The Role of Weathering in Trace Metal Distributions in Subsurface Samples from the Mayday Mine Dump near Silverton, Colorado

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ABSTRACT

Geochemical and mineralogical analyses of 46 samples from six drill cores in the Mayday mine pile near Silverton, Colorado, demonstrate wide variability in trace metal contents with spatial location. This variability results from the original geochemical composition of mined rocks, mixing of ore and non-ore rocks during emplacement of the pile, and weathering since rocks were placed in the pile. Weathering reactions are controlled by factors such as pile thickness (depth), water availability, microbial activity, and mineral dissolution and formation kinetics. These factors result in variable redistributions of trace metals from primary (ore) to secondary (weathering products) minerals within each core.

INTRODUCTION

The ability of mine wastes in the western US to produce acidity and dissolved metals that may find their way into receiving waters is influenced by many factors. These include climate, host rock composition and mineralogy, material grain size and reactivity, thickness of the mine waste pile (depth to soil or bedrock), surface and ground water availability, microbial activity, and mineral dissolution and formation kinetics.

Studies of trace metal distributions in mine dumps are usually restricted to surficial samples, primarily because of ease of collection and accessibility, and resultant lower overall costs. In addition, most investigators assume that surface samples represent the most geochemically active component of mine wastes because they are exposed to the atmosphere and precipitation, and thus, weathering and mineral dissolution. Although drill cores are more expensive to obtain, they provide unique opportunities to examine metal mobility and geochemistry at different depths in abandoned mine dumps. Examination of the distribution of metals and minerals in drill core samples from depths up to six meters (19 ft) in the Mayday mine dump near Silverton, Colorado suggest that weathering processes similar to those at the surface also occur at depth and cause some trace metals to be mobile in the subsurface.

The spatial distribution of trace metals within primary (formed during ore emplacement) and secondary (formed by weathering) minerals at different locations in the Mayday mine dump indicates the metals owe their distribution to the following factors: 1) original geochemical composition of host (non-ore) and ore rocks, 2) initial placement of host and ore rocks onto the waste pile during mining, 3) oxidative weathering and differential solubilities of primary (ore) minerals, primarily sulfides, 4) formation of secondary minerals, primarily iron-sulfate salts, 5) microbial activity that affects the mobility of metals such as iron, and 6) aqueous (chemical) and hydrologic (physical) processes that affect downward and lateral movement of trace metals in the pile.

SITE DESCRIPTION

The Mayday mine dump is considered a "mine waste" pile. That is, the economic value of the site material was not sufficient to be sent to a mill for further processing. In contrast, a "mine tailings" location would be a waste pile produced by milling processes. The difference is usually one of grain size;

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mine wastes consist of a wide range of grain sizes with variable ore and gangue content, while mill tailings wastes consist of smaller grain sizes, and usually higher ore but lower gangue content. In this paper, "mine dump" and "mine pile" are used interchangeably to denote mine wastes such as the Mayday pile that were not transported to a mill for further processing.

Surface rocks at the Mayday pile are variably stained by fine-grained, secondary (weathered) minerals, mainly red-to-orange iron oxides and yellow-to-gray jarosite type minerals (of the general formula [$KFe_3(SO_4)_2(OH)_6$]). Both iron-oxide and jarosite are inclusive terms used here to denote the fine-grained pile material that likely formed via oxidative decomposition of metal sulfide minerals, primarily pyrite (FeS_2), sphalerite (ZnS), and galena (PbS). Jarosite is used here to denote trace metal- (i.e., Fe, Pb, Zn) and SO4- bearing phases. The compositions of the jarosite-type minerals in the pile vary widely (G. Desborough, USGS, written comm., 1999). Oxidative weathering of sulfide minerals can lead to release of metals, along with production of sulfate and acid.

