CONTRIBUTIONS OF MERCURY TO CALIFORNIA'S ENVIRONMENT FROM MERCURY AND GOLD MINING ACTIVITIES—INSIGHTS FROM THE HISTORICAL RECORD

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California environmental mercury issues relate to historical mining operations in two ways. The first is to mercury mining activity. Between 1846 and 1981, about 103.6 million kg of mercury were produced within the state. The second is to historic gold mining activities that took place during the last half of the 19th century and the early 20th century, which depended upon gold recovery processes using mercury. Significant quantities of mercury were lost to the environment during both of these activities. This paper will show that historic records and reports from a variety of sources provide valuable information and insights into how and where these mercury losses occurred. They also allow estimation of the quantity and timing of these losses.

Most of the mercury deposits in California occur within a portion of the Coast Ranges geomorphic province extending from near Clear Lake in the north to Santa Barbara County in the south. Other mercury deposits are present in northwestern California, in the Basin and Range Province, and one small deposit was mined in the Sierra Nevada foothills. From historic records, the California Department of Conservation, Division of Mines and Geology (DOC/DMG) has identified 239 mines with production of at least one flask (34 to 34.7 kg) of mercury. An additional 54 sites may have had small unrecorded production. Based on published and unpublished data from the U.S. Bureau of Mines and DOC/DMG, these mines produced about 103.6 million kg of mercury. As is typical for metallic ore deposits, a few large mines account for most of the mercury production. The 25 largest mines account for about 100 million kg, or about 97 percent, of California's mercury production. The two largest mines, New Almaden and New Idria, account for about half of the total production. Cinnabar (HgS) is the dominant mercury ore mineral in most of these deposits. Some deposits also contain significant occurrences of metacinnabar (also HgS in composition) and, in a few instances, native mercury. Many mercury deposits were originally found by the recognition of the presence of silica-carbonate rock, a topographically prominent rock type commonly associated with many mercury deposits. Other deposits were found by panning stream sediments and hillside soils for the presence of cinnabar or native mercury.

Mercury ore processing routinely occurred at the mine sites. Mercury ore processing was relatively straightforward and involved heating the ore in furnaces or retorts to break down the mercury sulfide ore minerals and liberate the mercury vapor. The mercury vapor was subsequently cooled and collected as liquid mercury in a condenser. Some mercury was lost to the environment wherever processing occurred. Mercury losses occurred by absorption into furnace bricks, trapping as fine droplets in solid residue, called soot, that formed in the condensers, as vapor that failed to be trapped in the condensers and exited to the atmosphere, during cleaning of the condensers and by spillage of recovered mercury during handling.

Mercury furnace losses gradually decreased over time as more efficient furnaces and better recovery practices were developed. By 1890, 15-20 percent losses could be achieved at well run plants, but losses at poorly run plants were still as much as 40 percent. By 1917, overall losses were believed to be about 25 percent and by 1950, losses of 5-10 percent were achieved at the best plants (Roush, 1952; Bradley, 1918). If it is assumed that an average furnace loss rate for all mercury ore processed in California is 25 percent, then roughly 34.5 million kg of mercury may have been lost to the environment from historic mercury mining activity. Some mercury lost at these sites was recovered later by processing old furnace bricks in new furnaces, mining and processing soil under old furnace sites, reprocessing soot and tailings piles, and processing gravel downstream of mercury mine sites.

From 1850 until the 1890's, the California mercury mines were the only domestic source of mercury in the United States. During this period, mercury production greatly exceeded domestic need and about 70 percent of the mercury produced in California was exported, primarily to other Pacific Rim countries. Small quantities of mercury were imported during this time but these were probably largely utilized for manufacturing of vermilion, other mercury products, and for felt manufacturing at factories in the eastern United States. A large amount of California mercury was shipped to Virginia City, Nevada, for use in processing the Comstock Lode silver ores. With these exports, little or no foreign imports, and no other domestic mercury sources, it is very unlikely that the amount of mercury available for use in the gold mining industry in California could have exceeded 10.3 million kg during the period 1850 to 1890.

