

“Eureka!” – The Evolution of Gold Mining

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Abstract

The geological processes that shaped California over hundreds of millions of years had a significant role in American history. Hydrothermal ore deposits, specifically gold, formed by steam saturated with valuable minerals that were precipitated out as the steam cooled were mined extensively throughout the 19th and 20th centuries. Terranes that were accreted by the west coast of the North American continent added more hydrothermally generated gold especially around the Mother Lode region in Northern California. Placer mining sprung up in the late 1840's after James Marshall discovered yellow, metallic flakes in a river near a saw mill he was building for John Sutter. Technological advances in mining allowed for harder-to-reach deposits to be mined out of source rock using high-powered jets of water. In the late 1890's, dredges were used to extract gold from riverbeds in the Central Valley and enormous profits were generated. Open pit mining used today has allowed companies to extract very low-grade ore deposits from the earth with environmental consequences. Mercury contamination is a significant problem in Californian watersheds and around abandoned mines. Cyanide leaks have caused drastic environmental damage to rivers and streams. However, even with its disadvantages, the Gold Rush had significant positive effects and propelled California into the modern age.

Introduction

In the late 1840s, the entire nation was swept into a gold frenzy [PBS The Gold Rush]. Newspapers across the country were reporting mass migrations of self-proclaimed miners to California in search of easy money. The population in San Francisco plummeted when gold was discovered just east of the city in 1848. Ships were abandoned in the harbor and businesses were closed as owners tried their luck as placer miners [Bancroft, 1886]. Boom towns sprung up anywhere there was an economically viable gold deposit. News spread quickly to other countries and immigrants from Asia, Chile, Australia, and Europe arrived in the newly acquired territory of Alta California seeking riches in 1849 [PBS The Gold Rush]. San Francisco acted as the main harbor for the influx of people to the region and its population of about 800 in 1848 skyrocketed to 25,000 in 1850 [Bancroft, 1886]. Strain on the infrastructure was evident as thousands of people lived in tents and makeshift shelters outside the city [Holliday, 1999].

Geologic processes leading to ore deposition

However, hundreds of millions of years before the California Gold Rush began, tectonic processes were at work shaping what would become the ore deposit-rich western U.S. About 200 million years ago, the underwater Farallon plate began to subduct under the North American plate to its east thereby initiating the orogeny of the Sierra Nevada [Hill, 2006]. Magma production resulting from the subduction and hydrothermal activity along fault lines were the most significant contributors to the deposition of concentrated gold ore. As magma cooled and cracked it allowed water to flow in where, due to the high temperatures, it bonded easily with gold. As the water solution rose to the surface it cooled and the gold was precipitated out; occasionally in concentrated amounts. It was these economically viable gold deposits that

attracted countless numbers of miners to the region in the mid-19th century and triggered the California Gold Rush.

A shallow sea covered much of what is now the western United States 400 million years ago [Hill, 2006]. The border of North America and this ancient sea is thought to have run from southeastern Idaho through central Nevada and into southeastern California [Hill, 2006]. Arcs of small islands dotted the ocean just west of the current location of the Sierra Nevada Mountains [see fig. 1 below].

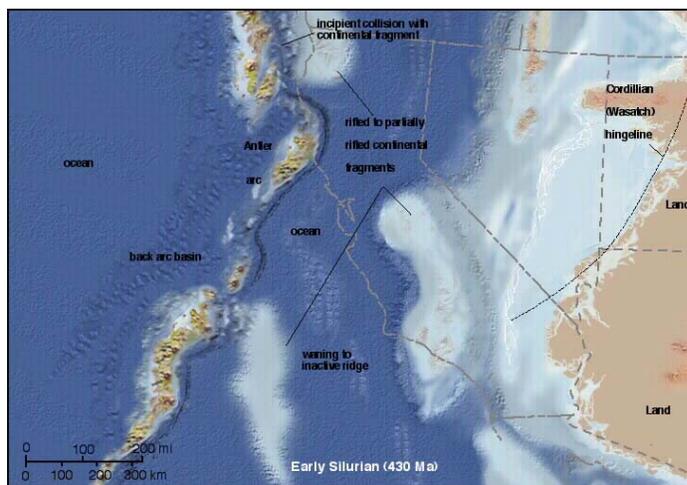


Fig. 1 shows the presumed geographic locations of land on the North American plate and the approaching island arcs. The light blue represents shallow seas and reefs while the darker blue represents deeper water. The creation and waning of islands indicates an area of tectonic movement and subsequent volcanic activity [Blakely, 2006]. A subduction zone existed to the west of the volcanic islands [Hill, 2006]. Figure reproduced from Blakely [2006].

