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Waste as a Resource: Seeking Critical Minerals and Other Commodities in Mine Waste and Reducing Environmental Footprints at Legacy and Modern Mines

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The combination of increasing demand for critical minerals, many of which are exclusively derived as by-products or coproducts of other commodities, and the increasing environmental footprint of mines due to growing emphasis on mining larger, lower-grade deposits necessitates a paradigm shift to improve sustainability. Mine waste as a resource represents a potential approach to simultaneously address these issues using a synergistic strategy.

A suite of nearly 100 mill tailings samples from over 20 different mineral deposit types has been assembled to evaluate the potential for critical mineral, base metal, and precious metal recovery. Deposit type clearly influences critical mineral abundances. Concentrations are compared to average crustal abundances to identify anomalous concentrations warranting further study.

A mass balance approach was applied more specifically to the ore-processing scheme at an active porphyry copper-molybdenum mine to better understand the deportment of critical minerals and other commodities in concentrates and tailings. This analysis indicates that roughly half of the gold, silver, zinc, platinum group metals, selenium, and antimony in the ore is lost to tailings. Approximately two-thirds of the tellurium and indium and most of the cobalt, germanium, gallium, and rare earth elements also reside in the tailings. The chalcophile nature of gold, silver, and many of the by-product critical mineral commodities suggests that they may be associated with pyrite—a hypothesis supported by ongoing mineralogical studies. Thus, the increasingly common practice of producing a pyrite concentrate at many porphyry copper mines to better manage acid drainage risks may also be an important step toward recovering valuable resources. This approach combines resource recovery with improved environmental management.

Any attempt to reprocess mine waste for recovery of critical minerals or other commodities, however, must account for the present-day hosts of those elements. Investigations at an abandoned lead-zinc Mississippi Valley-type mine that was an historically important by-product germanium producer highlight the influence of mine waste weathering on germanium deportment. Sphalerite was the original germanium host, but weathering of the waste piles produced hemimorphite as a secondary phase, which now hosts a majority of the germanium in wastes sampled.

Synergies between resource development and improved environmental protection also include consideration of the carbon footprint of mining. Mafic and ultramafic magmatic nickel-copper-platinum group metal deposits are predominantly hosted by high calcium and magnesium silicate minerals, such as olivine, pyroxene, and plagioclase. Extensive crushing and grinding create mafic silicate tailings with high surface area that are prime targets for mineral carbonation through the production of calcium and magnesium carbonate minerals. The voluminous amounts of mafic gangue minerals in tailings can sequester carbon dioxide and contribute to the development of carbon-neutral mines.

Waste streams at legacy and active mines should be reevaluated to identify additional resource potential. The most tenable scenarios will likely be situations where resource recovery can be combined with improved environmental management to enhance the remediation of abandoned mines and the sustainability of active mines. At abandoned mines, resource recovery can also help offset remediation costs.