POTENTIAL METAL RECOVERY FROM WASTE STREAMS

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Introduction

‘Waste stream’ is a general term that describes the total flow of waste from homes, businesses, industrial facilities, and institutions that are recycled, burned or isolated from the environment in landfills or other types of storage, or dissipated into the environment. The recovery and reuse of chemical elements from waste streams have the potential to decrease U.S. reliance on primary resources and imports, and to lessen unwanted dispersion of some potentially harmful elements into the environment. Additional benefits might include reducing disposal or treatment costs and decreasing the risk of future environmental liabilities for waste generators. Elemental chemistry and mineralogical residences of the elements are poorly documented for many types of waste streams.

‘Critical mineral commodities’ can be characterized as those commodities that: (1) are important to the Nation’s economy or security; (2) have few or no satisfactory substitutes; and (3) meet a country’s demand, to a large extent, by imports (Gunn 2014). In 2008, a National Academy of Sciences report described a method for characterizing mineral criticality (National Research Council 2008). Examples of selected critical mineral commodities, major sources and their applications are listed in Table 1.

Table 1. Selected critical mineral commodities, major sources and their applications

Mineral Commodity[1]	Major Sources	Applications
Antimony (Sb)[2,3]	Primary commodity of antimony ores, lead ore byproduct, recycling	Ammunition, cable covering, catalysts, ceramics and glass, flame retardants, friction bearings, lead-acid batteries, pigments, plastic stabilizers, semiconductor devices (e.g., diodes, infrared detectors), solders
Gallium (Ga)[4,5,6,7]	Byproduct of zinc ore and bauxite ore, recycling	Integrated circuits, light-emitting diodes (LEDs), photodetectors, semiconductors, solar cells
Indium (In)[4,7,8]	Byproduct of zinc ore, recycling	Alloys, indium tin oxide (ITO) thin-film coatings for liquid crystal and LED displays, semiconductors, solders
Tellurium (Te)[4,7,9]	Byproduct of copper ore	Free-machining steel, photovoltaics
Rare Earth Elements (REEs)[7,10,11]	Byproduct of copper, gold, iron, phosphate, and uranium ores, primary mining, recycling	Automobile catalytic converters (Ce), battery alloys (La, Ce, Nd), catalytic cracking (La, Ce), ceramics (Y, La, Ce, Nd), glass additives (Ce, La), glass polishing (Ce, La), metallurgy (Ce, La, Nd), permanent magnets (Nd, Pr), phosphors (Y, Ce, Eu, La)

[1] U.S. Geological Survey (2014)
[2] Butterman & Carlin (2004)
[3] International Antimony Association, http://www.antimony.com/
[4] Bleiwas (2010)
[5] Foley & Jaskula (2013)
[6] Moskalyk (2003)
[7] Wilburn (2012)
[8] Indium Corporation, http://www.indium.com/
[9] Selenium-Tellurium Development Association, Inc., http://www.stda.org/
[10] Goonan (2011)
[11] Association for Rare Earth, http://www.rareearthassociation.org/

Rare-earth elements (REEs), which comprise the lanthanide series of elements (Fig. 1) plus Sc and Y, have received considerable attention as critical mineral commodities. REEs are used as components in high-technology devices, and large quantities of some REEs are used in clean energy and defense technologies (see Table 1; Haxel et al. 2002). Although REEs are fairly abundant in the Earth's crust, they do not readily concentrate in deposits that can be economically exploited (Van Gosen et al. 2014). In mature market sectors (e.g., catalysts, glass industry, metallurgy excluding battery alloy, and phosphors), La and Ce account for about 80 percent of REE use; in developing high-technology market sectors, Nd, La, Ce, Pr, Y, and Dy account for about 98 percent of REE use (Goonan 2011).

57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
La	**Ce**	**Pr**	**Nd**	**Pm**	**Sm**	**Eu**	**Gd**	**Tb**	**Dy**	**Ho**	**Er**	**Tm**	**Yb**	**Lu**
Lanthanum	Cerium	Praseodymium	Neodymium	Promethium	Samarium	Europium	Gadolinium	Terbium	Dysprosium	Holmium	Erbium	Thulium	Ytterbium	Lutetium

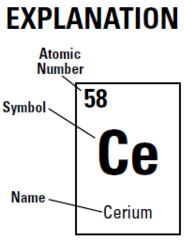

Figure 1. Lanthanide series of elements from the periodic table

Indium is a critical mineral commodity used in relatively significant quantities in liquid-crystal displays (LCDs) and light-emitting diodes (LEDs) (Table 1). Indium can be present in relatively high concentrations in some minerals, particularly sphalerite and chalcopyrite. Elevated concentrations of In have been reported in mineral deposits at: Mount Pleasant, New Brunswick, Canada; Bingham district, Utah; Central district, New Mexico; Central City district, Colorado; Cornwall, England; Balmat-Edwards district, New York; Rammelsberg mine, Germany; Argentina, various areas; Yugoslavia, various areas; Metaline district, Washington; Coeur d'Alene district, Idaho; Pinos Alto district [including the Cleveland mine], New Mexico; and in various areas in Maine, New Hampshire, Connecticut, and Rhode Island (Briskey 2005). Schwarz-Schampera (2014) lists additional locations of In deposits.