The Mayday mine site is 4 km (2.5 mi) north of the town of Silverton on State Highway 110 in San Juan County, Colorado (Figure 1). The pile is located 30 m west of Cement Creek at an elevation of 3035 m (9960 ft). The Mayday pile consists of two benches composed of mine dump material. The upper bench abuts the forested hillside to the west while the lower bench slopes down to meet the Cement Creek road to the east. The lower bench road (Figure 1) that divides the pile from north to south is generally devoid of mine waste material. Figure 1 shows the pile in plan view and profile view [looking from the south]. The pile height from the Cement Creek road to the forested hillside is approximately 21 meters (70 ft), and including both benches, approximately 80 meters (250 ft) long by 50 meters (150 ft) wide (surface area =4,000 m^2). Only the upper bench and slope, and eastern slope of the lower bench, have significant amounts of mine waste present. Of the six holes drilled, four are on the upper bench (1-4), one is on the lower bench near the foot of the upper bench slope (5), and one is at the foot of the lower bench next to the Cement Creek road (6). Drill hole locations are shown in the plan view on Figure 1. Drill hole 3 is in a scoured part of the upper bench and is approximately three m (10 ft) lower than holes 1, 2, and 4.
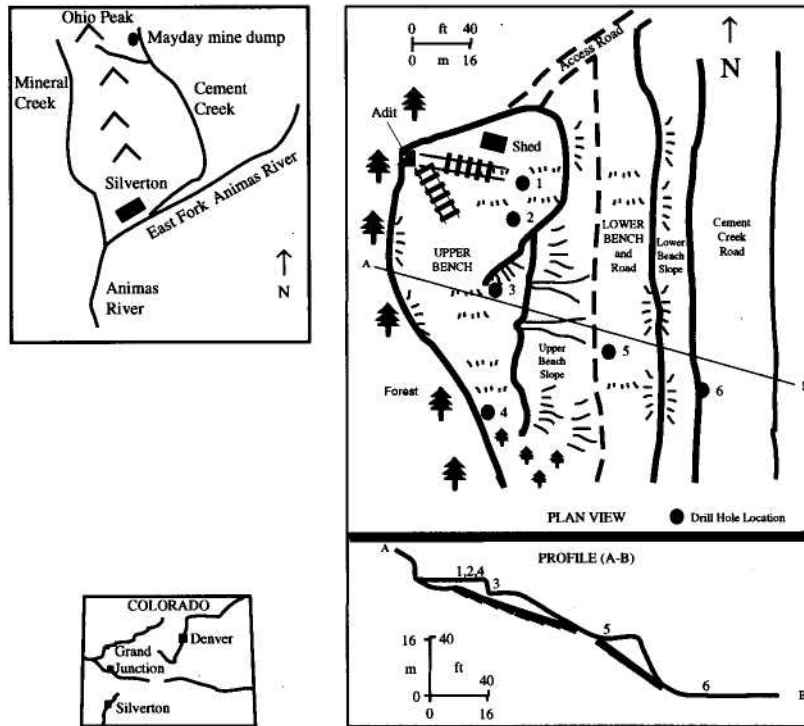

Figure 1 Location maps and plan and profile views of Mayday mine pile, showing approximate locations of the six drill holes, mine dump benches, and roads

The greatest thickness of the mine dump cored during the drilling operation was at drill hole 1, which reached a soil horizon just below 6 m (19 ft). The dump is thinner towards the mountainside (west) and Cement Creek road (east). The shallowest hole drilled was hole 5, a depth of three m (10 ft).

The pile is barren of vegetation except for sparse plant cover over the upper bench surface and about a dozen small (<2 m tall) spruce trees growing at the edge of the pile near hole 4. The vegetation on the adjacent mountainside consists of dense mixed pine, fir, and spruce forest with abundant plant cover on the ground surface. Extensive workings and relict ore-car rails and ties are on the surface of the upper bench and near the adit (Figure 1).