Over hundreds of millions of years small plates, called terranes, crashed into North America and became part of its land mass. One example of a terrane occurred approximately 380 million years ago and pushed its way to present day Utah. Another example is the Sonomia Terrane which was accreted about 280 million years ago and later became the Sonoma Mountain Range [Blakely, 2006] [Hill, 2006]. These terranes made moderate contributions to the growth of the western edge of North America. However, not until about 160 million years ago did events occur that would directly affect the deposition of gold in the Sierra Nevada [Hill, 2006].

The accumulation of sediments off the western edge of North America created a wedge that was twisted and broken under pressure [Hill, 2006]. The rocks within this wedge, called the Smartville block, were rich in gold due to underwater hydrothermal deposition. As a result of tectonic activity, they rose up from the ocean and were carried to an island arc. The arc eventually docked with the North American landmass and brought with it the gold-rich blocks that would become known as the Mother Lode [Hill, 2006]. It is estimated that about 35 million ounces of mined gold originated in terranes accreted to the Sierra Nevada in the Jurassic period [Goldfarb et al., 1998].

Other deposits of gold appear to have been produced in the Sierra just after the mountain range underwent its peak stages of orogeny about 155 million years ago [Walker et al., 2007]. Many fault zones were produced during this mountain creation that allowed mineral-rich steam to rise to the surface and cool. As the steam cooled it could no longer maintain its bond with the minerals and they precipitated out [Walker et al., 2007]. This hydrothermal process was the main method of ore deposition in the Sierra as many veins were formed along these fractures [Hill, 2006].

Gold deposits are not particular about the type of rock they form in, although in California they were frequently found within quartz [Hill, 2006] [Fairbanks, 1911]. Some experienced miners argued that they could predict whether or not a vein of quartz contained gold by its color. “Live” quartz, the kind that might contain gold, was milkier and more lustrous than “dead” quartz [Hill, 2006]. Even so, once the “dead” quartz was sorted out, they could not say which veins of “live” quartz actually contained gold. Besides quartz, some of the gold-bearing veins along the foothills of the Sierra were hosted in metamorphosed, faulted rock like serpentinized peridotite and granite [Walker et al., 2007]. Dating performed using Rb-Sr

(Rubidium-Strontium) and K-Ar (Potassium-Argon) tests on surrounding ores have given the gold a formation age of anywhere between 144 and 108 million years ago [Walker et al., 2007].

Discovery of gold

The extensive deformation of the Sierra and erosion by water and ice were the key processes involved in exposing the gold for humans to find [Mining and History of the Mother Lode]. Gold was first extracted from streams where water had eroded the containing rock and carried the valuable particles downstream to deposit them in riverbeds [Fairbanks, 1911]. James Marshall was credited with discovering gold in California on January 24, 1848 when he found pieces of the shiny, yellow metal in the water at a saw mill he was building for John Sutter [Bancroft, 1886]. Marshall took the metallic flakes to Sutter who, after performing some tests on the metal and consulting an encyclopedia, confirmed Marshall's hypothesis that he had found gold [Bancroft, 1886].

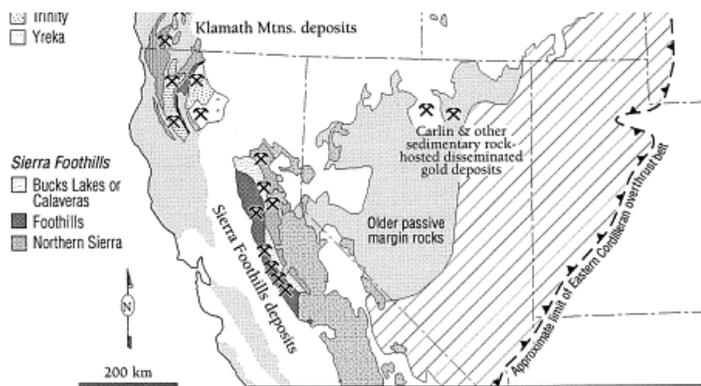


Fig. 2 shows the locations of large, known gold deposits in the southwest. Those in eastern California are constrained to the Sierra foothills and the Mother Lode region. Economically viable gold deposits were also found in northern California where a lesser-known surge of prospectors had success. Figure adapted from Goldfarb et al. [1998].

