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Quantitative mineralogy and geochemistry of pelletized sulfide-bearing gold concentrates in an alkaline heap leach

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ABSTRACT

Sulfide-rich gold mill concentrates from the Cripple Creek & Victor Gold Mining Co. (CC&V) in Colorado, USA were pelletized with Portland cement at 20, 80 or 200 lbs./ton. The hand-formed ~1 in. diameter pellets were leached in a bench-scale heap leach system for 16 weeks in a 0.3 mM NaOH solution at pH 10.5, in a matrix of crushed ore or clear acrylic balls. Leached pellets were sampled every two weeks. The sampled pellets were encapsulated in epoxy, cut, polished, and examined using a field emission scanning electron microscope equipped with an automated mineralogy system. Leachate samples were collected after 2, 4, 6, 8 and 16 weeks and analyzed for major cations. Higher cement concentrations produced pellets with better macroscopic integrity, although microscopically and chemically detectable degradation occurred at all cement concentrations tested. Pellets with 200 lbs./ton cement retained their physical integrity macroscopically throughout the trial, whereas pellets with 20 and 80 lbs./ton cement were significantly fractured within 2 days of leaching. Mineralogical analyses by electron microscopy showed that physical degradation was localized where cement had been removed. The electron microscopy also revealed that all pellets had cement-leached rims by 8 weeks, and sulfide:oxide ratios decreased in most experiments. Leachate concentrations of Ca, Ba and Sr were initially high and decreased over the experiment, consistent with rapid dissolution of cement from the pellets in the first 4 weeks. These results show that pellets will break apart and dissolve on the heap leach pad at all of the tested binder concentrations; thus pelletizing CC&V mill concentrates is not likely to improve leach pad permeability or minimize acid generation. The combination of automated mineralogy, element mapping, and chemical analysis of leachates proved to be an effective means of monitoring leach behavior of fine-grained materials. The Ca element mapping was the most efficient method of monitoring cement binder degradation.

1. Introduction

In the 1970's the US Bureau of Mines developed a protocol to improve heap-leach recovery from fine-grained gold and silver ores by agglomeration (Heinen et al., 1979). Agglomeration increases the permeability of the ore assemblage (Heinen et al., 1979; McClelland and Eisele, 1981; Kawatra et al., 2006), either by adhering the fine grains onto other existing coarse particles, or by adhering the fines together into pellets prior to placing the material on the leach pad (McClelland and van Zyl, 1988). The latter is referred to as fine particle agglomeration or pelletization (Bouffard, 2005). At production scale, the fine particles, a binder, and water or leach solution are combined in a disk pelletizer or a rotary drum, and rounded pellets are generated by tumble growth. For gold ores, the most common binders are Portland cement, lime, or vinyl polymers (Dhawan et al., 2013).

Agglomeration is generally practiced empirically, and few studies have systematically examined the behavior of agglomerated gold ores during leaching. The strength, stability, and permeability of the materials are governed by binder concentration, length of curing period (Heinen et al., 1979) and moisture content (Heinen et al., 1979; Butwell, 1990; Braun and Lehoux, 1993). In column experiments, McClelland and Eisele (1981) found that flow rate peaked at 10 lbs./ton Portland cement, whereas Li and Plouf (1987) achieved a maximum flow rate at 18% moisture, 32 lbs./ton cement binder, and 50 h curing time. However, none of the pioneering studies evaluated the long-term stability of the agglomerates or the impact of binder concentration on factors other than flow rate. Prior to the present study, no published work has examined the physical and chemical changes that occur in agglomerated gold ores during leaching.

Agglomerated ores present an analytical challenge due to their fine-grained nature, and it can be difficult to capture meaningful data in situ in the heap leach environment. Hoummady et al. (2017) developed a protocol for examining the mineralogy of uranium ores agglomerated with a sulfuric acid binder, including qualitative study of the pellets using scanning electron microscopy (SEM) and X-ray diffraction (XRD) analyses before and after leaching. However, these approaches do not quantify the effects of leaching on pellet mineralogy. If fine-grained exogenous material has been introduced to the ore (e.g. a cement binder), quantitative analyses of pellet mineralogy may be needed to differentiate the behavior of the ore from the behavior of the binder.

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A number of mines already implement automated mineralogical analyses of mine plant feed material (e.g. Fandrich et al., 2007; Baum, 2014; Gu et al., 2014); for example characterization of ore prior to milling, or characterization of mill concentrate prior to agglomeration. Other authors have demonstrated that automated mineralogy can be used to characterize the mine wastes produced by ore processing (e.g. Jamieson et al., 2015; Jackson and Parbhakar-Fox, 2016). These and other studies have shown the utility of automated mineralogy on ore processing inputs and outputs; the present work demonstrates that automated mineralogy can also be used as an intermediate step to characterize the behavior of materials during ore processing.

The present study utilizes a multi-faceted approach to document the progressive physical and chemical deterioration of agglomerated gold ores during an alkaline leach, including quantitative SEM-based automated mineralogy and element mapping of a series of pellets extracted from the leach, as well as successive chemical analyses of the leachate.

