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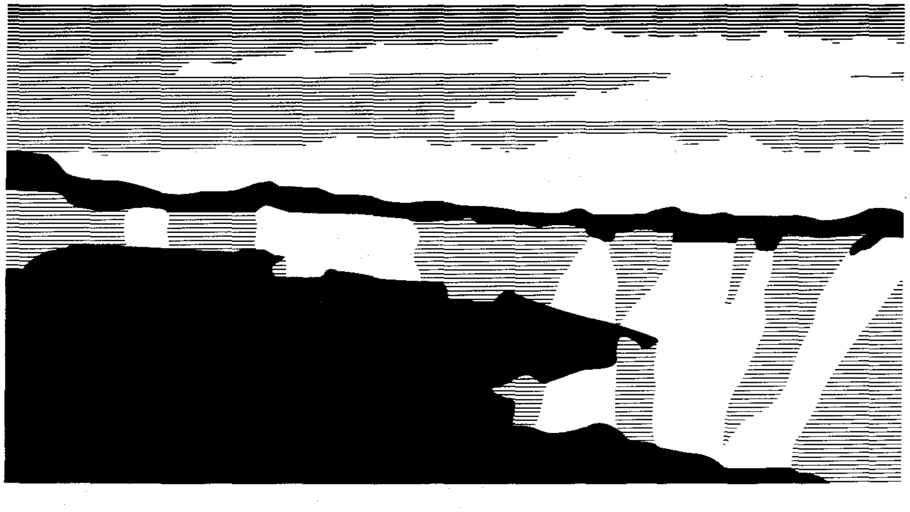

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Metal-residence sites in mine tailings in the Magdalena District, New Mexico, USA

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Abstract: Mineralization in the Kelly Mining Camp is hosted by the Mississipian Kelly Limestone and comprises Zn-Pb skarn, replacement, and vein deposits related to Tertiary intrusive activity. The ore consists of primary (hypogene) sulfide mineralization which has been oxidized near surface to form secondary (supergene) mineralization. A zone of secondary sulfide-enrichment separates the sulfide and oxide ores. Mine tailings in the camp contain primary sulfide, oxide and gangue minerals, secondary (supergene) minerals formed during weathering of the primary ore, and tertiary minerals formed by alteration of hypogene and supergene assemblages after deposition in the tailings impoundment.

1 INTRODUCTION

Currently in North America, mines operate under stringent environmental controls. Environmental concerns have become an important factor in determining the viability of a mine, as costs related to environmental standards may increase the cost of production (and thus, the cut-off grade) of an orebody. Aqueous transport of metals, whether during the formation or degradation of ore deposits, is governed by fundamental processes. Understanding these processes is necessary in order to predict and possibly modify how metals move in our environment. The purpose of this paper is to present preliminary results of a study of the mineralogical residence sites of metals released by weathering of mine tailings in the Kelly Mining Camp of the Magdalena District in New Mexico, U.S.A.

2 GEOLOGICAL SETTING

The Magdalena Mining District is located in south-central New Mexico in the southwest U.S.A. (Fig. 1). Precambrian sedimentary and igneous rocks form the core of the Magdalena Mountains. These are overlain unconformably by west-dipping Upper Paleozoic sedimentary rocks. Tertiary extrusive and intrusive rocks overlie and intrude the Paleozoic rocks, and are in turn overlain by Quaternary alluvial deposits.

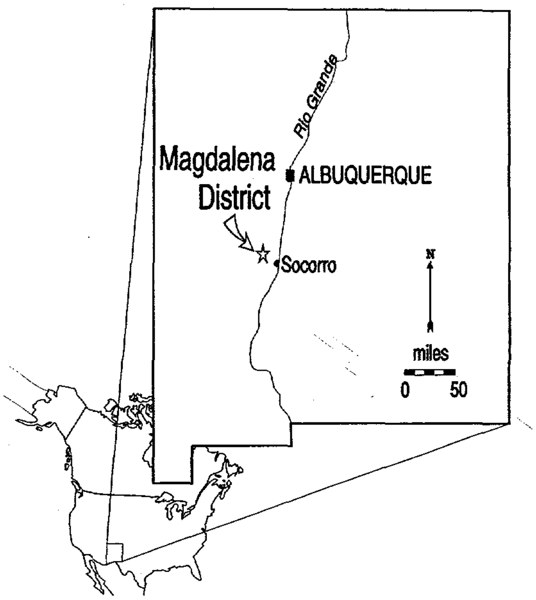

Fig. 1: Location of the Magdalena Mining District in south-central New Mexico, U.S.A.

