Presentation to
Northern California Geological Society (NCGS), September 28, 2011

Abstract

California's Gold: History, Geology, and Geochemistry

THE "MINES"

Placer and Underground Mining: In January 1848, James Marshall was camped with a work crew on the American River at Coloma near present-day Auburn, building a saw mill for John Sutter. On January 24, Marshall discovered several gold nuggets in the river's gravel; the subsequent announcement published in San Francisco's one-page newspaper *The Californian*, was not widely believed but it resulted in one of the largest historical human migrations with perhaps 500,000 people world-wide finally descending on California with the desire to reap instant wealth. Placer gold was subsequently discovered in the Feather River and Trinity River drainages. By August 1848, news had reached the east coast and by December, President Polk announced the discovery in congress setting off the Great California 1849 Gold Rush with thousands of itinerant miners descending on the rich surface and near surface placer deposits of the western Sierra Nevada. These *Forty-Niners* also followed the placers back to their quartz vein origins or to *The Mother Lode* (ML) where underground mining began at the Mariposa mine in Mariposa County. In 1850, California became a state with the border moved eastward to include the entire Sierra Nevada. Also in that year, gold-bearing quartz veins were discovered at Gold Hill in Grass Valley, leading to development of large underground mines such as the Empire and Idaho-Maryland mines. In 1853, the first extensive underground mining of buried alluvial river channels (drift mining) commenced at Foresthill in Placer County.

Hydraulic Mining began in 1852 at American Hill just north of Nevada City and at Yankee Jims in Placer County. It rapidly replaced the solitary prospector's panning methods and by 1864 was conducted on a large-scale industrial process. Miners dammed and diverted streams in a vast system of canals (called *ditches*) so that they could wash down auriferous gravel hillsides with high-pressure jets of water (known as *water cannons* or *monitors*). Washed gravels were processed through long wooden sluice boxes to extract placer gold. Gravels and fine sediment—called *slickens*—were then discharged back into the streams, subsequently washing down into the lower Sacramento Valley. From about 1850 to 1884, an estimated 250 million cubic yards ($Myds^3$) of gravel produced 12 million ounces (Moz) of gold. The large influx of hydraulic mine tailings (up to 685 Mft^3 of debris) were deposited in the lower Yuba River, raising the river bed as much as 45 feet in places. In 1884, hydraulic mining was prohibited by the now famous Sawyer Decision.

Dredging in California river alluvium began in 1850, when a small boat fitted as a dredge attempted gravel mining on the Yuba River above Marysville. In 1893, the California Debris Commission also began dredging the Yuba River near Marysville to mitigate environmental damage caused by earlier hydraulic mining. Gold production also commenced again increasing with the construction of larger dredges. In 1898, the first successful gold dredge was introduced on the lower Feather River near Oroville. In 1904, the Yuba Consolidated Gold Fields Company was founded becoming a large, profitable placer dredging operation on the Yuba River. By 1911 California had 62 operating bucket-elevator dredges. Of those, only a single dredge (Yuba No. 17) currently mines gold.

Open Pit (OP) mining for disseminated gold (DG) actually began in 1902 at Randsberg with development of the Yellow Aster OP and more recently the Baltic OP (1983 to 2003), which produced ~1.0 Moz) gold (Au). Homestake's McLaughlin mine (1985 to 1996) in Napa-Sonoma Counties, a mercury-gold "fossil" hot springs deposit produced 3.3 Moz Au. From 1983 to 1994, the Harvard OP at Jamestown (near Sonora), produced 0.660 Moz Au from the ML veins and gold disseminated into surrounding wall rock. Other OP gold mines occur in the Basin Ranges and western Sierra Nevada.

THE "GOLD"

ML Gold Belt (GB) Geology

The ML GB has a very complex geology: rocks are composed of both island arc (mafic, intermediate, and felsic rocks mostly of pyroclastic origin), oceanic (mafic, tholeiitic volcanic, and associated sediments), and intrusive accreted terrains from about mid-Devonian to Cretaceous time (~400 to100 million years ago or Ma). These now form the Western Metamorphic Belt (WMB) on the west side of the Sierra Nevada batholith, extending northwest for ~200 miles through the foothills of the central and northern Sierra. The southern WMB, near Mariposa is ~30 miles wide, widening northward to ~60 miles in the northern Sierra. The WMB is divided into three major northwest trending units: (1) The Shoo Fly Complex on the eastern side, (2) the Calaveras Complex (CC) in the center, and (3) the Foothills Terrain on the west. Each is bounded and separated by large fault systems many of which extend the entire WMB length. This series of faults are also comprises the Foothills fault system (FFS) and most of the ML gold deposits occur here. One of these, the Melones fault zone (MFZ), dips steeply eastward, bisecting CC rocks; it is identified by intensely sheared rocks, quartz veins, and serpentine lenses. The MFZ has been mineralized with gold and copper, zinc, and lead sulfides. Large ML vein gold deposits closely follow the MFZ from Placerville to Mariposa. In the southern and central parts of the WMB, the MFZ splays northward; however, there is some uncertainty concerning its northern Sierra counterpart. Most of the gold/sulfide mineralization postdates WMB and Sierra Nevada plutonic rocks with estimated emplacement between 115 and 120 Ma.

