Mobilization of metal(oid) oxyanions through circumneutral mine waste-rock drainage

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The environmental impacts of open-pit mining can be enormous: millions of tons of waste rock are produced around the world annually. Weathering of this waste rock can mobilize metals and thereby critically affect downstream environments, which requires long-term and costly environmental management. Unfortunately, our current understanding of waste-rock weathering mechanisms is largely derived from studies on acidic drainage types from reactive waste rocks, and metal(loid) release under neutral-rock drainage (NRD) conditions has received relatively limited attention.

In the frame of a long-term experimental research collaboration with the Antamina mine in Peru, we assessed the weathering of 49 different waste rocks under natural conditions using long-term (>10 yr) kinetic field tests. Geochemical analyses on >5,500 drainage samples were combined with quantitative mineralogical analysis of the waste rock and chemical-equilibrium modeling. Weathering of most rock lithologies in the field experiments generated circumneutral to alkaline drainage (6<pH<9) but with concentrations of the oxyanion-forming metal(loid)s As, Mo, Se and Sb in the mg/L range. Mobilization of As and Sb was particularly efficient from intrusive, marble and hornfels rocks that contained labile As- and Sb-sulfides, irrespective of bulk elemental content or waste-rock reactivity. High-alkalinity drainage from these relatively Fe-poor materials sustained neutral-pH conditions that are unfavorable to oxyanion adsorption and therefore enhanced As and Sb leaching. The release of Mo and Se from sulfidic skarn and intrusive waste rock was more proportional to their elemental content but equally enhanced by pH-inhibited adsorption onto Fe-(oxyhydr)oxides and negligible secondary mineral precipitation under NRD conditions.

Our results suggest that oxyanion concentrations of environmental concern may be conveyed by neutral- to alkaline-pH waste-rock drainage and should be a focus of mine wastewater monitoring programs.