1.1. Study site

Newmont Mining Corporation's Cripple Creek and Victor Gold Mine (CC&V) is located in a historic mining district in Teller County, Colorado, west of Colorado Springs (Fig. 1). The deposit was discovered in 1891, and high-grade alkalic low-sulfidation epithermal style veins were historically exploited by underground methods. Modern operations started in the 1980's, targeting lower grade disseminated ore comprising gold tellurides, native gold and gold-bearing pyrite (Dye, 2015). The ore is associated with potassium feldspar, biotite, pyrite, carbonates and minor clay alteration (Jensen, 2003). In 1994, CC&V commenced large-scale surface mining of the lower grade ore with gold recovery by valley fill cyanide heap leach.

In February 2014, a milling circuit (Fig. 2) was commissioned at CC&V to exploit ores less amenable to recovery on the existing heap leach pad. The mill circuit features conventional grinding and flotation unit processes with a target particle size (p80) of 150 µm. Flotation concentrate is reground to a p80 of 25 µm and leached in cyanide solution to recover the gold, which is adsorbed onto activated carbon and then transported to CC&V's recovery facility for refinement. In contrast to conventional gold milling operations, the flotation and concentrate tailings are dewatered via thickening and filtration and placed on the active heap leach (Fig. 2). Additional recovery from cyanide-soluble gold in the flotation tailings justifies the processing strategy, but the presence of finely-ground sulfides in the concentrate tailings presents challenges for long-term heap leaching operations. Fine-grained materials can decrease overall heap permeability thereby hindering efficient leaching of ore, and oxidation of sulfide minerals can cause changes in heap chemistry that can protract gold extraction rates.

The goal of this study was to determine whether pellitization could effectively minimize or forestall oxidation of the fine-grained sulfide material. Concentrate tailings were mixed with 20, 80 or 200 lbs./ton Portland cement and formed by hand into one-inch diameter pellets simulating fine particle agglomeration (e.g. Bouffard, 2005). The pellets were leached for 2–16 weeks in a bench-scale reactor system in synthetic leach solution with pH 10.5. Parallel experiments were run with pellets in matrices of crushed ore or clear acrylic balls allowing visual monitoring of the agglomerates. Every two weeks, leachate was sampled and pellets were extracted and examined using a field emission scanning electron microscope equipped with an automated mineralogy system. The automated mineral and element mapping and the chemical analyses of leachate were used to test the hypothesis that pellets with higher binder concentrations would undergo less physical and geochemical degradation during leaching.

2. Methods

2.1. Heap leach reactors

Heap leach experiments were conducted for 16 weeks in a series of rectangular (3 × 3 × 4 in.) acrylic bench-scale reactors in a fume hood (Fig. 3). Each reactor was irrigated with heap leach solution through gravity-fed individual vinyl tubing drip lines at a constant rate of 1 mL

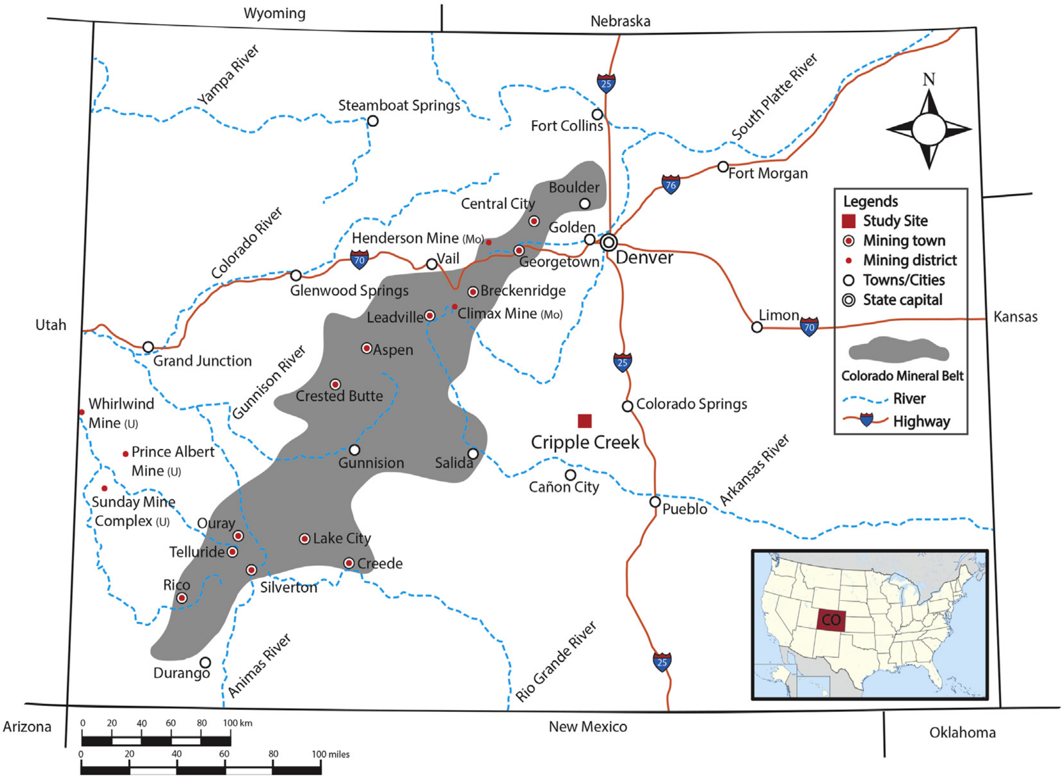

Fig. 1. Location of the Cripple Creek and Victor gold deposit, Colorado.