The public's immediate reaction to news of the gold discovery was one of little interest. Not until April of 1848, when adventurous miners were returning from the area around Sutter's Mill with containers full of gold, was much attention paid to the discovery [Bancroft, 1886]. Samuel Brannan was among the few who had explored the rumors of gold and returned to San

Francisco with a glass bottle full of gold flakes exclaiming, “Gold! Gold! Gold from the American River!” [PBS The Gold Rush]. After this, the news of the gold discovery spread rapidly throughout California. By August, news had made its way to the east coast and *The New York Herald* published a story about the finds out west [PBS The Gold Rush]. Travelers from other states and immigrants from other countries began pouring into California to try their luck as placer miners. It was estimated that by the end of 1848, 5,000 people were mining in California and the non-native population was 20,000 [PBS The Gold Rush]. A year later in 1849, the number of miners swelled to 40,000 and the non-native population increased to 100,000 [PBS The Gold Rush]. San Francisco, acting as the main receiving city, could not support the massive amount of arriving persons. Devastating fires caused millions of dollars worth of damage, mail was unreliable due to lack of employees, and abandoned ships cluttered the harbor [Bancroft, 1886] [Holliday, 1999]. After 1850, most of the surface gold had been mined and miners had to develop new techniques for extracting gold that was previously impractical to obtain [PBS The Gold Rush].

Methods of gold mining

Up until this time, most gold was extracted from rivers and streams by placer mining. Placer mining is the extraction of gold from gravel and small sands called placer deposits [Dictionary.com]. There were three commonly used methods for placer mining: panning, rockers, and long toms [Early Gold Mining Methods]. Panning was a common, inexpensive way to sift through river sediments for gold. The main device used was a pan: a bowl-shaped strainer with small holes in the bottom typically layered by a fine mesh. The miner would crouch along the river, dip his pan into the riverbed, and allow the water to wash most of the sand through the

mesh. After this separation, if the miner was lucky, there would be gold flakes in the bottom of the pan [Early Gold Mining Methods].

A rocker was a more complex wooden machine built to provide an efficient alternative to placer mining. Rockers were typically custom made with lengths of about 1 meter and varying widths and heights. River sediment was poured onto the top of the machine followed by buckets of water to separate the gold from the sand [Gold Mining Tools]. The uppermost part of the machine was a receiving screen that acted as a filter for larger gravel and sand. Underneath the screen was the body of the rocker which was fitted with a series of riffles to catch any gold particles in the water being filtered [Early Gold Mining Methods]. The rocker was mounted on a frame with a handle that would allow the miner to rock it back and forth to expose more gold [Gold Mining Tools].

The last major piece of equipment used in placer mining was the long tom. It was more efficient than the rocker and had a higher capacity for receiving sediments [Swiecki, 2007]. As with the rocker, a receiving box was the first stop for gravel and sand. Here the materials were mixed with a constant supply of water and the mixture was carried to a washing box. The washing box was typically 6 to 12 feet long and had a screened lower half that sorted out larger objects. The final step in a long tom was the sluice which had riffles in it for catching the heavier gold particles [Early Gold Mining Methods].

The early 1850s marked the end of widely successful placer mining [PBS The Gold Rush, 2006]. A new, efficient method was needed to extract the gold that miners knew existed in gravel beds and exposed rock. In 1853, hydraulic mining was introduced in California by Edward Matteson [Hayes, 1998] [Hydraulic Mining]. This new technique utilized high pressure

water hoses to tear down exposed gold-bearing terrace gravels. Once dislodged, the fallen sediments would be washed over riffles carved into the underlying bedrock and the gold would be collected [Hayes, 1998]. Mercury was commonly used in the riffles to amalgamate with the gold and increase the amount extracted [Alpers et al., 2005].

Hydraulic mining quickly became a popular practice due to its high efficiency. 20,000 miners were employed by the industry in 1880 and by 1884 an estimated 11 million ounces of gold were mined in California using this method [Hayes, 1998]. However, a significant drawback to the system was the need for a consistent source of water. To overcome this challenge, miners built an elaborate system of reservoirs and channels that redirected water to their pumps [Hayes, 1998]. Over 6,000 miles of water-diverting structures were constructed throughout the mountains to channel water to hydraulic mining operations [Hydraulic Mining].

