities and wastewater treatment systems thus need to be designed and operated strategically to minimize environmental impact. However, the efficacy of waste storage, water treatment or remediation methods relies heavily on our ability to predict the reactivity of waste rock and tailings and the resultant wastewater quality, ideally decades beyond mine closure.

It has long been recognized that mine waste reactivity and leaching dynamics are governed by a complex combination of mineralogical and biogeochemical reactions as well as hydrogeological transport processes that occur across a wide range of scales. These various controls underscore the importance of understanding quantitatively the geochemical, mineralogical, textural, and physical properties of waste materials, which vary widely across sites and are often expensive to measure.

Despite this persistent engineering challenge, increasingly detailed field and laboratory data is used to improve operational management and closure planning at mine sites. We will discuss recent advances in

1. applied hydrogeochemistry, including (unconventional) isotope systems and aqueous speciation analyses, that can be deployed as tracers for (bio)geochemical processes and mineralogical dynamics;
2. high-resolution monitoring of in-situ physicochemical conditions in waste systems that can be used to delineate redox gradients and parameterize hydrogeological transport parameters, and;
3. the upscaling of mechanistic prediction models using reactive-transport simulations that span from the microscale (i.e. individual minerals) to macroscale (i.e. hundreds of meters tall waste rock piles).

Climate change resilience and growing volumes of waste produced by the pursuit of increasingly diffuse and lower-grade deposits present emerging challenges for sustainable mine waste management. Yet, ongoing fundamental and site-specific work in these and other areas continues to expand our scientific knowledge base and may enable the paradigm shift from historically reactive to fully proactive approaches in mine waste management.