

ENVIRONMENTAL EFFECTS OF ABANDONED MERCURY MINES IN THE HUMBOLDT RIVER BASIN, NEVADA, USA

By John E. Gray, James G. Crock, and David L. Fey

U.S. Geological Survey, P.O. Box 25046, Federal Center, MS 973, Denver, CO 80225 USA, email: jgray@usgs.gov

Abstract

Numerous abandoned mercury mines are located within the Humboldt River basin, which is the largest river system in Nevada and a closed basin. Sediments, waters, calcines, and leachates of the calcines were analyzed for Hg to evaluate any adverse environmental effects from the mines. Calcines collected from the mines contain up to 2,000 mg/kg Hg. Stream-sediment samples collected within 1 km of the mines contain up to 170 mg/kg Hg, but sediments collected greater than 5 km from the mines contain < 1 mg/kg Hg. Sediment samples collected from the Humboldt River contain < 0.2 mg/kg Hg. Calcine leachates contain up to 1,500 µg/L Hg, suggesting that some calcines contain soluble mercury compounds. However, Hg concentrations in Humboldt River water samples are below the EPA 0.012 µg/L Hg standard to protect against chronic effects to aquatic wildlife. Adverse environmental effects from these mines are minimal because the primary ore mineral is cinnabar, which is highly resistant to weathering, and acid-water-generating sulfide minerals (such as pyrite) are rare. Furthermore, these mines are typically > 8 km from the Humboldt River, and Hg is diluted through significant pediment before it reaches the Humboldt River.

Introduction

Mercury mines in western and central Nevada are part of a broad mercury belt. These mercury mines are found in a variety of host rocks including sandstone, limestone, chert, granitic rocks, diabase dikes, rhyolitic tuffs and flows, andesites, and metamorphic rocks such as schists and phyllite (Bailey and Phoenix, 1944; Willden, 1964; Johnson, 1977). "Opalite," a common host rock, is typically volcanic rock altered to amorphous and cryptocrystalline quartz including opal. Silicified veins, and siliceous sinter deposits formed by the surface deposition of hot-spring fluids, are also common host rocks of mercury ore. The ore mineralogy is dominantly cinnabar (HgS), but minor metacinnabar (HgS), native mercury (Hg⁰), calomel (Hg₂Cl₂), and mercury oxychlorides (e.g., Hg₂ClO and Hg₄Cl₂O) are found in some deposits; pyrite, marcasite, sphalerite, and stibnite are rare (Bailey and Phoenix, 1944). Historic production from mercury mines in Nevada exceeds 10,000 metric tons (approximately 300,000 flasks; 1 flask=76 lbs), about 90 percent of which came from the McDermitt mine (Willden, 1964; Johnson, 1977; Noble and others, 1988). These deposits were mined between about 1907 and 1991, when the last mine at McDermitt closed. Mercury mines in Nevada and throughout the United States are not presently operating because of low prices and low demand for mercury.

Many of the mercury mines are found within the Humboldt River basin, which is a closed basin and the largest river system in Nevada. The primary objective of this study was to determine if runoff from these mercury mines has resulted in any adverse effect to surrounding ecosystems, specifically the Humboldt River. Mercury is a heavy metal of environmental concern because high concentrations are toxic to organisms, including humans. Thus, the presence of these abandoned mercury mines is a potential hazard to residents and wildlife when drainage from these mines enters streams and rivers. At most mines in Nevada, mercury ore was processed on site in small retorts or in large rotary furnaces (Bailey and Phoenix, 1944). Mercury-bearing ore (primarily cinnabar) remaining at these sites, as well as elemental mercury that was lost to the environment during ore processing, are the dominant environmental concerns. In the summer of 1999, we collected and chemically analyzed samples of ore, calcines (roasted ore), stream and lake sediment, and stream and lake water to evaluate the geochemical dispersion of Hg and other heavy metals from these mines. We also conducted water leaching studies of the calcines to evaluate the potential of the mine wastes to liberate (leach) Hg.