The environmental effects of hydraulic mining to the Californian landscape were devastating. Miners were not picky about what was in the way of their nozzles as long as gold was to be had from the rock underneath. Because of this, entire hillsides were destroyed and left barren [Hayes, 1998]. The tailings left over after running through the riffles were carried downstream by water and deposited in the riverbeds [Learn California]. Rivers rapidly filled up with the runoff and began to cause problems for steamboats who found it difficult to traverse the shallow waters. Farmers were affected the most as flooding from the artificially raised riverbeds left sand and tailings (which often contained mercury) in their fields and rendered them infertile [Hayes, 1998]. 39,000 acres of farm land are estimated to have been lost and 14,000 acres partially damaged by mining debris [Learn California]. The Yuba Basin was among those hardest hit by irresponsible mining. Over a drainage area of 1554 sq km, 907 sq km were

affected by a volume of 344,000,000 m³ of mining sediment [James, 2004].



Fig. 3 shows the destructive effects of hydraulic mining. This particular photo is of the Manzanita Mine where over 37 million m³ of rock was displaced. The operation was issued a permit to remove 806,000 m³.

In 1884, after years of farmers protesting the use of hydraulic mining, the Sawyer decision halted the dumping of tailings into rivers and streams throughout the state [Learn California]. The ruling used the law of equity that states any use of one's private property that damages another's is unlawful [Learn California]. Hydraulic mining was not prohibited by the decision just severely limited, and the majority of operations were shut down shortly thereafter [Hayes, 1998].

The restrictions on hydraulic mining forced the inventive California gold mining industry to seek out new ways of mining previously hard to reach gold. Flood plains and rivers throughout the Central Valley were full of unconsolidated gold located in sediments that had been deposited over thousands of years by the erosion of gold-bearing rocks upstream [Hayes, 1998]. The first profitable mining of this gold was done by dredging in 1898. Dredges were mobile, floating structures that extracted gold from the river sediments. The sediments were lifted into the center of the structure by buckets then processed and sorted to separate the gold from the sand [Swiecki, 2007]. Dredges were used throughout the 1960's and mined more than

20 million ounces of the valuable metal as it was profitable to do so when the sediments contained only 10-15 cents of gold per cubic yard [Hayes, 1998].

Beginning in 1849, miners used a different approach called hard rock mining to extract a significant quantity of gold-bearing quartz [Hayes, 1998]. The quartz was organized into veins, which are thin strips of mineral-filled fissures found in the Earth [Hill, 2006]. An area in the Mother Lode region called Grass Valley was one of the richest areas for hard rock gold mining in California. The mines in the region operated for nearly 106 years until they were closed down in the 1950s and are estimated to have mined 13 million ounces of gold [Hill, 2006]. A few veins in Grass Valley were mined to an inclined depth of 3,353 m. The average grade of the gold varied from one-quarter to one-half ounce of gold per ton [Hill, 2006].

In order to mine gold from the quartz veins, excavation was necessary. This posed new challenges to the miners as quartz is a very hard mineral. Tunneling and gold extraction cut deeply into profits until dynamite and the steam-powered drill were introduced in the mid-1860s [Hayes, 1998]. These improvements revolutionized the industry and allowed for more efficient expansion of the mines. Tunnels previously measured in hundreds of feet increased to contain miles and miles of underground operations [Hayes, 1998].

A key fixture found near almost any hard rock mine was a stamp mill. The stamp mill was the destination of all gold-bearing quartz extracted from the mines. Here the quartz was processed and host mineral was separated from the gold by a series of steps. The first step was to send incoming materials over grizzlies which were parallel iron bars that allowed the finer ore to drop through and moved the larger blocks of ore to a rock crusher [Quivik, 2003]. After being crushed, the previously separated ore was sent to the stamps. The stamps were a collection of

wooden blocks with iron-coated bottoms weighing upwards of 450 kg that would pound the quartz into a fine powder [Hayes, 1998]. This powder was then mixed with water which created what miners called “pulp.” The pulp was filtered through screens and sent over aprons of mercury where any exposed gold amalgamated with the quicksilver. Every so often, the resulting amalgam would be cleaned from the aprons and hauled off for gold extraction. Tailings that ran off the aprons were moved into amalgamating pans where additional crushing exposed more gold to mercury [Quivik, 2003].

