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Evaluation of selected static methods used to estimate element mobility, acid-generating and acid-neutralizing potentials associated with geologically diverse mining wastes

Philip L. Hageman [a,*], Robert R. Seal [b], Sharon F. Diehl [a], Nadine M. Piatak [b], Heather A. Lowers [a]

[a] U.S. Geological Survey, Bldg. 20 Box 25046, MS 964D, DFC, Denver, CO 80225-0046, USA
[b] U.S. Geological Survey, 954 National Center, Reston, VA 20192, USA

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ABSTRACT

A comparison study of selected static leaching and acid–base accounting (ABA) methods using a mineralogically diverse set of 12 modern-style, metal mine waste samples was undertaken to understand the relative performance of the various tests. To complement this study, in-depth mineralogical studies were conducted in order to elucidate the relationships between sample mineralogy, weathering features, and leachate and ABA characteristics. In part one of the study, splits of the samples were leached using six commonly used leaching tests including paste pH, the U.S. Geological Survey (USGS) Field Leach Test (FLT) (both 5-min and 18-h agitation), the U.S. Environmental Protection Agency (USEPA) Method 1312 SPLP (both leachate pH 4.2 and leachate pH 5.0), and the USEPA Method 1311 TCLP (leachate pH 4.9). Leachate geochemical trends were compared in order to assess differences, if any, produced by the various leaching procedures. Results showed that the FLT (5-min agitation) was just as effective as the 18-h leaching tests in revealing the leachate geochemical characteristics of the samples. Leaching results also showed that the TCLP leaching test produces inconsistent results when compared to results produced from the other leaching tests. In part two of the study, the ABA was determined on splits of the samples using both well-established traditional static testing methods and a relatively quick, simplified net acid–base accounting (NABA) procedure. Results showed that the traditional methods, while time consuming, provide the most in-depth data on both the acid generating, and acid neutralizing tendencies of the samples. However, the simplified NABA method provided a relatively fast, effective estimation of the net acid–base account of the samples. Overall, this study showed that while most of the well-established methods are useful and effective, the use of a simplified leaching test and the NABA acid–base accounting method provide investigators fast, quantitative tools that can be used to provide rapid, reliable information about the leachability of metals and other constituents of concern, and the acid-generating potential of metal mining waste.

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1. Introduction

Mining impacted water (MIW) is a major concern for metal-mining operations. MIW results from the oxidative weathering of sulfide minerals, principally pyrite or pyrrhotite, in waste rock, mill tailings, pit walls, and mine workings. MIW can cause a host of environmental problems because low pH waters have the ability to dissolve and transport metals and other constituents. However, the solubility of metals, and other contaminants vary with pH. Cationic species, such as Cu, Pb, Zn, Cd, Ni, and Co, are more soluble at low pH. In contrast, elements that form anionic species, such as As, Sb, Se, Cr, V, and Mo, tend to be more soluble at high pH. Thus, the acid-generating potential of mining waste greatly influences the composition, transport, and fate of contaminants mobilized from mining waste.

Abbreviations: ABA, acid–base account; AMD, acid mine drainage; AP, acid-generating potential; CVAFS, continuous flow-cold-vapor-atomic fluorescence spectrometry; DI, deionized; FLT, Field Leach Test; IC, Ion chromatography; ICP-AES, inductively coupled plasma-atomic emission spectrometry; ICP-MS, inductively coupled plasma-mass spectrometry; MIW, mining impacted water; NABA, net acid–base account; NNP, net-neutralization potential; NP, neutralizing potential; NPR, neutralization potential ratio; SEM, scanning electron microscope; SPLP, synthetic precipitation leaching procedure; TCLP, toxicity characteristic leaching procedure; USEPA, U.S. Environmental Protection Agency; USGS, U.S. Geological Survey; XRD, X-ray diffraction analysis.

* Corresponding author.

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Ultimately, mineralogy and weathering determine and control the potential for a mine waste to be a generator or a neutralizer of acid (Plumlee and Logsdon, 1999; Seal and Hammarstrom, 2003; Maest et al., 2005). Mechanical, chemical, and biologic weathering processes result in the breakdown and reaction of minerals, and if climatic and mineralogical conditions are conducive, weathering results in the formation of end-member, readily soluble, hydrated weathering salts like those shown in Fig. 1(a).

Secondary salts such as these represent the end product (sum) of all of the geochemical and acid–base reactions that have taken place in the mine waste over time. The salts play a key role in moving acid and metals from the mine waste into the environment because they serve as sinks that control the characteristics and constituents of leachate that will be generated from the waste upon exposure to water.

The risk of acid generation and metal mobility can be assessed and characterized through a series of tests that fall into two broad categories: static tests and kinetic tests. Static tests, the subject of this paper, comprise a single test or set of tests performed on mining waste at a single time. In contrast, kinetic tests consist of continuous or intermittent leaching for extended periods, sometimes spanning months to years, and are sampled on a periodic basis, such as weekly. Static tests can be further divided into leaching tests and acid–base accounting (ABA) studies. Static testing methods are well established and widely accepted and a general overview of static leaching and ABA methods are found in INAP (2009), Maest et al. (2005), and Lapakko (2002).