Climate, **Precipitation, and Drainage**

The site is within a montane biogeographic zone characterized by heavy snowfalls from about October to April that result in deep accumulations of snow. Snowpack depth prior to spring runoff may often exceed 6 m (19 ft). From about May to September, the area is subject to intermittent rain showers that vary in intensity from light to heavy, and in duration from a few seconds to several minutes or hours. Thus, these rainstorms produce variable amounts of precipitation that fall on the Mayday pile surface. Although no major drainage traverses the mine pile, small rills, depressions, and erosional features on the benches and slopes indicate the Mayday pile receives intermittent runoff over the surface and along its edges. However, precipitation at the Mayday site is sporadic and the actual amount of runoff over the pile will depend upon the time of year and local weather conditions.

Mining and Geology

Production and mining records specific to the Mayday mine are generally lacking, but local records from other mines indicate the period of greatest activity was from approximately 1910 to 1950 (Bird, 1992). During mining, material was initially separated by placing non-ore rocks (gangue) at the outer (southern) edges of the mine dump while metal-rich ore-rocks were delivered to haulage trucks in an area close to the mine workings. Old but still visible ore-car rails and ties show that ore delivery to trucks took place due east of the adit, while gangue and/or less-enriched ores were deposited south of the adit (see Figure 1).

The host rock for the Mayday mine is the Burns Formation, one of 3 major volcanic units in the San Juan Mountains (Lipman et al. 1973). The Burns Formation is composed primarily of light-to-dark gray silicic lava flows of rhyolitic composition. Flows up to 250 m thick have been recognized in several areas of the San Juan Mountains (Lipman et al. 1973). Fresh clasts and outcrops of the Burns Formation near the Mayday mine dump are brown-gray in color and generally free of iron-oxide coatings.

DRILLING AND SAMPLING PROCEDURES

Locations of the six drill cores from the Mayday pile are shown in Figure 1. From these six complete cores (which consisted of as many as 5 individual "drives" or lengths), 46 subsamples were obtained. The subsamples were selected in the field based on differences in lithology (sulfide-bearing vs unmineralized bedrock), grain size, alteration as indicated by iron oxide or jarosite (iron-sulfate) staining or rinds, and the presence/absence of clays or clay-sized material and organic matter. Visible organic material consisted primarily of pieces of mine timbers strewn within the pile rocks, with minor contributions from small plant rootlets and plant remains from the nearby forest. Few macroscopic differences were apparent in the samples with the exception of major iron-oxide (red) and jarosite (yellow) staining, or minor manganese-oxide (black) staining. Therefore, sample separation was based primarily upon staining colors that suggested potential differences in alteration and weathering of the mine dump rocks.

After completion of core length descriptions and separation into the 46 subsamples, the material was sealed in plastic bags for transport to the laboratory. Two additional subsamples (10 g each) were taken from each core subsample on-site for microbial analysis to determine if iron- or sulfur-oxidizing microbes were present in the pile.

The midpoint depth of a sample interval defines sample locations. For example, sample H5-C2-M covers the interval from 2.4-2.8 m (5.0-6.0 ft); its midpoint depth is thus 2.6 m (5.5 ft). These midpoint values are used to refer to samples in the data tables and to locate samples on downhole plots.

ANALYTICAL METHODS

Core samples were air-dried, split, powdered to <230 mesh (57 micron) using a shatterbox, then analyzed by inductively coupled plasma-atomic emission spectrometric analysis (ICP-AES) for 40 elements. Details of sample preparation and analytical techniques for this method can be found in Briggs (1990). Duplicate samples and quality assurance and quality control (QA/QC) standards were included with each batch of samples analyzed. The powdered samples were also analyzed for total carbon [$C_{(tot)}$] and total sulfur [$S_{(tot)}$] by induction furnace methods (Curry, 1990a; 1990b).

For bulk X-ray diffraction work (XRD), a separate sieved aliquot of a <230 mesh composite sample was prepared as a packed powder mount and scanned with an X-ray diffractometer using Ni-filtered Cu K_a radiation. The analytical parameters for all samples analyzed were as follows: generator settings of 40 Kv and 25 mA, step size of 0.025, and a one-second count time from 4°-65° 26. The detection limit of a mineral phase with this method is >5 weight percent.

