

**TOOLS FOR THE RAPID SCREENING AND CHARACTERIZATION  
OF HISTORICAL METAL-MINING WASTE DUMPS**

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**ABSTRACT**

Assessment of metal mobility, acid-drainage production, and toxic effects from the weathering of historical mine-waste dumps is an area of growing need as the environmental effects of inactive mine-waste sites across the country are being evaluated and mitigated. The U.S. Geological Survey Mine Waste Characterization Project has taken a multidisciplinary approach to assemble, develop, and refine methods and tools for characterizing and screening weathered solid-mine wastes. Researchers from a variety of disciplines, including geophysics, geochemistry, analytical chemistry, geology, mineralogy, geomicrobiology, remote sensing, spatial modeling, and aquatic toxicology, have worked together at several metal mining waste sites to develop an integrated "tool kit" for the rapid screening and characterization of historical mine-waste sites. This paper provides a brief overview of some of these tools.

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## **INTRODUCTION**

There are thousands of historical mine-waste dumps present on inactive metal-mining sites, some of which are on Federal lands and have been abandoned. Since these are historical dumps, generally they are relatively small. However, the potential release of dissolved metals, acidity, or suspended particulates from mine-waste dumps can be a serious and long-lasting problem. Assessment of the potential environmental effects of historical mine-waste dumps is an area of growing need. The U.S. Geological Survey Mine Waste Characterization Project has taken a multidisciplinary approach to assemble, develop, and refine methods and tools for characterizing and screening weathered solid-mine wastes. Researchers from a variety of disciplines have worked together at several metal-mining waste sites in Colorado and New Mexico to develop an integrated "tool kit" for the rapid screening and characterization of historical mine-waste sites. Tools developed from this work can be used in ranking and prioritizing historical mine-waste dumps. A brief overview of several of these tools is given below.

## **SCREENING TOOLS**

### **Sampling Strategy**

We sought to develop a statistically based, cost-effective sampling strategy that could provide the foundation for screening and prioritizing mine-waste dumps on a regional or watershed basis. Because we are concerned with average properties, our sampling strategy entails collection of a composite sample from each waste dump. When more detailed site characterization is required, other sampling strategies might be employed, depending on the objectives of the work. A detailed discussion of our sampling strategy is given in K.S. Smith et al. (2000). In order to minimize sampling errors, our strategy requires that a composite sample consist of at least 30 increments (subsamples). Hence, we divide a mine dump into at least 30 cells of roughly equal surface area. Multiple surficial samples of roughly equal mass are collected from each cell with a trowel, successively placed in a bucket, and mixed to create a mine-dump composite sample. The sample is air-dried and dry-sieved to  $< 2$  mm. The resulting  $< 2$  mm mine-dump composite sample should weigh at least one kilogram. For screening and prioritizing historical mine-waste dumps, use of the  $< 2$  mm size fraction generally should provide a worst-case scenario for metal leachability and appears to be a good choice to reduce the sampling error and reduce the sample size to one reasonable for reconnaissance field collection (K.S. Smith et al., 2000).

### **Metal Leachability Determination**

Leaching tests are one of the main screening procedures used to evaluate and prioritize mine-waste dumps. We sought to develop a test that easily could be performed in the field, could provide on-site pH and conductivity information, and could furnish samples for metal analyses. The Field Leach Test is described in detail by Hageman and Briggs (2000). It is based on the premise that the most chemically reactive material in weathered mine waste consists of relatively soluble components in the fine fraction ( $< 2$

mm) of the waste. The test involves combining 50 grams of < 2 mm mine-dump composite sample (see above) with 1,000 grams of deionized water in a capped one-liter polyethylene bottle. The mixture is vigorously shaken for five minutes, and then allowed to settle for 10 minutes. Specific conductance and pH can be measured in the field, and subsamples can be filtered and preserved for analyses of chemical constituents. Hageman and Briggs (2000) show that results from the Field Leach Test reveal geochemical trends that correlate favorably with results from the routinely used Synthetic Precipitation Leaching Procedure (U.S. Environmental Protection Agency, 1994).

### **Net Acid Production Determination**

There are a variety of methods to determine the potential of a mine-waste material to produce acid. Many of these methods are designed for coal-mine waste or for fresh waste material. For historical metal-mining waste dumps that consist of weathered material, it is necessary to adopt a method that incorporates the potential acid production of secondary and tertiary minerals and the potential acid-consuming capacity of host-rock minerals (e.g., carbonates, chlorite, biotite). We have adopted a slightly modified version of the net acid production (NAP) method of Lapakko and Lawrence (1993). In this method, a sample of pulverized waste material is digested with a heated solution of 30% hydrogen peroxide. Acidic filtrates are titrated to pH 7 and NAP is calculated in terms of kilograms CaCO<sub>3</sub> per metric ton of waste. Fey et al. (2000) demonstrate that mine-waste dumps segregate into different groups when NAP is plotted against either the sum of five leachable metals (arsenic, cadmium, copper, lead, and zinc) or against leachable iron.

### **Microbial Activity Determination**

Microbial processes can contribute to many of the geochemical parameters (e.g., acid production, metal release) determined in mine-waste dumps. The level and type of microbial activity in mine waste may be variable depending on such factors as temperature, acidity, water content, and sunlight. Many techniques, such as culture methods, direct counts, diagnostic molecular methods (e.g., chemotyping of lipids, proteins, cell wall materials), DNA/RNA sequencing techniques, and isotopic fractionation of the "bioelements" C, H, O, N, and S, can be used to determine microbial activity in mine-waste materials. Relative microbiological activities attributable to different groups of bacteria can be determined in the field (or laboratory) using BART (Biological Activity Reaction Tests; Hach Chemical Co., 1998).

