Metal Recovery from Mine Waters: Feasibility and Options - An Example Assessment from the Colorado Mineral Belt, USA

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Abstract
The high concentration of metals in some mine waters and increasing stringent environmental regulations has led land owners, mining companies, technology companies and even government agencies to consider the potential for metal recovery from impacted water. The Colorado Mineral Belt in the central USA presents examples where research and testing has been carried out to characterize metal loading and potential metal recovery from mine waters and mine waste.

Key words: Mine water, metal recovery

Introduction
This paper provides a review of the limitations that exist for metal recovery from mine water and focusses on case studies from the Colorado Mineral Belt. The Colorado Mineral Belt is a northeast-trending zone that extends from southwestern Colorado, USA, to the north-central part of the state. The Belt hosts numerous precious and base metal deposits within several different mining districts. Many of these deposits were exploited in the late 19th to mid-20th century and have left potentially substantial environmental liabilities in terms of soil, sediment, water, and ecological impacts. In the last four decades, considerable efforts have been put into developing remediation strategies to mitigate environmental impacts at some of these sites. These efforts are costly and, as a consequence, a number of mining sites have not been remediated and still pose an environmental risk. Mine water is currently being treated at several locations where high tracemetal concentrations are a concern. The same contaminant sources potentially represent an opportunity for metal production and an opportunity to mitigate environmental liability.

Mine Water Chemistry
Examples of some of the mining districts are listed in Table 1 along with the anticipated composition of their associated waters. Mine water chemistry is highly dependent on many factors such as ore deposit geology (e.g., mineralogy, element enrichments, host rock type/alteration, spatial zoning), mining methods, and climate.
Mine waters are typically described by $Ca\text{-}Mg\text{-}SO_4 \pm Al \pm Fe \pm HCO_3$ with a broad range in pH and metal content. In many cases, these waters contain metals at concentrations that could potentially impact the environment and downstream drinking water supplies.
Colorado geology reflects a series of mountain ranges and basins that are dominated by the Rocky mountains. These host many of the metal bearing mineral deposits and were formed during the Antler orogeny. A major focus of this is the Colorado Mineral Belt (CMB) that extends from the La Plata Mountains north of Cortez, in Southwestern Colorado to the centre of Colorado near Boulder (Figure 1). This area was a major source of metals in the late nineteenth and early twentieth century from which more than 780 t of gold and more than 1000 t of silver were extracted (Dorset, 2011).
The CMB belt is a northeast-striking zone hosted in a Proterozoic shear zone system with a suite of Laramide-aged plutons and related ore deposits (Tweto and Sims, 1963; McCoy, 2001). The belt lies

within a geologically active zone that was initiated at the time of crustal accretion in central Colorado at least 1.6 billion years ago until the present.

Table 1. *Examples of deposit types and anticipated composition of their associated waters, Colorado Mineral Belt, USA (Plumlee et al., 1995, 1999)*

Mining District	Mineral Deposit Type	pH Range	Mine Water Composition Range (in mg/L)
Summitville; Red Mountain Pass; Red Mountain	Quartz alunite epithermal	1.5 to 3	Fe, Al, Mn = 100s to 1,000s; Cu, Zn = 10s to 100s; As, Cr, Ni, Pb, Co, U, Th = 0.1s to 10s
Cripple Creek-Victor; Eldora; Magnolia	Alkalic Au-Ag-Te veins	> 7	Zn = 0.01s ; U = 0.001s to 0.01s
Central City; Silverton; Creede; Bonanza	Polymetallic veins	Variable	Widely variable depending upon the base-metal sulfide, pyrite and carbonate content of the veins, the type and amount of wallrock alteration, and the location of the mine relative to spatially variable mineralization zones
Leadville; Breckenridge; Rico	Polymetallic vein/replacement	Variable	Widely variable. Vein ores in igneous intrusions produce highly acidic mine water with high levels of Fe, Al, Cu, Zn, Pb. Replacement ores in carbonate rocks produce acidic, Fe-, Pb-, Cu-, and Zn-rich water to near-neutral water that contains high Zn.