Mineralogical results in composite samples are reported as major (concentrations of >25% by weight), minor (concentrations of >5 to <25% by weight), or trace (concentrations <5% by weight). Major, minor, and trace designations are for qualitative purposes only and to convey relative abundances of crystalline phases detected in a sample.

MINERALOGY OF ORE AND NON-ORE (HOST) ROCKS

Sulfides are the major ore minerals in the Silverton Mining District. Galena (PbS), sphalerite (ZnS), pyrite (FeS_2), and chacopyrite ($CuFeS_2$) are found in many ore bodies (Lipman et al. 1973). Mineralogical and geochemical analyses done for this report indicate "intact" (unweathered) ore minerals in the mine dump have retained their metal signatures. Gangue minerals present in the ore rocks include quartz and feldspars.

Secondary minerals are those solid phases that have formed at near-surface conditions via [acidic] weathering processes. These are primarily hydrous iron- and sulfate- bearing minerals such as jarosite-group [$KFe_3(SO_4)_2(OH)_6$] and copiapite-group [$Fe_4(SO_4)_6(OH)_2 \bullet 20H_2O$] minerals. These two groups comprise many minerals that vary in composition as a result of metal substitution. Other important iron and sulfate phases are alunogen [$Al_2(SO_4)_3 \bullet 18H_2O$] and rhomboclase [$HFe(SO_4)_2 \bullet 4H_2O$]. Qualitative XRD analyses of the <230 mesh fraction from Mayday subsurface samples show mixtures of varying proportions of ore sulfides and secondary phases.

MICROBIAL ACTIVITY

Iron- and sulfur- oxidizing bacteria of the genus _Thiobacillus_ have been shown to be active geochemical agents in the oxidative weathering of sulfide minerals and production of acid drainage (Nordstrom and Southam, 1997). Determination of populations of these bacteria was undertaken for several samples, and results show greater numbers of two species, _Thiobacillus ferrooxidans_ (iron-oxidizers) and _Thiobacillus thiooxidans_ (sulfur-oxidizers), are present in ore samples compared to non-ore samples.

The field subsample was sieved to select grains smaller than <63 mesh (0.23 mm) size for microbial isolations. Larger grains were not used because earlier work at a mine site near Leadville, Co (Stanton et al. 1997), had shown thiobacilli were nearly always present in finer-grained (fine sand, silt, and clay) fractions.

Laboratory media selective for _Thiobacillus ferrooxidans_ and _Thiobacillus thiooxidans_ were prepared according to formulations by Atlas (1995) and Gerhardt et al. (1994), respectively. In addition to an initial low pH (<4.0), the principal features of these media are the presence of a reduced iron source (Fe^{2+}) for _Thiobacillus ferrooxidans_ or a reduced sulfur source (thiosulfate) for _Thiobacillus thiooxidans_. Solid 1.0 g samples were first placed into 9 mL of sterile 1% NaCl for use as the primary inoculum. Culture tubes of the selective broth media were then sequentially inoculated starting with 1 mL of the saline suspension up to 10"3. The inverse of the highest dilution factor (D.F.) at which growth was observed was used as the number of cells for that sample, for example, growth observed at the 10"3 D.F. = 1,000 cells/g.

AQUEOUS AND HYDROLOGIC MEASUREMENTS

The drill holes were completed as piezometers to monitor changes in water levels and water chemistry. Measurement of water levels (W. Wright, USGS, written comm., 1999) show liquid water is available at

most times of the year in the Mayday subsurface, but the amounts recovered from wells are small (<100 mL). Infiltration into the pile is limited and well levels reach their peak only during spring runoff, primarily via input from a small drainage west of the dump. Aqueous chemistry results indicate metal loads increase slightly during high flow periods (W. Wright, USGS, written comm., 1999). Flow paths in the pile are difficult to discern because of highly-variable "packing" of mine dump material and the wide variety of grain sizes that can impede or enhance subsurface water flow.

