Title:

PROCEEDINGS TITLE:
MINERAL DEPOSITS: FROM THEIR ORIGIN TO THEIR
ENVIRONMENTAL IMPACTS

TITLE OF PAPER:

METAL-RESIDENCE SITES IN MINE TAILINGS IN THE
MAGDALENA DISTRICT, NEW MEXICO, USA

APR 18 1996

OSTI

Author(s):

A. C. Larocque, C. E. Chapin, A. W. Laughling,
D. D. Hickmott

Submitted to:

3rd Biennial SGA Mtg.
Prague, August 1995

Los Alamos
NATIONAL LABORATORY

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the University of California for the U.S. Department of Energy under contract W-7405-ENG-36. By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. The Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy.

MASTER

Form No. 836 R5
ST 2629 10/91

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

at

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

Adrienne C.L. Larocque
*Department of Geological Sciences, University
of Manitoba, Winnipeg, Man., Canada*

Charles E. Chapin
*New Mexico Bureau of Mines and Mineral Resources,
Socorro, N.Mex., USA*

A. William Laughlin
ICF Kaiser Ltd, Los Alamos, N.Mex., USA

Donald Hickmott
*EES-1, MS D462, Los Alamos National Laboratory,
N.Mex., USA*

Abstract: Mineralization in the Kelly Mining Camp is hosted by the Mississippian 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 (Laughlin & 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, vanadinite
 Cu: malachite, azurite, aurichalcite, chrysocolla, cuprite, tenorite, spangolite, cyanotrichite, antlerite, chalcantinite, 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). Alteration of galena consists of lead sulfate on outside surface and lead oxide(?) adjacent to galena. Scale bar: 50 μ m.

Primary pyrite commonly is corroded and altered to iron oxide or iron oxyhydroxide. 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 plumbogjarosite 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, obscuring the timing of

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 μ m.

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

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. 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 μ m.

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.

REFERENCES

- Alpers, C.N., D.W. Blowes, D.K. Nordstrom & J.L. Jambor 1994. Secondary minerals and acid mine-water chemistry. In J.L. Jambor & D.W. Blowes (eds.), *Min. Assoc. Canada Short Course* 22:247-270.
- Gerth, J. 1990. Unit-cell dimensions of pure and trace metal-associated goethites. *Geochim. Cosmochim. Acta* 54:363-371.

Ildefonse, P., A. Manceau, D. Prost & M.C.T. Groke 1986. Hydroxy-Cu-vermiculite formed by the weathering of Fe-biotites at Salobo, Carajas, Brazil. *Clays Clay Min.* 34:223-345.

Ilton, E.S., D. Earley III, D. Marozas & D.R. Veblen 1992. Reaction of some trioctahedral micas with copper sulfate solutions at 25°C and 1 atmosphere: an electron microprobe and transmission electron microscopy investigation. *Econ. Geol.* 87:1813-1829.

Jambor, J.L. 1994. Mineralogy of sulfide-rich tailings and their oxidation products. In J.L. Jambor & D.W. Blowes (eds.), *Min. Assoc. Canada Short Course* 22:59-102.

Larocque, A.C.L., H.W. Nesbitt, R.N.W. DiLabio & G.D. Guthrie 1993. Fixation of Zn by vermiculite in weathered glacial sediments. *Geol. Soc. America Abstr. Prog.* 25:A234.

Loughlin, G.F., & A.H. Koschmann 1942. *Geology and Ore Deposits of the Magdalena Mining District, New Mexico*. U.S. Dept. Interior, Prof. Paper 200, 168 p.

FROM THE SAME PUBLISHER:

Blenkinsop, Tom G. & Paul L. Tromp (eds.) 90 5410 6107
Sub-Saharan economic geology
 (Geological Society of Zimbabwe Special Publication nr.3)
 May 1995, 25 cm, c.300 pp., Hfl.165/\$95.00/£61

Emphasis is on new mines, new exploration activity and methods, and new ideas in the Sub-Saharan sector. *Topics:* Base metals, greenstones and ultramafic rocks; Softrock, hydrogeology, geophysics and diamonds; Gold at any price; Structural geology; Shamva Greenstone belt; Coalbed methane & Karoo.