Mineralization in the Magdalena District is hosted by Upper Paleozoic sedimentary rocks (Loughlin & Koschmann, 1942). The sedimentary sequence comprises the Kelly Limestone (Mississippian age), the

Sandia Formation and Madera Limestone (Pennsylvanian age), and the Abo Sandstone (Permian age). The Kelly Limestone was the most productive of the formations, and hosts the deposits of the Kelly Mining Camp. Throughout the camp, the Kelly Limestone consists of upper and lower calcic limestone separated by a bed of argillaceous limestone. The latter is called the "silver pipe" because of its close association with ore shoots (Loughlin & Koschmann, 1942).

3 PETROGRAPHY AND CHEMISTRY

Mineralization in the Kelly Camp comprises Zn-Pb skarn, replacement, and vein deposits related to Tertiary intrusive activity. The ore consists of primary (hypogene) sulfide mineralization which has been oxidized to form secondary (supergene) mineralization near surface. A zone of secondary sulfide-enrichment separates the primary sulfide and secondary oxidized ores. The hypogene ore assemblage in the Magdalena District is simple, consisting of sulfides of iron, zinc, lead, and copper, and oxides of iron. In contrast, the supergene ore assemblage is complex. It includes native copper and copper sulfides, as well as oxides, sulfates, carbonates, and silicates (many of them hydrous) of zinc, lead, copper, and iron (Table 1).

A combination of optical microscopy, X-ray diffraction (XRD), scanning electron microscopy (SEM) and electron microprobe analysis were used to identify the nature and composition of samples of mine tailings from the Kelly Camp. The samples contain primary sulfide, oxide, and gangue minerals, secondary (supergene) minerals formed *in situ*, and tertiary minerals formed by alteration of hypogene and supergene assemblages after deposition in the tailings pile. As alteration of primary ore minerals after deposition in the tailings pile may give rise to the same mineral species that are present in the secondary assemblage, genetic differentiation is based mainly on textural characteristics. Features such as continuous reaction rims and coating on grains are interpreted to have formed in the tailings pile; the constituent minerals are part of the tertiary assemblage (Figs. 2-5).

Primary ore minerals present in the tailings include pyrite, sphalerite, galena, chalcopyrite, and magnetite, all of which exhibit varying degrees of dissolution and alteration. Alteration products commonly consist of fine-grained mixtures, making quantitative analysis difficult. However, it is clear that metals released by weathering of primary minerals have been incorporated into tertiary phases.

Table 1. Ore Minerals in the Magdalena District*

Hypogene

Oxidized
Fe: limonite/goethite, hematite, jarosite, melanterite
Zn: smithsonite, hydrozincite, aurichalcite, hemimorphite, chalcophanite, goslarite, willemite
Pb: cerussite, anglesite, plumbojarosite, wulfenite, vanadanite
Cu: malachite, azurite, aurichalcite, chrysocolla, cuprite, tenorite, spangolite, cyanotrichite, antlerite, chalcanthite, native copper

Sulfide Enrichment
Cu: chalcocite, covellite

Supergene

Fe: pyrite, pyrrhotite, hematite, magnetite
Zn: sphalerite
Pb: galena
Cu: chalcopyrite, bornite

* from Loughlin & Koschmann (1942)

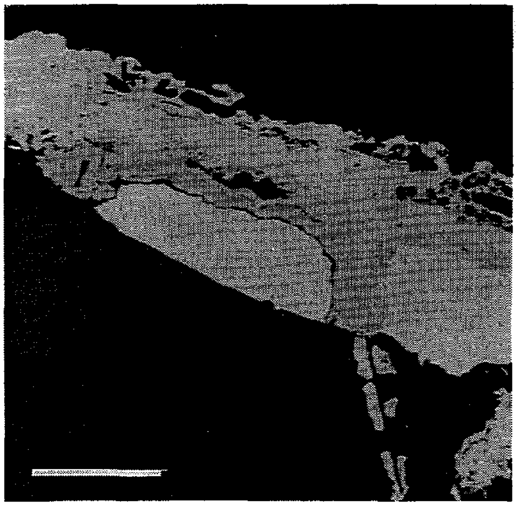

Fig. 2: Backscattered-electron image of intergrown galena (white) and sphalerite (dark grey). Alterion of galena consists of lead sulfate on outside surface and lead oxide(?) adjacent to galena. Scale bar: 50 µm.

Primary pyrite commonly is corroded and altered to iron oxide or iron oxyhyroxide. In some samples, energy-dispersive X-ray (EDX) spectra of suspected iron oxides/oxyhydroxides exhibit zinc or copper peaks. This is consistent with solid-substitution of copper, zinc, and other trace metals in synthetic goethite (Gerth, 1990). Iron sulfate does not occur in alteration zones on iron sulfides, but likely is a component of fine-grained mixtures in coatings on grains.

Some galena grains are altered to lead sulfate and possibly lead oxide on exposed surfaces and along fractures (Fig. 2). Others are rimmed by fine-grained material which may contain a mixture of plumbojarosite and goethite. According to Jambor (1994), goethite and jarosite are two of the principal secondary products of the oxidation of iron sulfides.