RESULTS AND DISCUSSION
Trace and Major Element Distributions
The downhole plots for the cores from holes 1, 2, and 3 in Figure 2 illustrate selected major and trace element abundances seen in most samples. Major elements are Al, Fe, C, and S; trace elements are Pb, Zn, Cu, and As. These eight elements have been identified as important constituents related to water quality issues in the region (Church et al. 1997). Table 1 shows the minimum and maximum values of these elements in all six drill cores.

Mineral Dissolution and Precipitation
Most sulfide minerals are formed at depth and under non-surface conditions (Sato, 1992). Sulfides are unstable in the surface environment and undergo oxidative weathering as a result of exposure to atmospheric oxygen, water, and microbial action. A common feature of non-ore volcanic clasts recovered at depth within the pile is the presence of iron-oxide rinds. Country rocks outside the pile (e.g., from drill core 4) and adjacent hillside rocks have no rinds, suggesting that mobile iron for rind formation comes from within the pile rather than from an outside source. A likely source for the iron in the rinds comes from iron in sulfide minerals.

An example of the impact of weathering on the mine pile is demonstrated by samples from core 1. Generally, only remnants of sulfides are seen in hand specimen and microscopic work in this core; the residual sulfides are found within a fine-grained matrix of yellow secondary minerals. The high concentrations of trace metals in the bulk material in the cores suggests that the drill holes penetrated an old zone of "ore" just beneath the pile surface.

Lead, Zn, Cu, and As reach their maximum abundances over the 2-3 m (6-9 ft) depth interval in core 1 (samples H1-C2-M and H1-C2-B). Lead and zinc concentrations are 32,000 and 27,000 ppm, respectively, in sample H1-C2-M which is centered at 2 m (6 ft). In fact, the lead and zinc abundances at this level in core 1 are the highest for both metals from all core samples. Lead and zinc exceed a few weight percent (10,000 ppm =1.0 weight percent) in just a few other samples in the Mayday mine dump; these high lead and zinc samples are from either core 1 or 2.

Total sulfur (4.3 weight percent) and total carbon (1.0 weight percent) are also high where lead and zinc reach their maxima (Figure 2) in core 1. [Iron, however, is not especially high at 4.2 weight percent]. The association of high total sulfur ($S_{(tot)}$) with lead and zinc initially implies that a sulfide-bearing zone of waste rock might be present at approximately 2 meters, and indeed, XRD analysis of this sample showed major ZnS (>25 weight percent) and minor (>5 to <25 weight percent) PbS. The yellow "jarosite" material imparted its color to the entire sample and coated both the mineral and organic detritus. Several weathered jarosite-type minerals (based on color differences) and several large (7-8 cm long x 1-2 cm diam) portions of old mine timbers were present in this sample.

Besides galena, other lead-bearing minerals identified by qualitative XRD include minor plumbojarosite [$PbFe_6(SO_4)_4(OH)_{12}$] and trace (<5 weight percent) anglesite ($PbSO_4$) and cerrusite ($PbCO_3$). Another sulfate-bearing mineral, gypsum ($CaSO_4 \bullet 2H_2O$), was present in a trace amount. Quartz and muscovite were the only other minerals identified. Thus, all but two minerals in this highly-weathered sample contain at least one of Pb, SO_4, or Zn. Zinc is predominantly in the original ore sulfide sphalerite, while lead is distributed among four different minerals. Three of these minerals are secondary phases, indicating lead has been mobilized from the ore sulfide to the weathering products.