Waste streams can contain a variety of chemical elements that might represent untapped resources for metal recovery and reuse. Moreover, there is a growing demand for critical mineral commodities that are being used in high-technology and green-energy applications. For any type of waste stream it is important to note that the economic feasibility, technical feasibility and other aspects of metal recovery need to be evaluated on a case-by-case basis.

The U.S. Geological Survey (USGS) is characterizing diverse waste streams, such as municipal biosolids, slag, mine waters, and mining wastes, for their potential as sources for metal recovery. As part of this effort, the USGS is characterizing waste-stream samples from historical mining to determine the degree to which they contain enriched concentrations of trace elements and how their enrichments vary as a function of mineralogy and mineral deposit type. Some historical metal mining wastes contain critical and valuable commodities that might be recoverable if economically and technologically feasible. In addition, recovery of certain materials could reduce the risk of environmental liabilities (e.g., GAO (U.S. Government Accountability Office) 2006).

Methodology

Example: Waste Streams from Metal Mining

Most modern hard-rock mining operations are required to treat process and drainage water while in operation and may also be required to treat water in perpetuity. Historical metal mining sites can also have drainage waters that require treatment. Mining influenced waters (MIWs) commonly contain elevated concentrations of metals such as Cu and Zn. Revenues generated from the recovery of mineral commodities from MIWs may have the potential to offset a portion of the treatment costs. Some MIWs also contain critical mineral commodities. For example, elements that may be present at relatively high concentrations in porphyry copper deposits include Cd, Co, Ga, In, Ni, and Te (Yano et al. 2013). Smith et al. (2013) describe a framework to conduct a 'metal recovery feasibility assessment' for MIWs and associated treatment sludge.

Solid wastes from historical metal mining operations may represent a possible source of valuable and critical mineral commodities. The USGS has accumulated samples from a variety of historical metal mining wastes and currently is analyzing them for a variety of chemical elements to determine the concentrations and mineral forms of the elements. Analytical techniques for this work include inductively coupled plasma mass spectrometry (ICP-MS), inductively coupled plasma atomic emission spectroscopy (ICP-AES), and instrumental neutron activation analysis (INAA). Selected samples will be characterized using X-ray diffraction (XRD) and scanning electron microscopy (SEM).

Results and Discussion

Trace-element concentrations are quite variable among the mining waste samples analyzed (Fig. 2) for 32 samples from 11 different mineral deposit types. Individual samples from three different mineral deposit types have different trace-element signatures (Fig. 3) for selected trace elements. This variability is a result of the types of mineral deposits, mining and ore-processing techniques, the wide variety of mineral phases that contain trace elements, and the mineralogical variability that can occur within a single ore deposit. The predictability of these trace-element concentrations as a function of mineral deposit type and interaction with the environment is being investigated using geoenvironmental models (Plumlee et al. 1999).