Methodology

We studied mercury mines in eight districts that represented variability in deposit size (mercury production) and host rock geology (table 1). Some of the mines were within the Humboldt River basin including those in the Imlay, Dutch Flat, Poverty Peaks, Goldbanks, and Ivanhoe districts. In addition, we studied mines outside of the Humboldt River basin including the Antelope Springs, Bottle Creek, and Opalite districts to evaluate geochemical differences between mercury mines throughout Nevada. As a result of the arid climate and lack of surface water in the region, the Eldorado mine was the only locality where we were able to collect stream water. Due to the lack of surface water, we collected calcine samples from the mines for water-leaching studies using the U.S. Environmental Protection Agency (EPA) 1312 Synthetic Precipitation Leaching Procedure (SPLP) (U.S. Environmental Protection Agency, 1986). Sediment and water samples were also collected from the Humboldt River and Rye Patch Reservoir to evaluate geochemical baselines distant (generally > 8 km) from the mines.

Stream-sediment samples consisted of channel-bed alluvium. Lake-sediment samples were collected along the shoreline below the waterline of Rye Patch Reservoir. Both filtered and unfiltered water samples were collected for analysis. All filtered samples were passed through a 0.45- μm membrane. Stream-water characteristics such as pH, conductivity, alkalinity, turbidity, temperature, Fe^{2+} , and dissolved oxygen were measured in the field at each sample site. The mine calcines collected were grab samples. Following the 1312 SPLP method, 100 g of sample was leached with 2 L of deionized water acidified to pH 4.2, and then the samples were rotated at 28 rpm for 18 hours. Our only modification to the 1312 method was that the leachate was filtered at 0.45- μm , rather than with a 0.7- μm filter used in the 1312 method. This modification of the procedure was done so that the same filtration method was used for both the leachates and the collected surface waters. Conductivity, pH, Fe^{2+} , and alkalinity were also measured in the leachates.

Mercury was measured in the ore, calcine, and sediment samples using a cold-vapor atomic absorption spectrophotometry (CVAAS) technique modified from Kennedy and Crock (1987). Mercury concentrations in water and leachate samples were determined by cold-vapor atomic fluorescence spectrometry (CVAFS) (Bloom and Fitzgerald, 1988). The calcine and sediment samples were also analyzed for As, Bi, Cd, Cu, Mo, Pb, Sb, and Zn by inductively coupled plasma-atomic emission spectroscopy (ICP-AES) using the method of Motooka (1988); the water and leachate samples were analyzed for these trace elements and sulfate by inductively coupled plasma-mass spectrometry (ICP-MS) using a technique modified from Lamothe et al. (1999).

Results

Mercury concentrations in ore samples vary widely from 20 mg/kg (Dutch Flat mine) to 69,000 mg/kg Hg (McDermitt mine). The mean Hg concentration of ores collected in this study was about 14,000 mg/kg (table 2), which is similar to the average content of mercury ore mined throughout Nevada (Bailey and Phoenix, 1944; Willden, 1964; Johnson, 1977). Similarly, Hg concentrations are highly variable in calcine samples collected from various mines. For example, calcines collected from the Eldorado mine contain 25 to 2,000 mg/kg Hg, whereas calcines from the Silver Cloud mine contain 1.9 to 180 mg/kg Hg. The mean Hg concentration in the calcines is 310 mg/kg with a high standard deviation of 520 mg/kg (table 2). These data show that Hg concentrations vary significantly within calcine piles at individual mines and probably indicate that retorting was not totally efficient.