The discovery of gold in the Sierra Nevada Foothills in 1848 marks the beginning of significant gold mining activity in California. The DOC/DMG Minefile database contains approximately 13,500 historic gold mine and gold prospect listings for California. Most of these mines are located in the central and northern portions of the Sierra Nevada, the adjacent easternmost portions of the Great Valley, and the Klamath Mountains geomorphic provinces. Three types of gold deposits are dominant in these areas: 1) unconsolidated surficial placer deposits; 2) weakly to strongly consolidated ancient (buried) placer deposits, and 3) lode (quartz vein) deposits. *(Large low-grade disseminated gold deposits of several types have accounted for most gold production in the state for the last 20 years. Although some of these are located in the Sierra Nevada province, they will not be discussed further because mercury was not used in processing ore from these deposits.)*

Unconsolidated surficial placer deposits were the first gold deposits worked in California. These deposits were largely exhausted by 1858. Some mercury was undoubtedly used and lost in gold recovery from these surficial placers, but no records exist describing the quantities involved. About this time several technological innovations occurred that made the mining of ancient placer deposits and lode (hard rock) deposits practical. For the former, it was the development of a new method of mining called hydraulic mining. For the latter it was improvement in the design of the stamp mill for processing lode ore. Gold recovery in both of these operations depended upon the mercury amalgamation for gold recovery.

Hydraulic mining utilizes a high-pressure stream of water to expose and disaggregate ancient placer gravels. The gold bearing gravel is then transported by flowing water through a series of sluices (wooden troughs). The bottoms of these sluices have perpendicular cleats extending the full width of the sluice. Mercury is placed behind these cleats to trap and hold gold by amalgamation. Sluices used at hydraulic mining operations ranged in size from hundreds to thousands of feet in length. Periodically the flow of water and gravel was stopped, the gold-mercury amalgam from the bottom of the sluice removed, and the gold and mercury recovered by retorting the amalgam. This method of mining reached its peak in the 1870s. Debris deposition and resulting flooding problems downstream of these operations led to a legal decision in 1884 that greatly curtailed the practice of hydraulic mining in the state. Other methods of placer mining that followed hydraulic mining, such as gold dredging, also utilized mercury amalgamation but the mercury loss rates for these methods were much less. Estimates of mercury losses from placer mining are given in Table 1. These loss figures are based upon estimates of the amount of placer gold produced during different periods and published mercury loss rates per ounce of gold produced for different placer mining methods.

Lode gold mining is a mining technique where quartz veins are followed, usually by underground workings. The gold ore in and along the veins is removed and taken to a mill at the surface for processing to recover the gold. The predominant type of mill for processing lode gold ores from the late 1850s to about 1940 was the stamp mill. At the stamp mill, ore from the mine was roughly crushed and then slowly fed into a battery of stamps. A stamp battery consists of a series of adjacent steel rods held in a vertical, rectangular frame. Collars on the rods interact with a type of camshaft that raises the stamps and then let them drop by gravity. The rods are fitted with very heavy cone-shaped metal shoes at the lower end which strike metal dies when dropped, pulverizing any ore caught in between. This process liberates grains of gold from its host quartz. This ore pulverization process takes place in a cast iron trough, called a mortar, which is filled with mercury. The mercury amalgamates with the freed gold and traps it in the mortar. Water moving through the stamp battery removes the finely pulverized quartz and other rock waste from the mortar. This slurry then flows over an inclined table lined with copper sheeting coated with mercury to catch additional fine gold that may not have been trapped in the mortar. Additional mechanical or non-mechanical devices were sometimes employed after the amalgamation tables for further gold recovery or recovery of sulfides containing gold. Periodically, the stamp mill was shut down and the gold-mercury amalgam scraped from the mortar and from the amalgamation tables for gold and mercury recovery by retorting.

Mercury was lost at both hydraulic mining and stamp milling operations. A principle way mercury was lost in both operations was through "flouring." Flouring is a situation where small particles of mercury, generated during the churning action of stamps in the mortar, or turbulent flow of gravel and water in the sluice, are able to float off with the water moving across these devices. Mercury was also lost by leakage through the bottom of sluices, through chemical reactions during ore milling and during retorting to separate gold from amalgam. For hydraulic mining, probably about one pound of mercury was lost for every three or four ounces of gold recovered (Hanks, 1882). Other methods of processing placer deposits recovered 5 to 10 times this amount of gold per pound of mercury lost. Mercury loss at stamp mills gradually decreased over time from about 0.06 pounds of mercury per ton of ore processed in the 1850s to about 0.03 pounds per ton in the 1890s and finally to about 0.004 pounds per ton for the 1930s and later (Preston, 1895; Richards, 1906; Ransom, 1918). Estimates of mercury lost during the processing of lode gold ores by stamp milling are given in Table 2. These losses are based upon estimates of lode gold produced, likely average ore grades during different periods, and published mercury loss rates per ton of lode ore processed.