Placer Geology

Tertiary alluvial placer deposits generally form in moderate to high energy depositional environments where gradients tend to flatten and river velocities decrease, particularly at the inside of river meanders, below rapids and falls, beneath boulders, and in vegetation mats. These deposits are therefore composed of silt and sand to cobble and boulder sized gravel and conglomerate containing white quartz clasts with sand and sandstone generally of secondary importance.

Placer deposits may contain either gold, with minor platinum group metals (PGM) or PGM with minor gold in grains and nuggets. Gold occurs with very little silver and PGM occurs as platinum-iron and/or osmium-iridium alloys. Gold forms flattened flakes with rounded edges and as "flour" gold which consist of extremely fine-grained flakes. Nuggets are generally irregular and very rarely equi-dimensional in form (see descriptions of geochemical formation below).

Gold Geochemistry

Primary or hypogene gold is that which has been deposited and/or precipitated from high-temperature hydrothermal fluids originating deep in the crust commonly associated with intruding magma or shallower meteoric water. Native or free gold commonly occurs in crystalline form. Most primary gold ores are gold-silver (Au-Ag) alloys, generally with Au/Ag ratios greater than (>) 1. Primary gold typically contains from 5 to 20% silver, but in some deposits, it may be almost pure; in other cases, silver may exceed 50%.

Secondary or supergene gold occurs when primary gold is mobilized or dissolved as Au-complexes from several organic and inorganic ligands that are then reprecipitated in surface or weathering environments. It also may form from reduction by bacteria of Au-chlorides in saline Au-rich groundwater where visible gold plates are precipitated at the water table as nanoparticles (100 to 300 µm), ultimately producing hexagonal and triangular gold crystals as small as 50 nm. Most fine or placer gold is secondary, which is nearly pure with high fineness, generally having less than (<) 1% Ag. Secondary gold may occur in soil, deep regolith, stream sediments, and placers.

Placer gold may also form as nuggets generally having Au–Ag alloys chemically similar to that of primary gold; commonly there is Ag depletion on crystal boundaries where exterior surfaces are exposed to weathering. Physical crystallography analysis of nuggets also indicates a hypogene origin because many nuggets have internal even-textured, polycrystalline fabrics, with crystals often exhibiting both coherent and incoherent twinning. Such textures have also been confirmed in Au-Ag metallographic studies characteristic of thermal annealing at temperatures >250°C. These similarities show a definite hypogene origin. Therefore, the relative abundance of nuggets in surficial environments is due to physical concentration by weathering of primary ores and subsequent fluvial transport.

SPEAKER'S BIOGRAPHY

Dr. William E. (Bill) Motzer, Ph.D., PG, CHG has 37 years of experience as a Professional Geologist and more than 25 years of experience in conducting surface, subsurface, and environmental forensic geochemical investigations. He is a recognized expert in forensic geochemistry, with particular expertise in stable and other isotopic "fingerprinting" and age dating techniques and water quality/contaminant geochemistry, particularly in MTBE, NDMA, PPCPs, perchlorate, chromium(VI), arsenic, lead, mercury, and nitrate issues. Bill has conducted more than 400 environmental and water quality projects throughout California and other western states particularly for water districts, municipalities, and state agencies. Additionally, he has 15 years experience as a minerals/mining exploration geologist, specializing in base and precious metal deposits and has been retained as an expert witness for mine litigation issues. He has contributed to several book chapters and is the author of numerous journal articles. Bill served as the 2007-2008 San Francisco Bay Branch President of the Groundwater Resources

Association of California (GRA); he regularly contributes articles to GRA's on-line publication *HydroVisons*, and is also Co-chair of GRA's Technical Committee. He is Vice President for the International Society of Environmental Geochemistry and Health (2010-2011) and is also the 2011-2012 Chair for the Northern California Section of the Society for Mining, Metallurgy, & Exploration (SME), and is a contributing editor for the California Section of American Chemical Society on-line newsletter *The Vortex*.