

# TERTIARY GOLD BEARING MERCURY DEPOSITS OF THE COAST RANGES OF CALIFORNIA

By

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## INTRODUCTION

Recently an unsuspected reserve of gold, estimated to exceed 3.2 million ounces, was discovered by Homestake Mining Company at the Knoxville mercury mines in Napa County. This is one of several occurrences of gold associated with mercury or antimony in the Coast Ranges of California (figure 1). These deposits began forming shortly after the emplacement of volcanic rocks in the Mid-Tertiary Period and continued to form through Quaternary time. Connate water squeezed from sedimentary units was heated and eventually found its way to the surface via fracture zones. Presumably this hot water, high in chloride (Cl), car-

bon dioxide (CO<sub>2</sub>), silica (SiO<sub>2</sub>), and containing abundant hydrocarbons, dissolved the gold and mercury contained in the sedimentary units. At the surface, hydrocarbons may have played an important role in the deposition of the gold, in a manner similar to the Carlin-type deposits of Nevada, which closely resemble the gold deposits of the Coast Ranges. Mercury is presently being deposited by hot springs at the Sulphur Bank mine near The Geysers steam field in the Clear Lake area of California.

## PREVIOUS STUDIES

The earliest and perhaps one of the most comprehensive studies of the mer-

cury deposits of the Pacific Coast was that of Becker (1888). He determined the presence of gold at mercury mines at Wilbur Hot Springs, Sulphur Bank Hot Springs, and the Knoxville mine area. He also reported the occurrence of gold at the Picacho Mine, located southwest of New Idria. Other workers (Crutchfield, 1953; Newmont Exploration, 1965; Bailey and Meyers, 1949) have identified gold at the Calistoga and Oat Hill mines, and the Stayton District (table 1).

## GEOLOGY

The major rock types found in the Coast Ranges are the Great Valley sequence, the Franciscan assemblage, a mafic-ultramafic sequence, and volcanic rocks of Tertiary and Quaternary age. The Great Valley sequence and the Franciscan assemblage consist predominately of marine sedimentary rocks of Late Jurassic to Late Cretaceous age. The Franciscan assemblage consists of graywacke, shale, mafic volcanic rock, chert, limestone, some of which have been metamorphosed to the zeolite and blueschist facies. The Great Valley sequence consists predominately of graywacke, shale, and some conglomerate. The Jurassic section of the Great Valley sequence depositionally rests upon an accumulation of mafic volcanic rocks, that in turn rest upon serpentinized ultramafic rocks. The mafic-ultramafic sequence closely resembles present in-situ oceanic crust (Bailey and Jones, 1970). The Coast Ranges thrust fault separates the Franciscan assemblage from the Great Valley sequence with outcrops of serpentinite occurring on the upper thrust plate.

Much of the mercury in the Coast Ranges occurs in altered serpentinite. Solutions enriched in silica (SiO<sub>2</sub>) and car-

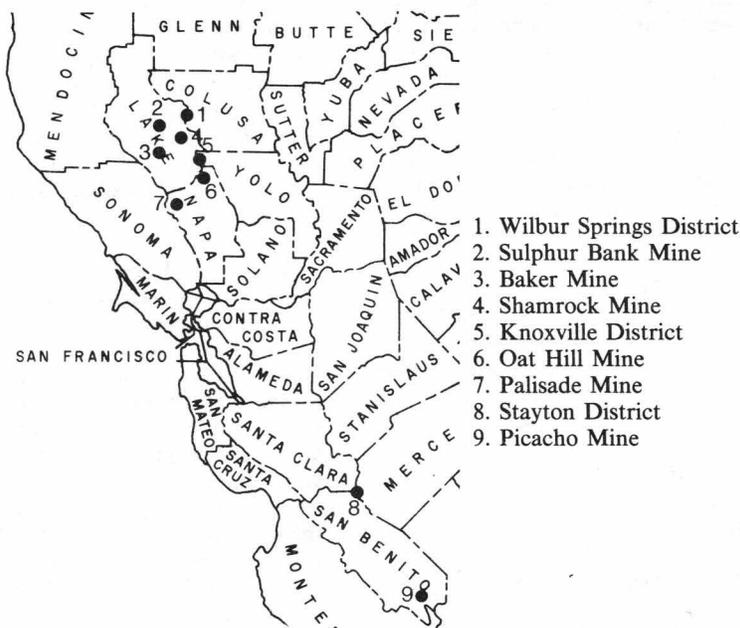


Figure 1. Tertiary gold deposit occurrences in the Coast Ranges of California associated with mercury or antimony.