Stream-sediment samples collected within 1 km of the mines contain as much as 170 mg/kg Hg, but those collected distant from the mines (>5 km) contain < 1 mg/kg Hg. Thus, the stream-sediment samples show significant dilution of Hg downstream from the mines. More importantly, sediment samples collected from the Humboldt River and Rye Patch Reservoir contain < 0.2 mg/kg Hg. These results are not overly surprising because all of the mercury mines are > 8 km from the Humboldt River and the reservoir, and as a result, there is significant dilution before any Hg reaches the Humboldt River. Other trace metals are also elevated in the stream-sediment samples collected near some of the mines. For instance, elevated concentrations of As (= 120 mg/kg), Sb (= 220 mg/kg), Pb (= 1,600 mg/kg), and Zn (= 210 mg/kg) were found in stream sediment collected downstream from the Juniper mine in the Antelope Springs district. Stibnite (Sb_2S_3), and several base-metal-sulfide ore minerals, have been reported in this area, and this mine also produced minor amounts of lead, copper, silver, and gold (Bailey and Phoenix, 1944). Generally, stream sediments collected near most mines do not contain abundant heavy metals other than Hg, and similar to Hg, such metals are significantly diluted within a few kilometers of the mines.

As previously mentioned, stream water was found only at the Eldorado mine, and in fact, this stream drainage was dry about 2 km below the mine in June, 1999. However, water samples were collected from the Humboldt River and Rye Patch Reservoir. Mercury concentrations in all of the surface-water samples collected were low, and ranged from less than 0.005 to 0.009 $\mu\text{g/L}$ in unfiltered water; all filtered water samples contained Hg concentrations = 0.005 $\mu\text{g/L}$, the lower limit of determination for the CVAFS method used. These Hg concentrations in water are below several important standards such as (1) the 2.0 $\mu\text{g/L}$ state drinking water standard for Hg, (2) the EPA 2.4 $\mu\text{g/L}$ Hg standard to protect against *acute* effects to aquatic wildlife, and (3) the EPA 0.012 $\mu\text{g/L}$ Hg standard to protect against *chronic* effects to aquatic wildlife (U.S. Environmental Protection Agency, 1992). Other heavy-metals that we determined are of low concentration in the water samples, generally below the EPA chronic toxicity standards, and do not warrant further discussion.

Because the lack of stream flow in the region prevented us from directly measuring Hg in surface water, we conducted water leach studies of mine calcines to simulate runoff from the mines. During our leach studies, we found highly variable amounts of Hg in the leachates, and some of the leachates contained extremely high concentrations of Hg. For example, leachates (3 samples) obtained from the Silver Cloud mine contained Hg concentrations from 0.2 to 1,500 $\mu\text{g/L}$, which include leachates with the highest and lowest Hg concentrations determined in this study. Leachates obtained from three calcine samples collected from the McDermitt mine contained relatively lower Hg concentrations (0.2-21 $\mu\text{g/L}$). The mean Hg concentration for the leachates was 96 $\mu\text{g/L}$ (table 2), which is highly elevated in comparison to Hg in the surface-water samples. There is no consistent correlation between leachate Hg concentrations and Hg in corresponding calcines leached. Conductivity (41-3,800

$\mu\text{s/cm}$) and pH (3.2-9.9) of the leachates also varied widely. Although the two leachates with the highest conductivities, 3,800 and 3,400 $\mu\text{s/cm}$, also contain high Hg concentrations, 1,500 and 81 $\mu\text{g/L}$ respectively, any overall correlation between high conductivity and Hg concentration is weak. Elevated Hg concentrations do not correlate closely with low pH, indicating that Hg leaching is not controlled by the capacity of calcines to generate acid.

Discussion

At the mercury mines in Nevada, the presence of mercury-bearing ore, mercury-rich calcines, and any elemental mercury around mills and retorts are the primary environmental concerns. Cinnabar-bearing ore remaining at these sites was not found to be widespread (often even difficult to locate), but there is minor cinnabar visible in the open-pit cuts and trenches, in a few outcrops, and in the calcine piles. Detrital cinnabar and cobbles containing cinnabar are clearly visible in stream drainages below the mines and indicate that mercury is eroding down gradient from the mines. Although Hg concentrations in the ores (as much as 69,000 mg/kg) and stream-sediment samples (as much as 170 mg/kg) collected at or near the mines are high, the dominant form of the mercury is cinnabar (HgS); cinnabar is very stable and resistant to chemical and physical weathering. In addition, there is little or no pyrite associated with ore at the mines, and thus, the potential for acid-water generation is minimal. During our 1999 fieldwork, elemental mercury, which is more reactive than cinnabar, was not observed at any of the mines studied.