Microscopic examination of sample H1-C2-M showed that the individual lead- and zinc- sulfide grains are small, less than 0.1 mm in diameter. The likely explanation for high lead (and to a lesser extent, zinc) in this oxidized (near-surface) zone is that these metals were originally (and are still) present in ore sulfides, then mobilized from sulfides but later reprecipitated within the secondary minerals, or perhaps adsorbed by the organic debris.
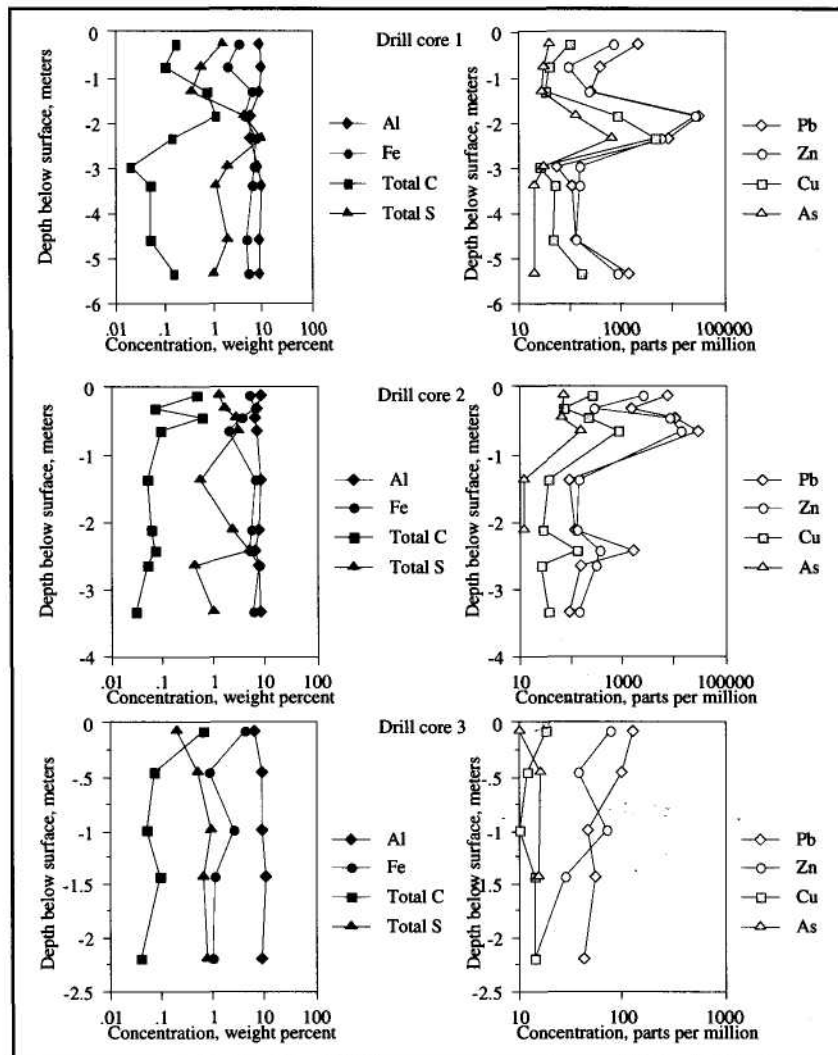
Figure 2 Downhole plots of major (Al, Fe, C, and S)   and trace (Pb, Zn, Cu, and As) elements from drill cores 1 through 3 from the Mayday mine dump

Arsenic and copper attain high concentrations at 2 m (130 and 870 ppm, respectively) but reach their maximum values at 2.5 m (7.6 ft) in sample H1-C2-B, which is just below the lead and zinc maxima. At 2.5 m, arsenic is nearly 700 ppm and copper is 4600 ppm, while lead and zinc decrease by more than two-thirds to 8600 and 6000 ppm, respectively. Iron also is at its maximum abundance, 7.4 weight percent, in this sample. There is much less total carbon (0.14 weight percent) but still high total sulfur (9.1 weight percent). There are no XRD detectable sulfides in sample H1-C2-B, only the secondary, fine-grained, jarosite-type materials. The lack of ore sulfides but an abundance of secondary Pb-, Zn-, and Fe- bearing phases suggests these metals have been mobilized and redeposited at a lower depth in the dump pile. The highest arsenic and copper values are also associated with the weathered iron-oxide/jarosite solids. Lead and zinc have decreased in abundance but are still high, indicating that their movement downward from the "ore" has been reduced at this point in the pile.