It is important to note that the use of mercury amalgamation for gold recovery declined significantly between 1890 and 1920, not just in California but nationwide. This decline coincides with the development of the cyanide process for gold ores and a change in character of gold ores as the lode mines deepened. The cyanide process reduced or eliminated the need for gold recovery by mercury amalgamation at some mines. Traditional stamp mill methods did not work well on the deeper, unoxidized ores, and different ore processing methods were often utilized.

Rough estimates of mercury losses due to gold mining activity can be made from available historic information on gold production and mercury loss rates for different mining methods. Based upon the amounts of placer gold produced by different methods and the approximate mercury loss rates for those methods, the amount of mercury lost from all placer gold mining activity in California is probably about 4.5 million kg. About 3.3 million kg (71 percent) of this loss likely occurred between 1859 and 1884, the principal period of hydraulic mining activity in California. Based on the amount of lode gold ore processed during different periods and approximate mercury loss rates for those time periods, the amount of mercury lost in milling of lode gold ore is probably about 1.3 million kg. Roughly 0.5 million kg (40 percent) were lost during the period 1859-1896 and 0.6 million kg (51 percent) were lost between 1897-1934. The total amount of all mercury lost to the California environment from all gold mining activity, the sum of the placer mining and lode mining losses, is about 5.8 million kg. Probably 80 to 90 percent of this amount was lost in the Sierra Nevada geomorphic province. For comparison, the loss of mercury during processing of the Comstock Lode silver ores at Virginia City, Nevada, has been estimated at 6.75 million kg (Miller and others, 1994).

The estimates presented here put into perspective the magnitude of mercury losses from both ore processing at mercury mine sites and historic gold mining in California. While mercury losses from both activities were substantial, it is probable that six or seven times more mercury was released in the Coast Ranges from mercury mining than was released in the Sierra Nevada from former gold mining activities.

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Table 1. Calculated Mercury Loss from Placer Gold Mining Activity in California

PERIOD	OZ PLACER GOLD* (MILLIONS)	HG LOSS RATE*—OZ GOLD RECOVERED PER POUND HG LOST	MILLION POUNDS HG LOST	MILLION KG HG LOST	PERCENT
1848-1858	26.2	16	1.64	0.75	16.6
1859-1884	21.2	3	7.09	3.22	71.1
1885-1899	2.2	4	0.55	0.25	5.5
1900-1934	10.8	23	0.47	0.21	4.6
1935-1968	7.8	34.25	0.23	0.10	2.2
1969-1976	0.0	16	0.0	0.00	0
TOTAL	68.2		9.98	4.53	100.0

*Production data compiled from Hill, 1929; Minerals Resources of the United States (USGS); and Minerals Yearbook (USBM-for example of loss rates see Review of 1940, p. 228) through 1976. Also see loss rates in Hanks (1882).

Table 2. Calculated Mercury Loss from Milling Lode Gold Ore in California

PERIOD	OZ GOLD** (MILLIONS)	GRADE OZ PER TON	TONS ORE (MILLIONS)	HG LOSS RATE LB PER TON	LBS HG LOST (MILLIONS)	KG HG LOST (MILLIONS)	%
1848-1858	0.240	1	0.241	0.0600	0.0144	0.0065	0.5
1859-1884	6.379	0.5	12.758	0.0450	0.5741	0.2614	20.0
1885-1896	5.396	0.3	17.987	0.0313	0.5629	0.2553	19.6
1897-1934	18.335	0.25	73.343	0.0200	1.4668	0.6653	51.1
1935-1968*	6.898	0.11	62.710	0.0040	0.2508	0.1137	8.7
1969-1978*	0.023	0.11	0.209	0.0040	0.0008	0.0003	0.0
TOTAL	37.271		167.248		2.8698	1.3017	99.9

*Stamp Mills were widely used until World War II, then gradually replaced by ball mills and rod mills after the war. For these periods on the table, mercury loss has been calculated at stamp mill rate.
**Production data from Hill, 1929; Mineral Resources of the United States (annual USGS publication); and Minerals Yearbook (annual USBM publication). Gold produced from volcanogenic sulfide ores is not included in these totals.