Calcines collected from some mines contain as much as 2,000 mg/kg Hg, and although these Hg concentrations are highly elevated, the potential of the calcines to leach Hg is more important. Leachates obtained from calcine samples contained variable and some highly elevated Hg concentrations (<0.2 to 1,500 $\mu\text{g/L}$); these concentrations are as much as 750 times higher than the 2.0 $\mu\text{g/L}$ drinking water standard for Hg. Our data indicate that there are some water-soluble mercury compounds in calcines from some mines, or that finely-particulate Hg-bearing material or colloidal material passed through the 0.45- μm filter during filtration. We suggest that the leachates represent the maximum Hg concentrations that can be obtained by water leaching of the calcines. In addition to the leaching potential of the calcines, we also estimated the volume of calcines at the sites studied. The amount of calcines remaining at the mines studied is variable, but is consistent with the general size and mercury production for each mine as shown in table 1. Calcines were estimated to vary from approximately 285 m^3 (at Dutch Flat, the smallest mine) to greater than 1,000,000 m^3 (at McDermitt, the largest mine). Thus, there is a considerable amount of Hg remaining in these calcine piles. However, both filtered and unfiltered water samples collected from the Humboldt River and Rye Patch Reservoir contain very low concentrations of Hg (<0.005-0.009 $\mu\text{g/L}$), indicating that runoff from the mercury mines has apparently not had a significant influence on the Humboldt River.

References

- Bailey, E.H., and Phoenix, D.A. 1944, Quicksilver deposits in Nevada: Nevada Bureau of Mines Geol. and Mining Ser. 41:206 pp.
- Bloom, N.S., and Fitzgerald, W.F., 1988, Determination of volatile mercury species at the picogram level by low-temperature gas chromatography with cold-vapour atomic fluorescence detection, *Analytica Chimica Acta*, 208:151-161.
- Johnson, M.G., 1977, Geology and mineral deposits of Pershing County, Nevada: Nevada Bureau Mines and Geol. Bull. 89:115 pp.
- Kennedy, K.R., and Crock, J.G., 1987, Determination of mercury in geological materials by continuous flow, cold-vapor, atomic-absorption spectrophotometry: *Analytical Letters* 20:899-908.
- Lamothe, P.J., Meier, A.L. and Wilson, S., 1999, The determination of forty four elements in aqueous samples by inductively coupled plasma-mass spectrometry: U.S. Geol. Surv. Open-File Rep. 99-151:14 pp.
- Motooka, J.M., 1988, An exploration geochemical technique for the determination of preconcentrated organometallic halides by ICP-AES: *Applied Spectroscopy* 42:1293-1296.
- Noble, D.C., McCormack, J.K., McKee, E.H., Silberman, M.L., and Wallace, A.B., 1988, Time of mineralization in the evolution of the McDermitt Caldera Complex, Nevada-Oregon, and the relation of Middle Miocene mineralization in the northern Great Basin to coeval regional basaltic magmatic activity: *Econ. Geol.* 83:859-863.
- U.S. Environmental Protection Agency, 1986, Test methods for evaluating solid waste, v. I and II (SW-846), 3rd ed., Nov., 1986. Updates are available through revision 2V, April 4, 1995.
- U.S. Environmental Protection Agency, 1992, Water quality standards; establishment of numeric criteria for priority toxic pollutants; states' compliance; final rule: *Federal Register*, 40 CFR Part 131, 57:60,847-60,916.
- Willden, Ronald, 1964, Geology and mineral deposits of Humboldt County, Nevada: Nevada Bureau of Mines and Geol. Bull. 59:154 pp.

Table 1. Description and production of mercury mines studied.