bon dioxide (CO<sub>2</sub>), rising along faults, have replaced serpentinite by silica-carbonate rock. Silica-carbonate rock typically consists of chalcedony, opal, quartz, magnesite, and calcite.

### LOCALIZATION OF ORE

Although over 50 per cent of the largest mercury deposits in the Coast Ranges are associated with altered serpentinite, mercury also occurs in rocks of the Great Valley sequence, the Franciscan assemblage, in Tertiary volcanic rocks, and at active hot springs. Thus, rock type does not appear to be the controlling factor in the deposition of mercury in the Coast Ranges metallogenic province.

The presence of young, high-angle faults appears to be the most important factor in the location of mercury deposits within the Coast Ranges. All mercury deposits are associated with faults and fracture zones. Averitt (1945) suggested that clay gouge zones associated with faulting, effectively channeled mineral-bearing waters, thus controlling mercury deposition at the Knoxville mine.

### ORIGIN OF ORE

The origin of the mercury, gold, hydrocarbons, and the water, which acted and still acts as a transporting medium, are all intimately associated with the marine sediments. In a study of thermal and mineral waters in the Clear Lake area, White and others (1973) concluded that the high chloride connate waters found at Wilbur Springs are chemically and isotopically similar to the oil-field waters of the Central Valley of California, but are generally enriched with bicarbonates and boron. This water probably evolved from compaction and loss of pore water in the marine sediments, but is also generated to some extent by the continuing low-grade metamorphism occurring at depth. Hydrocarbons present at Wilbur Springs and Knoxville are common in many of the mercury mines in this region and came to the surface in the same fracture zones that hot mineral-laden water did. At Wilbur Springs, hot water and hydrocarbons (liquid and gas) are ascending in the same fracture system.

Moisseff (1966) concluded that the mercury at Wilbur Springs probably was concentrated from sediments in "solutions of metamorphic or connate origin." It is likely that the gold has a similar origin. Noting the lack of flour gold in gold-

bearing gravels in the Sierras, Graham (1981) sampled the Great Valley sequence (and younger formations), hoping to detect the timing of gold emplacement in the Sierras. He noted a general increase in gold with decrease in age. The Knoxville Formation assayed .001-.002 oz. per ton in gold, and the Eocene formations assayed .006-.008 oz. per ton (Steve Graham, personal communication, 1981). The high chloride content of the water may have facilitated in the remobilization of gold, since in chloride-bearing hydrothermal solutions, gold is transported as the auriferous chloride complex AuCl<sub>2</sub> (Radtke and Scheiner, 1970).

As an alternative to this hypothesis for the source of gold, Eyans (1981) suggests that gold present in ultrabasic rocks may be chemically dissolved and reprecipitated in placer deposits by the process of laterization. If gold is present in the serpentinites, it could be leached by the connate water present in the system. Although this process may contribute to gold present in the Coast Ranges deposits, it probably is not the only source, since some mercury-gold deposits are not near occurrences of serpentinite.

### SOURCE OF HEAT

During Tertiary and Quaternary time the Clear Lake, Sonoma, Tolay, Berkeley Hills, Quien Sabe, and Neenach-Pinnacles volcanic fields erupted in the Coast Ranges, generally decreasing in age northward, and providing an ample source of heat for mercury and gold-bearing hydrothermal solutions. Hot volcanic rocks at depth in the Clear Lake area still provide a source of heat for geothermal fluids. The Geysers geothermal area is believed to be heated by a silicic magma body centered below 10 km in depth, the top of which is within 7 km of the surface (Hearn and others, 1981). At Wilbur Springs, on the basis of a detailed gravity study, a series of 100 m-deep temperature gradient holes, and two deep wells (400 m and 1,200 m), Harrington and Verosub (1981) concluded that the source of heat may be a deep magma intrusion. Fractures within the rock provide the conduits needed to transfer the heat in the form of hot water or steam from the intrusion to the surface.