Sphalerite grains commonly are corroded and coated with fine-grained material (Fig. 3). The compositions of the coatings vary from grain to grain, possibly because of variations in local chemical environments in the tailings, as well as variations in the iron content of the sphalerite. EDX spectra suggest that some of the coatings consist of jarosite. The fact that jarosite is capable of incorporating numerous elements in solid-solution (Jambor, 1994) may account for presence of zinc peaks in the spectra. Other sphalerite grains are rimmed by fine-grained zinc silicate (Fig. 3). A feathery tertiary phase containing iron, zinc, copper, and sulfur has been observed along the surface of one corroded sphalerite grain (Fig. 4). Although this phase has not been unequivocally identified, it may be related to filiform tertiary sulfates described by Jambor (1994, Fig. 3.9).

Calcite grains typically exhibit inward-growing reactions rims of zinc sulfate and bladed overgrowths of gypsum, formed during carbonate-buffered reactions with metalliferous acidic solutions (Fig. 5). Although zinc sulfate is highly soluble in tailings environments (Jambor, 1994), it is possible that the gypsum overgrowth prevented dissolution of zinc sulfate after it formed. Carbonates of lead, zinc, and copper have not yet been identified, likely because of the limitations of the analytical techniques employed thus far rather than the actual absence of these minerals. Future work will be directed at identifying these phases, as they are common products of the oxidation of Pb-Zn-Cu ores (Alpers et al., 1994).

In addition to precipitation as metal oxides, sulfates, and silicates (and possibly carbonates?), metals may be incorporated into secondary/tertiary minerals through ion exchange. Although textural relationships are ambiguous, obscurring the timing of formation, EDX spectra of vermiculite alteration products of biotite indicate the presence of zinc. This relationship has been documented in soils developed on glacial sediments in Canada, and has been attributed to

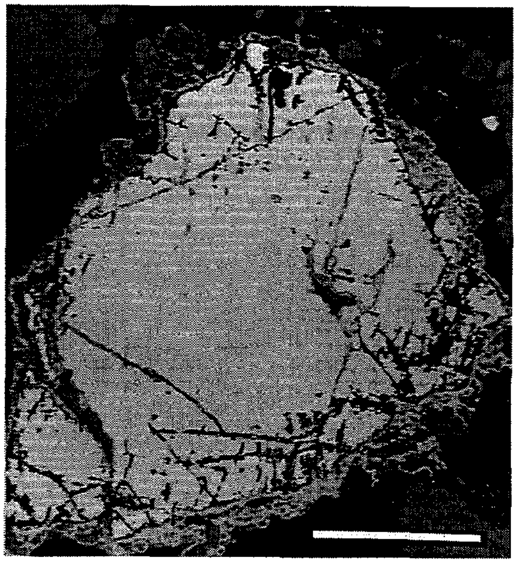

Fig. 3: Backscattered-electron image of corroded grain of sphalerite coated by rim of zinc silicate (light grey) with grains of calcite(dark grey). Scale bar: 500 μm.

Fig. 4: Backscattered-electron image of sphalerite grain with feathery tertiary phase along surface and in fracture. Scale bar: 25 μm.

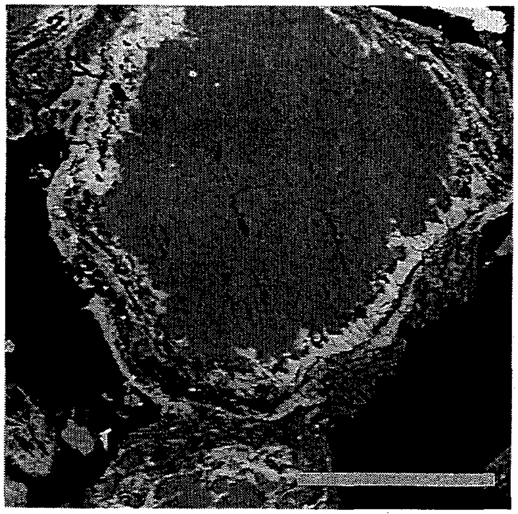

Fig. 5: Backscattered-electron image of calcite grain with inward-growing reaction rim of zinc sulfate (white) and bladed overgrowths of gypsum (dark grey). Scale bar: 200 µm.

progressive incorporation of zinc through ion exchange during weathering of biotite (Larocque et al., 1993). In addition, similar incorporation of copper into vermiculite has been observed associated with weathered copper mineralization in Brazil (Ildefonse et al., 1986) and in products of experimental weathering of biotite (Ilton et al., 1992).

4 CONCLUSIONS

In tailings in the Kelly Mining Camp, tertiary sulfate, silicate, and oxide minerals provide important sinks for metals released by chemical weathering of primary and secondary ore minerals. In addition to precipitation as metal compounds, metals have been incorporated into secondary/tertiary minerals through ion exchange.

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