District	Mines Studied	Host Rocks	Approximate Mercury Production per District
Imlay	Eldorado	Veins in Triassic limestone and shale	800 flasks
Dutch Flat	Dutch Flat	Veins in Paleozoic schist and phyllite cut by Tertiary granodiorite	90 flasks
Poverty Peaks	Cahill	Veins in Paleozoic and Triassic limestone and sandstone, and Tertiary opalite	600 flasks
Ivanhoe	Silver Cloud	Opalite altered Tertiary volcanic tuff	>2,000 flasks
Goldbanks	Goldbanks	Opalite altered Tertiary volcanic tuff and breccia	2,700 flasks
Bottle Creek	White Peaks	Veins in Paleozoic and Triassic tuffs and sandstone and Tertiary diabase dikes	4,500 flasks
Antelope Springs	Pershing and Juniper	Veins in Triassic limestone, dolomite conglomerate, and shale	12,500 flasks
Opalite	McDermitt	Opalite altered Tertiary volcanic tuffs	270,000 flasks

Table 2. Summary of mercury data for samples collected in this study.

Sample Type	Number of Samples	Mean	Standard Deviation	Range
Ore	12	14,000	21,000	20-69,000 mg/kg
Calcines	36	310	520	1.9-2,000 mg/kg
Sediments	25	12	34	0.05-170 mg/kg
Waters-unfiltered	12	0.006	0.0015	<0.005-0.008 µg/L
Waters-filtered	12	<0.005	0.009	<0.005-0.005 µg/L
Leachates	22	96	320	<0.2-1,500 µg/L

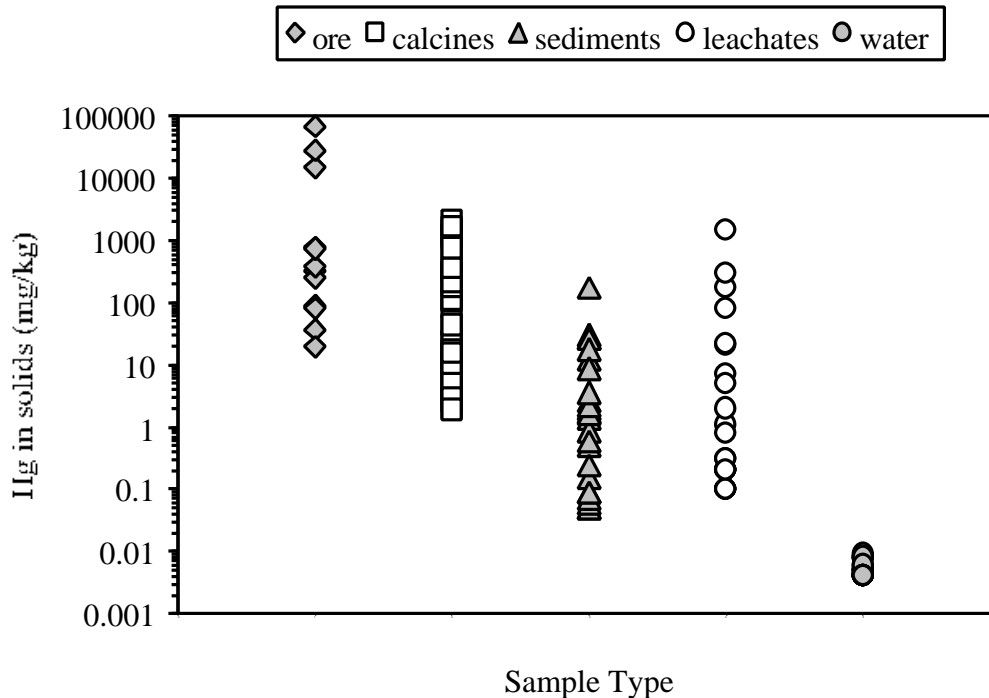


Figure 1. Plot of Hg concentrations in ore, calcines, stream and lake sediments, leachates of calcines, and surface-water samples collected in this study.