Kesse, G.O. 90 6191 5899
The mineral and rock resources of Ghana
 1985, 25 cm, 624 pp., Hfl.270/\$135.00/£100

Importance of minerals; Ghana: Geography, physiography, geology & geohydrology; Mineral resources of Ghana: background; Metallic & non-metallic minerals; Bulk construction materials; Radioactive minerals; etc. Author: Director Geol. Survey Dept. of Ghana.

Bhaskar Rao, B. 90 6191 4833
Metamorphic petrology
 1986, 22 cm, 190 pp., Hfl.120/\$70.00/£45 (No rights India)
 Experimental petrology; Techniques used to decipher the genesis of metamorphic rocks; Introductory thermodynamics: Understanding the history of metamorphic rocks.

Abramovich, I.I. & I.G. Klushin 90 6191 9320
Geodynamics and metallogeny of folded belts
 1990, 24 cm, 255 pp., Hfl.150/\$85.00/£55
 (Russian translations series, 78) (No rights India)
 The concept of 'metallogeny of lithospheric plates' specially resorting to geodynamic modelling. Different geodynamic situations of metallogeny on global perspective and specific situations for the formation of copper-molybdenum, tin-wolfram, mercury, lead-zinc and fluorite provinces. Geodynamic models; Metallogenic investigations of geodynamic models; Paramount indicators of the geodynamic regime; Copper-Molybdenum porphyry ore provinces; etc.

Page, Maurice (ed.) 90 5410 0206
Source, transport and deposition of metals - Proceedings of the SGA Anniversary Meeting, Nancy, 30 August-3 September 1991
 1991, 25 cm, 850 pp., Hfl.245/\$140.00/£91

Ladeira, E.A. (ed.) 90 6191 1958
Brazil Gold '91 - The economics, geology, geochemistry and genesis of gold deposits - Proceedings of the symposium Brazil Gold '91, Belo Horizonte, Brazil, 13-17 May 1991
 1991, 25 cm, 844 pp., Hfl.225/\$130.00/£85

Foster, R.P. (ed.) 90 6191 504 X
Gold 82: The geology, geochemistry and genesis of gold deposits
Proceedings of the symposium Gold '82, University of Zimbabwe, 24-28 May 1982
 (Geological Society of Zimbabwe Special Publication, 1)
 1984, 25 cm, 764 pp., Hfl.270/\$165.00/£100

Akrakhodzhayev, A.M., V.A. Babadagly & A.D. Dzhamugulov
Geology and exploration of oil- and gas-bearing ancient deltas
 1989, 24 cm, 213 pp., Hfl.165/\$95.00/£61 90 6191 907 X
 (Russian translations series, 69) (No rights India)
 Geological structure of deltas; Thermodynamics & geochemistry of sedimentary rocks: Generation & accumulation of hydrocarbons; Oil- & gas-bearing ancient deltas in the USSR & other countries; Methods of studying the oil & gas potential of ancient deltas; etc.

Oti, M.N. & G. Postma (eds.) 90 5410 614 X
Geology of Deltas
 June 1995, 28 cm, c.340 pp., Hfl.195/\$115.00/£73
 Deltas occur on every continent across the earth and their deposits span the geological record from the Precambrian to the Holocene. The book presents an in-depth exposition of some of the world's deltas, presented at the IAS sponsored international symposium, Port Harcourt, Nigeria, 1992. General considerations; Delta facies and architecture; Aspects of sedimentary petrology and diagenesis in deltas; Niger Delta: Exploration and production perspectives. 21 papers.

Bickle, M.J., A. Martin, E.G. Nisbet & J.L. Orpen (eds.)
The geology of the Belingwe Greenstone Belt, Zimbabwe: A study of Archaean continental crust
 1993, 25 cm, 248 pp., Hfl.165/\$95.00/£61 90 5410 1202
 Stratigraphy of the Belingwe Greenstone Belt: Complexity of the tectonic setting; Structure and metamorphism of the Belingwe Greenstone Belt and adjacent granite-gneiss terrain: The tectonic evolution of an Archaean craton; The Mchingwe Group in the West: Andesite, basalts, komatiites and sediments of the Ilkonui, Bend and Koodoovale Formations; Sedimentology of the Brooklands Formation, Zimbabwe: Development of an Archaean greenstone belt in a rapidly rifted graben; etc. 9 papers.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

All books available from your bookseller or directly from the publisher:
 A.A. Balkema Publishers, P.O. Box 1675, Rotterdam, Netherlands
 For USA & Canada: A.A. Balkema Publishers, Old Post Rd, Brookfield, VT, USA