### **Toxic Effects of Metals from Mine-Waste Dump Effluent (Aquatic Toxicology)**

Toxicity Identification Evaluation (TIE) procedures (U.S. Environmental Protection Agency, 1991, 1993a, 1993b) offer a biological approach to identify chemical constituents that are potentially harmful to the aquatic environment. We used a modified version of these procedures to expose aquatic organisms to sample manipulations (e.g., increased/decreased pH, dilution, filtration, aeration, ligand titrations) of mine-waste dump leachates. Biological response of the test organisms revealed different types of

toxicant(s) or toxicant characteristics. Metal(s) of biological concern in mine-waste dump effluents can be determined using these TIE procedures.

## **NON-INVASIVE RAPID-SCREENING TOOLS**

### **Remote Sensing**

Swayze et al. (2000a, 2000b) have demonstrated that airborne or orbital imaging spectrometers can be used to map minerals resulting from weathering of acidic mine waste. This approach is based on identifying iron-bearing secondary minerals that form on the surface of mine-waste dumps under acidic conditions. The best indicator mineral for acidic conditions appears to be jarosite. These remote-sensing tools can be used to screen large areas for potentially acidic mine-waste material and to identify sites that warrant closer examination. Hand-held spectrometers also can be used for on-site work.

### **Geophysical Methods**

Combining geological mapping with airborne geophysical surveying facilitates the task of screening large areas to locate historical mine dumps and assigning them initial priorities for further study. Airborne techniques include radiometric, magnetic, and electromagnetic mapping and can be used to map subsurface lithology, structure, and ground-water flow. B.D. Smith et al. (2000) illustrate how airborne geophysical techniques can be applied at both a regional scale (e.g., state) and a local scale (e.g., watershed, mine site). Geoelectrical methods, such as direct current resistivity, electromagnetic, and induced polarization, can be used to study conditions at depth within particular mine-waste dumps. These methods can infer information about lithology, mineralogy (especially sulfide minerals), pore-water saturation, or location of pore water or groundwater containing high total-dissolved solids. Hence, these methods can be used to trace plumes of contaminated water and discern compositional variations in mine-waste dumps. Campbell and Fitterman (2000) and Campbell et al. (1999) provide an overview of geophysical methods in mine-waste characterization.

## **DETERMINING THE RESIDENCE PHASE(S) OF METALS**

In the study of the potential impact of mined sites on the environment, it is important to understand the source(s) of possible metal contaminants, the processes controlling their release into the environment, and their transport mechanisms. The concept of the availability of metals from natural materials, referred to as the geoavailability, is defined as that portion of a chemical element's or a compound's total content in an earth material that can be liberated to the surficial or near-surface environment (or biosphere) through mechanical, chemical, or biological processes. The geoavailability of a chemical element or a compound is related to the susceptibility and availability of its resident mineral phase(s) to alteration and weathering reactions (Smith and Huyck, 1999).

Detailed examination of the residence phase(s) of metals in mine-waste material is necessary to understand the geoavailability of metals in mine-waste dumps. A

combination of X-ray diffraction, bulk chemical analyses, chemical-extraction techniques, and X-ray microanalysis can shed light on metal geoavailability and subsequent mobility from mine-waste material (Smith et al., 1999). This type of information is key to the understanding of processes controlling metal release from mine-waste materials. Once these processes are understood, informed decisions can be made about mitigation, cleanup, disposal, and remediation of mined sites.

### **X-Ray Diffraction**

X-ray diffraction (XRD) methods can be used to identify mineral phases in mine-waste samples. This information can be combined with bulk chemical analyses to try to account for residence phase(s) of chemical constituents. However, weathered mine-waste material commonly contains a significant portion (often as high as 40-50%) of non- or poorly crystalline material that is amorphous to XRD techniques. This amorphous material likely contributes to the geoavailability and subsequent mobility of some chemical elements. Hence, it is necessary to combine XRD methods with other methods that can address the amorphous phases in the mine-waste material.

### **Sequential Chemical Extractions**

In sequential chemical extractions, metals are extracted from some or all of a sequence of operationally defined phases (Chao, 1984). The sequence of extractions exposes the sample to increasingly rigorous chemical treatments. This provides a means for evaluating the potential mobility of metals extracted from the various phases. The operationally defined phases adopted for our work include water soluble, ion-exchangeable, carbonate, amorphous iron oxide, crystalline iron oxide, sulfide, and silicate. Leinz et al. (1999, 2000) describe the details of the sequential chemical extractions used in our work.

### **X-Ray Microanalysis**

Metals of interest generally reside in microscopic phases within mine-waste materials. Microanalysis techniques, including x-ray mapping, x-ray point analysis, and electron microscopy, can locate particles as small as 1 micrometer that contain trace elements. These particles can be individually analyzed to determine mineral chemistry, mineral identification, and weathering sequences.

## **PUTTING MINE SITES INTO CONTEXT**

### **Use of Geologic Information**

Geologic information can contribute a wealth of information about a mined site. For example, geologic setting can provide information about the pH buffering capacity of surrounding rocks, the potential ease of subsurface contaminant transport, and possible routes to receptors. The type of mineral deposit can reveal which metals are present and allow for estimation of the acid-generating and acid-consuming capacity of the waste

material (Plumlee et al., 1999). Knowledge of historical mining, milling, and metal-recovery processes can help determine the efficiency of sulfide removal and anticipate the presence of other contaminants of concern (e.g., mercury, cyanide).

### **Use of Spatial Modeling**

Multidimensional spatial modeling techniques can be used to integrate and synthesize disparate information about a mine site. This approach can be a visually intuitive tool to examine spatial relationships and to view digital data. Yager and Stanton (2000) provide an example of spatial modeling by combining topographical, geophysical, and geochemical data for a mine-waste dump.

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