While numerous studies have compared the use of several static tests at specific sample sites (i.e. Lei and Watkins (2005) and Lengke et al. (2010)). The primary goal of our study is to compare several different static tests on a suite of modern mine waste samples that span a diversity of mineralogical and geochemical compositions in order to assess and compare results produced by both traditional and simplified static methods. Results produced from this study help constrain, correlate, and verify the relationship between leaching, mineralogy, and the net acid–base account of the samples.

2. Samples included in this study

The samples included in this study represent modern-style mine waste, meaning that, although some samples are from abandoned or inactive mines, all of the ore was processed using methods currently in use. The samples represent diverse base and precious metal mineral deposit types and the samples include a range of mineralogical and geochemical, characteristics (Table 1).

Previous mineralogical studies showed that the mine waste samples are of mixed sulfide mineralogy, containing varying amounts of pyrrhotite, pyrite, chalcopyrite, sphalerite, galena, and arsenopyrite, and are potential repositories for acid-generating potential and metal contaminants (Piatak et al., 2007). A number of the samples also contained varying amounts of carbonate minerals. All the samples except (NZ-A) were collected from the oxidized surface of the mine waste piles. The (NZ-A) sample was collected from mostly un-oxidized mill tailings.

3. Methods

3.1. Sample preparation

After collection, bulk samples were dried in ambient air and then homogenized. The samples were then dry-sieved to pass a −10 mesh (2-mm) stainless steel screen and the <2 (mm) fraction was used for study.

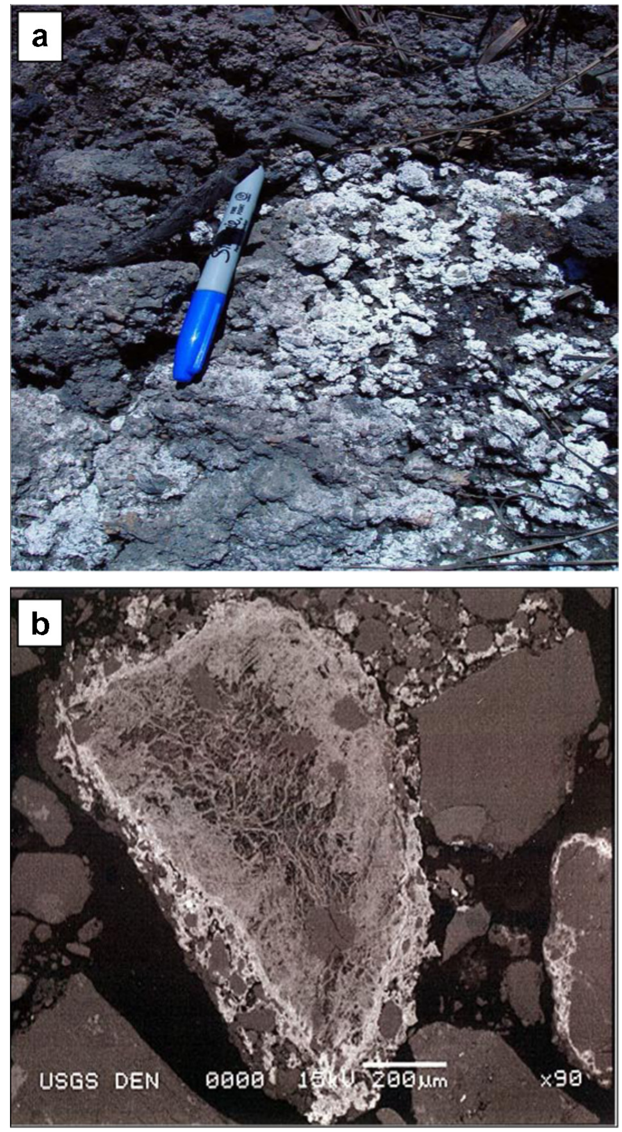

Fig. 1. (a) Photograph of typical, readily soluble secondary salts (white areas) forming on the surface of metal mining waste. These weathering salts represent the "sum" of all the geochemical reactions that have taken place in the mine waste over time. (b) Scanning electron microscope (SEM) photomicrograph showing weathered sphalerite (ZnS) grain from processed metal-mine waste material. Mineralogy studies showed that the grain has undergone advanced oxidation, dissolution etching, and alteration to iron oxides and readily soluble secondary sulfate salts (bright white coatings).

3.2. Mineralogy

Previous studies of metal mine waste have shown that micro-mineralogical and micro-structural controls (Diehl et al., 2005, 2006, 2007, 2008) influence both the net acid–base account and the leaching potential of water-soluble constituents. In order to highlight these processes, we conducted extensive mineralogical characterization on sample splits from this study using transmitted- and reflected-light microscopy, scanning electron microscope (SEM) and electron microprobe in combination with X-ray diffraction (XRD). In addition, thin sections and bulk grain samples were studied to determine mineralogy, provide qualitative minor- to trace-element content and residence, textures, and microstructures such as micro-veining, micro-faulting, and lattice defects. Sulfide grains from mine waste were examined specifically to search for readily soluble metal-bearing phases like those shown

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