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Call to action: The need for new waste quality indicators in metal mining

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The vast majority of metal mining operates under traditional linear economic models, whereby metals are extracted to create products, and any resulting waste is deposited in designated repositories. In this context, geochemical and mineralogical protocols and tests are routinely applied to waste materials to gather data and indicators regarding their current and future environmental conditions, particularly their likelihood to develop acid and metalliferous drainage (AMD) [1], [2]. However, existing AMD protocols and tests primarily focus on environmental risks, exhibit significant limitations, contain uncertainties that are difficult to quantify, and often yield predictions that reflect only best estimates. It is essential to enhance our scientific efforts to accurately characterize waste across all scales - from micro to macro - which will facilitate resource development at various exploration sites, mines, and waste locations. Additionally, geochemical and mineralogical characterization can play a crucial role in advancing circular economy systems by eliminating waste from entire value chains or reintegrating resources from mine wastes back into material flows. Achieving greater confidence in waste characterization will require the adoption of new macro-level approaches (such as remote sensing and geophysical surveys), meso-scale testing (including XRF probes and sensors), and micro-level laboratory analyses (like computed tomography). Conversely, remote locations and developing regions necessitate a distinct set of low-cost, easily accessible, and user-friendly waste quality indicators – examples include infrared cameras attached to mobile phones. There is reason for optimism regarding the potential for innovative advancements in this field. Moving forward, researchers must develop new waste quality tools and indicators that support novel strategies for sustainable resource development.

[1] Lottermoser BG (2010) *Mine Wastes: Characterization, Treatment and Environmental Impacts*. 3rd edition. Springer-Verlag, Berlin Heidelberg, 400 pp.

[2] Lottermoser BG (2017) *Environmental Indicators in Metal Mining*. Springer Nature, Springer International Publishing Switzerland, 413 pp.