These results show that in addition to the original sulfide minerals located above sample Hl-C2-B, Pb, Zn, Cu, and As are now associated with the oxide-jarosite (and perhaps "organic") fractions. The presence of secondary (non-sulfide), metal- and sulfate-bearing minerals indicates weathering has played a strong role in the (downward) movement of major and trace elements in the dump pile. The

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actual transport mechanisms and routes of these elements from their source (sulfides) to current sink (oxide-jarosite) are not known. Continuing work is aimed at understanding the mobility of the trace metals in the mine pile solids and waters.

Table 1   Minimum and maximum concentrations of select elements from Mayday drill core samples. Values are from composite samples. Units are weight percent for Al, Fe, total carbon ($C_{(tot)}$) and total sulfur ($S_{(tot)}$), and parts per million (ppm) for Pb, Zn, Cu, and As

	Core 1		Core 2		Core 3		Core 4		Core 5		Core 6	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Al	5.4	9.1	6.5	8.7	6.7	11.0	1.8	7.6	7.1	8.4	7.2	8.6
Fe	1.9	7.4	2.0	8.0	.82	4.2	2.5	4.7	3.6	6.3	4.3	6.3
C(tot)	.02	1.08	.03	.58	.04	.63	.01	.36	.08	.18	.14	.21
S(tot)	.36	9.14	.43	5.21	.20	.89	.39	5.05	.26	1.04	.23	.62
Pb	55	32000	88	30000	41	130	76	4700	59	550	146	340
Zn	92	27000	120	14000	14	79	21	5100	43	300	65	89
Cu	25	4600	26	820	10	18	20	140	9	33	14	34
As	19	680	11	160	10	16	11	120	19	58	11	61

An elongate "sphere" is formed by elevated lead and zinc concentrations centered on core holes 1 and 2 at the two meter depth. Lead and zinc values decrease laterally and downward from the top of the sphere while the percentage of weathered minerals increases in those directions. In this spherical body, trace metals (especially lead) are now strongly-associated with weathered minerals as well as ore sulfides. The location and shape of this subsurface sphere is in agreement with geophysical results (Instantaneous Potential [IP] method) from the Mayday pile (Campbell et al. 1999). While the original composition and metal abundances in this spherical body are not known, it is likely that the material was unweathered or only slightly weathered when first mined and placed at the surface. Thus, within less than 100 years, weathering of this "ore" material has been rapid.

Microbial Activity

Table 2 shows results of inoculations for *Thiobacillus* species for five samples from drill core 1 - these results are typical of most cores. Overall, the *Thiobacillus thiooxidans* medium showed a greater number of culture tubes positive for growth compared to *Thiobacillus ferrooxidans*. This result is not surprising because most iron is in Fe^{3+} -oxide, so energy via Fe^{2+} oxidation is unavailable to *Thiobacillus ferrooxidans*. Pyrite abundance in this area of the pile is 1.0 weight percent or less (Campbell et al. 1999); the low but nonzero growth of *Thiobacillus ferrooxidans* may be explained by the presence of small amounts of pyrite. In other cores, most tubes positive for *Thiobacillus ferrooxidans* were obtained from samples that contained XRD-detectable (>5 weight percent) pyrite.