Even after being sent to the amalgamating pans, tailings still contained a considerable amount of low-grade gold. It was not until the late 19th-century that a method was devised for obtaining these deposits [Quivik, 2003]. The solution was to spray cyanide over tailing ponds. Cyanide has the unique property of dissolving gold into a water-soluble compound that can later be separated using zinc and sulfuric acid [Modern Gold Mining Techniques] [Moran, 1998]. Cyanide processing aided in the profitability of mining operations at Bodie, California where heaps of tailings underwent cyanide treatment and allowed prolonged operations at the mine [Quivik, 2003].

Modern-day gold mining is much different than the placer mining of the 1800s. In 1971, President Nixon lifted gold price controls and the value of gold soared [Hayes, 1998]. Increasing prices made the extraction of low-grade ore economically viable and open pit mining was used to acquire the precious metal. Mining grades as low as 0.025 ounces per ton of processed ore became profitable due to new technology and improved prospecting techniques [Hayes, 1998].

Open pit mining is an expansive and environmentally-taxing operation. After satellite surveys and geochemistry analysis, a computer model is produced that designates the perimeters

of the mine [Gold Mining in the 21st Century]. Next, holes are drilled into the ground and charges are dropped down the holes to cut into the earth. Once the desired depth is reached, machines scoop the rock from the ground in layers and, after it is crushed, process it using cyanide [Hayes, 1998]. In the United States, open pit mines are typically required to perform a reclamation process on the mined land costing companies somewhere between \$2,000 and \$10,000 per acre restored [Gold Mining in the 21st Century].



Fig. 4 is a panorama of an open pit mine in Garzweiler, Germany. As seen from the photo, the scale of the operation is enormous and effects on the environment are considerable. Figure reproduced from Spekking [2005].

Environmental effects of mining

The environmental effects of mining techniques involving chemical extraction methods have been a continuing issue in protests against mining operations. Irresponsible mercury use in hydraulic mining operations caused large amounts of ecological problems for the region. Mercury used to separate gravel from gold and eventually amalgamate with gold in the riffles was often carried downstream and into the rivers [Alpers et al., 2005]. The total amount of mercury lost to the environment during hydraulic mining operations is estimated at 10,000,000 lbs. of which 80-90% was deposited in the Sierra Nevada [Alpers et al., 2005]. Hard rock mines were also sites of mercury loss accounting for around 3,000,000 lbs. of contamination [Churchill, 2000]. Research done in the Bear River and Yuba River watersheds has indicated that fish have bioaccumulated enough mercury to pose a human health risk [Alpers et al., 2005].

As mercury was phased out of use for gold extraction, cyanide became a more popular substitute for separating gold from surrounding rocks [Moran, 1998]. Sunlight breaks down cyanide into less toxic compounds and most mining operations are adamant about monitoring their processing facilities, but accidents do happen. Cyanide leach heaps are intended to be a closed system, however, over time many of them become plagued by leaks and cyanide contaminates the surrounding environment [All That Glitters Is Not Gold]. In 1995, a tailings dam in Guyana broke, releasing 3 billion liters of cyanide into surrounding rivers and, according to the Pan American Health Organization, killed all aquatic life in the affected water [Poisoned Waters].

Hundreds of millions of dollars may be required to restore areas around abandoned mining operations to levels safe enough for wildlife habitation and many organizations are working to survey the extent of contamination around these locations [Alpers et al., 2005] [No Dirty Gold]. Groups like the USGS and California Office of Environmental Health Hazard Assessment are monitoring the levels of mercury in streams and lakes to warn against human consumption of wildlife living in these ecosystems [Alpers et al., 2005].

Although the scars of mining still remain in California, we cannot overlook the positive effects of the infamous Gold Rush. Economic effects in the state of California and the nation in the 19th century were brought about by the wealth generated by the mining industry. New mining technologies were constantly being introduced, the West was explored at an accelerated rate, and an increased national money supply allowed for higher standards of living. In addition, the transcontinental railroad was partially funded by money earned in the Gold Rush and the boom in population pushed California into statehood in 1850 [Rawls, 1999]. The geological processes that shaped the region over millions of years played a major role in American history as the Gold

Rush was a time of unparalleled excitement and transformed parts of California into the state we know today.

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