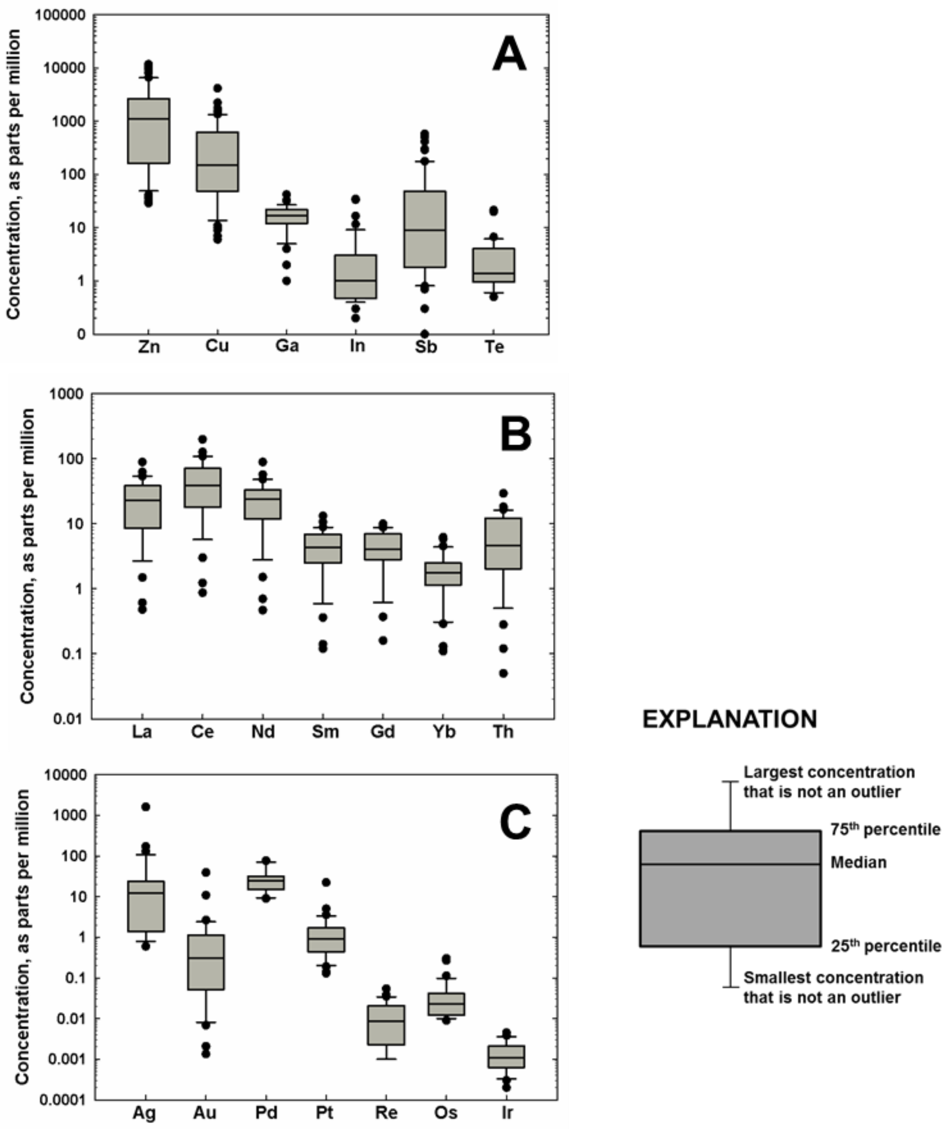

Figure 2. Box plots illustrating the range of selected trace-element concentrations in 32 samples collected from historical mining derived-wastes from 11 mineral deposit types. A, selected elements, analyzed by ICP-AES and ICP-MS. B, rare earth elements and Th, analyzed by INAA. C, precious and platinum-group elements, analyzed by INAA.

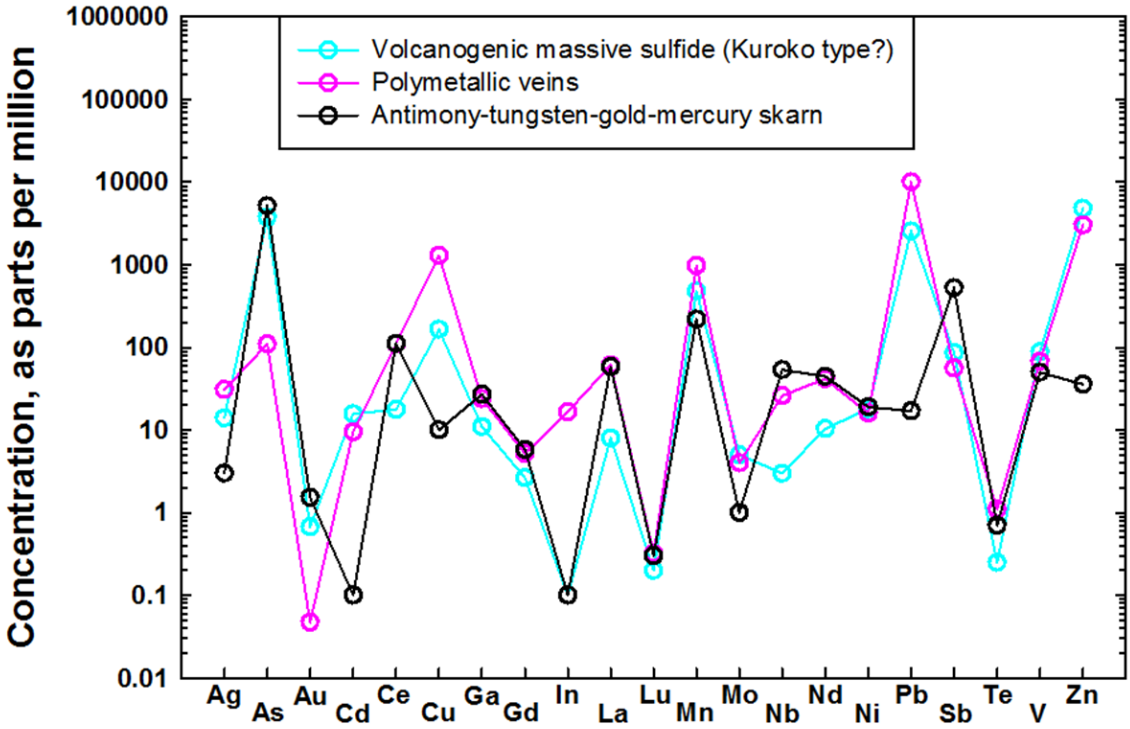

Figure 3. Line plots illustrating the variability of selected trace-element concentrations in three individual historical mining waste samples from three different mineral deposit types analyzed by ICP-AES and ICP-MS, fire assay (for Au), and hydride generation atomic absorption spectrometry (for Te)

Conclusions

Some historical metal mining wastes contain critical and valuable commodities that might be recoverable if economically and technologically feasible. The economic and technical feasibility of metal recovery from historical mining wastes needs to be evaluated on a case-by-case basis. Although metal recovery may not be commercially attractive by itself, removal and recovery can be used to offset treatment and disposal costs and to reduce long-term environmental liability.

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