An interesting result is the lack of iron-oxidizing thiobacilli from sample H1-C2-M, which is characterized by high lead (32,000 ppm) and zinc (27,000 ppm); other trace metals (Ag, As, Cd) are also high. Despite these high metals, sulfur-oxidizing thiobacilli are plentiful. It appears that high metal concentrations may be affecting growth of iron-oxidizers but not sulfur-oxidizers. This may be a result of the fact that the sample mineralogy is dominated by [fine-grained] lead and zinc sulfides, rather than pyrite. Recent work by Schippers and Sand (1999) has shown that mineralogy will affect the type of sulfide mineral degradation pathway employed by thiobacilli. For example, when Fe^{3+} is absent, *Thiobacillus ferrooxidans* can solubilize iron-free sulfides (e.g., CuS) but not FeS_2, and thus behaves more like *Thiobacillus thiooxidans*. There are other possible reasons for the lack of growth of iron-oxidizers. For example, trace metal concentrations other than lead or zinc, such as copper or silver, may be high enough to inhibit growth of thiobacilli. And as noted above, because all iron is already in the Fe^{3+} state, no energy is available to iron-oxidizing microbes. Regardless of the cause, the results suggest that mineralogy and trace metal abundances do impact the numbers of iron- and sulfur- oxidizing bacteria that are found in the mine dump.

Table 2   Results for growth of thiobacilli from samples in drill core 1. Each symbol (+; growth) or (-; no growth) represents one tube at the dilution factor shown

Core Sample	Dilution Factor	Thiobacillus thiooxidans	Thiobacillus ferrooxidans
Hl-Cl-T	10^{-1}	- + +	- - -
	10^{-2}	- + +	- - -
	10^{-3}	+ + +	- - -
Hl-Cl-B	10^{-1}	- + +	- - -
	10^{-2}	- + +	- - -
	10^{-3}	+ + +	- - -
H1-C2-T	10^{-1}	- + +	+ + +
	10^{-2}	- + +	+ + +
	10^{-3}	+ + +	+ - -
H1-C2-M	10^{-1}	++ +	+ - -
	10^{-2}	+ + -	- - -
	10^{-3}	+ + +	- - -
H1-C2-B	10^{-1}	+ + +	+ + +
	10^{-2}	+ + -	+ - +
	10^{-3}	+ + -	+ - -
H1-C3-B	10^{-1}	+ + -	+ + +
	10^{-2}	+ + +	+ + +
	10^{-3}	+ + +	- + +

Aqueous and Hydrologic Processes

Abundances of secondary (weathered) minerals present in drill core samples indicate that trace metal movement away from ores near the mine works occurs via dissolution and reformation of the secondary phases. In turn, this dissolution-reformation mechanism suggests metals are moving in response to aqueous processes that are influenced by mine pile hydrology (porosity, permeability, infiltration of surface water). Although the hydrologic properties of the mine pile are beyond the scope of this paper, observations suggest that the Mayday pile is subject to intermittent (and perhaps infrequent) water infiltration that permits aqueous geochemical reactions to occur in the subsurface. For example, the formation of iron-oxide rinds was found only on subsurface rocks. Increases in metals loads with high flow periods also indicate mineral solubilization and metal mobilization is occurring in subsurface materials (W. Wright, USGS, written comm., 1999).

SUMMARY

Weathering of primary ore minerals has resulted in a "sphere" of high-trace-metal containing secondary minerals located near old ore mineral accumulations in the Mayday mine dump centered around drill holes 1 and 2. These mineral accumulations coincide with historical and visual observations of ore placement during mining. Because the original emplacement of ore minerals cannot be precisely determined, the results of this investigation define only the limits to the potential movement of trace metals from primary to secondary mineral phases. Microbial activity, or a lack thereof, may be a key control on the dissolution of sulfides and immobility of iron as evidenced by the lack of iron-oxidizing microbes but an abundance of sulfur-oxidizing bacteria in a lead/zinc ore-mineral accumulation that contained minor pyrite. Water availability is highly variable at the Mayday pile, suggesting that infiltration and aqueous weathering reactions occur only on a sporadic basis rather than at all times of the year. Thus, the rates of mineral dissolution will also vary.

CONCLUSIONS

Examination of drill core samples suggests that surface weathering processes also operate at depth in the Mayday mine dump. The high concentration of lead associated with weathered mineral phases, large numbers of iron- and sulfur- oxidizing microbes (compared to non-ore samples), and formation of

abundant secondary minerals and iron-oxide rinds on non-ore clasts indicate that several metals are mobile in the subsurface in the Mayday mine dump.

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