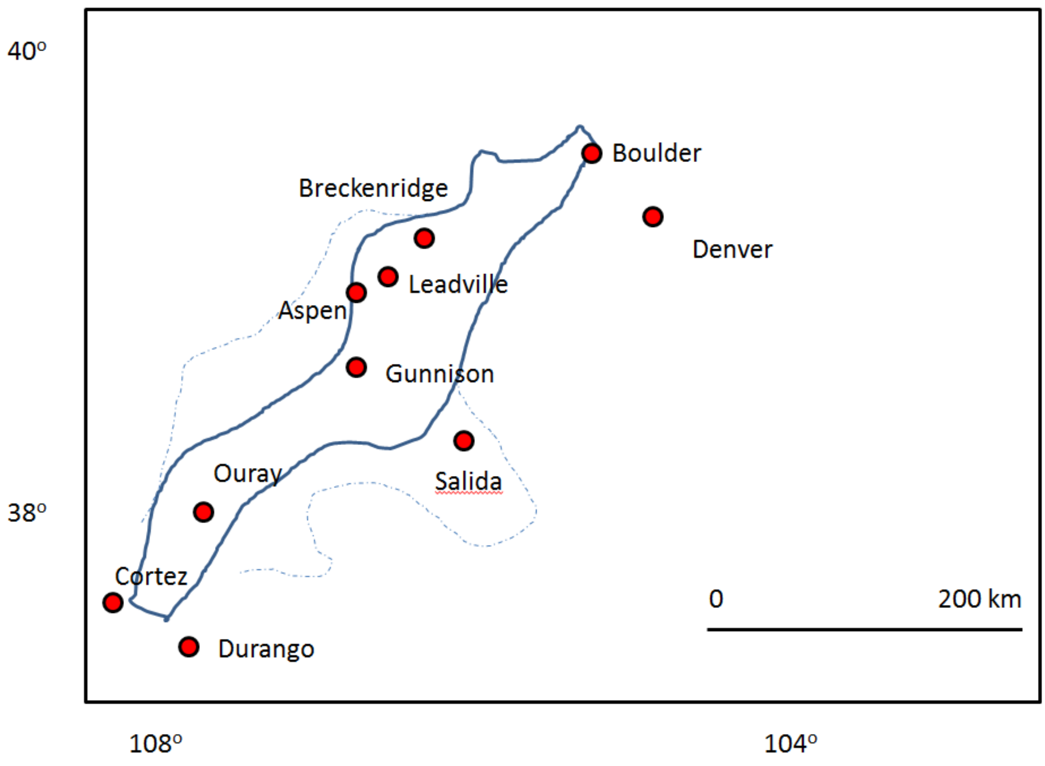

Figure 1: *Schematic of Colorado Mineral Belt (from Tweto and Sims, 1963). Area in solid is the main part of the CMB.*

Host rocks vary from Precambrian age through to Palaeozoic and Mesozoic. Igneous rocks were intruded about 60 to 70 million years ago during the Laramide orogeny. Some mineral deposits are spatial associated with these as well as with younger magmatic bodies of approximately 20-25 Ma in age (Cunningham et al 1994).

Options for Metal Recovery

Some options that exist for metal recovery include:

- Metal precipitation using biogenic produced hydrogen sulfide, such as in the SART, Paques or BioteQ systems;
- Copper cementation using copper reduction on iron metal;
- Direct electrowinning of metals from acid rock drainage (ARD);
- Ion exchange recovery directly from ARD;
- Direct solvent extraction and electrowinning (metals are extracted using conventional hydroxyoxime extractants, stripped using a spent electrolyte solution, and then electrowon in conventional cells);
- Solvent impregnate metal recovery as salts (such as in the Umatilla process) followed by stripping with spent electrolyte and electrowinning to produce copper metal; and
- Hybrid of ion exchange and solvent extraction with a two-stage recovery involving chelation using ion exchange resin and conventional solvent extraction and electrowinning to complete metal recovery (primarily copper).

Mine water treatment options typically employed to mitigate environmental clean-up tend to precipitate or remove metals as one or two products that generally cannot be economically refined to recover value. However, options do exist for selective removal of certain metals, particularly copper, zinc, silver, and uranium, based on existing metallurgical recovery processes. The most commonly applied of these are copper cementation, electro-winning and biological reduction of sulfate or sulfur to produce a metal sulfide concentrate. Initial testwork on mine waters from the San Juan mountains has shown potential for direct metal removal and application of solvent extraction, particularly for metals such as Cu, Zn and Cd, into a potentially economic precipitate.

Conclusions

Metal recovery from mine water could be a source of revenue to offset water treatment costs and at some locations may represent an economic project in its own right. A caveat exists, however, that even if the “ore potential” can be proven, and that the technology will recover economic amounts of metal, there may still be little incentive to “re-mine” many old mining districts. The is because new mining ventures may be held responsible for past mining legacies as well as any new disturbance, and the mere mention of metal value from these old districts might result in legal action from property owners or bankruptcy trustees who could lay claim to any recovered value.

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