Geochemical controls on mine waste drainage quality: long-term monitoring of waste rock weathering at the Antamina mine, Peru

BAS VRIENS[1,*] HOLLY PETERSON[2] LAURA LAURENZI[3] LESLIE SMITH[1] K. ULRICH MAYER[1] ROGER D. BECKIE[1]

[1] Department of Earth, Ocean and Atmospheric Sciences, University of British Columbia, 2020-2207 Main Mall, Vancouver BC, V6T 1Z4, Canada. *bvriens@eoas.ubc.ca

[2] Department of Geology, Guilford College, 5800 West Friendly Avenue, Greensboro NC, 27403, USA

[3] BGC Engineering Inc., 500-980 Howe Street, Vancouver BC, V6Z 1N9, Canada

The weathering of waste rock creates environmental risks through the potential release of acidic and metal-laden drainage. Mitigation of these risks requires accurate prediction of the timing, volume, and composition of waste rock drainage. Such predictions, however, are complicated by the intricate coupling of geochemical and physical transport processes, and the scarcity of long-term, integrative field data required to verify upscaling methods and hydrogeochemical models.

We present unique hydrological and geochemical data from a decade-long monitoring program at the Antamina mine in Peru, in which large (~20,000 t) experimental piles with different types of waste rock were weathered in a strongly monsoonal climate. Coarse, carbonate-rich waste rock (the dominant type of waste rock at Antamina) generated neutral drainage for over 10 years with low Cu and Zn concentrations in the $\mu g \cdot L^{-1}$-range. However, fine-grained, low-carbonate waste rock showed high apparent sulfide oxidation rates (>1 $g\ S\ kg^{-1}$ waste rock yr^{-1}) and rapidly produced acidic (pH 3) drainage with elevated metal loads in the $g \cdot L^{-1}$-range. The drainage quality was not only affected by the physical and geochemical characteristics of the waste rock (e.g., particle size and primary mineralogy), but also by (temporary) metal retention of over 95% within the piles, due to sorption and the precipitation of discrete secondary minerals (e.g., gypsum, Fe-(oxy)hydroxides, and Cu-/Zn-hydroxy-sulfates). In addition, small sections of reactive waste rock (<10% of total pile mass) dominated the drainage quality from composite, mixed waste-rock piles.

Our results provide quantitative evidence for the strong decoupling of primary mineralogy and waste-rock drainage quality, and demonstrate that, on practice-relevant temporal and spatial scales, the timing and composition of waste-rock drainage can hardly be predicted *a priori* from conventional static-testing alone.