### PARAGENESIS

A paragenetic sequence for minerals has been worked out for the Sulphur Bank mine, Wilbur Springs mines, the Palisades

mine and the Stayton District; however, the relationship of gold with other minerals has not been determined. Where gold has been reported at mercury mines in the Coast Ranges, it either occurs as free gold or is contained within the iron sulfides of pyrite or marcasite. The nature of the gold's occurrence has not been determined at the Shamrock mine, Palisades mine and the Stayton District. Investigations at the Palisades mine (Crutchfield 1953, p. 49, 50) and in the Stayton District (Bailey and Meyers 1949, p. 47) have shown that cinnabar was deposited after other base metals. Pyrite was deposited with both the base metals and cinnabar, but it is not known if the gold is associated with cinnabar or other metals.

### COMPARISON WITH CARLIN-TYPE DEPOSITS

There are some conspicuous similarities between mercury-gold deposits in the Coast Ranges and the Carlin-type gold deposits which have become the source of large quantities of gold being mined in Nevada. Radtke and other workers (see Boyle, 1980, for a summary) have done the pioneer work on the Carlin-type deposits. From their work a checklist of geologic, mineralogic, and geochemical features common to these types of deposits has been developed. This list includes: silty carbonate rocks, the presence of hydrocarbons, gold associated with mercury, arsenic, antimony, tungsten and thallium, replacement by fine-grained silica and minor pyrite, and mineralization related with large displacement normal faulting. Fluids at these deposits have been shown to be of meteoric origin. Work by Radtke and Scheiner (1970) suggests that the presence of carbonaceous materials (hydrocarbons) may be critical for the deposition of gold.

In the Coast Ranges of California, mercury deposits are largely, but not entirely, restricted to occurrences of serpentinite which has been replaced by silica and carbonate. Hydrocarbons and pyrite are very common in these deposits. The presence of hydrocarbons supports the findings of White and others (1973) that the water which transported the mercury is of connate origin, and that the silty sediments of the Great Valley sequence are the source of the connate water. This water, therefore, has a different source than the water associated with Carlin-type deposits in Nevada. With some exceptions, gold is associated with mercury and/or antimony in the Coast Ranges. The mercury depos-

its of the Coast Ranges are of late Tertiary to Quaternary age and are associated with normal faults.

From this discussion, it can be shown that there are numerous similarities between the mercury deposits in the Coast Ranges of California and the Carlin-type gold deposits. The Knoxville gold deposit is the first major deposit of this type to be

recognized in California. However, it is clear that there is evidence for the potential existence of other epithermal gold deposits in California.

#### ACKNOWLEDGMENTS

I would like to thank the following persons who helped in the preparation of this report: Susan Skinner, Bureau of Land

Management, Ukiah District Office; Edmond Lawrence, consultant; Christine Carlson, Robert McLaughlin, and Don White, all of U.S. Geological Survey, Menlo Park; Steve Graham, Stanford University; Foster Howland, Resource Exploration; M.C. Smith. I would like to thank Roger Haskins, Bureau of Land Management, for reviewing this manuscript.

TABLE 1. MERCURY BEARING DEPOSITS (See figure 1).

| PROPERTY NAME   | LOCATION                               | GEOLOGIC DESCRIPTION  |
|---|--|---|
| Baker   | Section 16, T12N, R6W MDM              | ▶ Isolated bodies of serpentinite altered to silica-carbonate rock occur in sediments of the Great Valley sequence. Minerals include cinnabar, meta-cinnabar, pyrite, and marcasite. Marcasite assayed by Becker (1888, p. 368) contained .048 oz. of gold per ton (Brice, 1953).   |
| Knoxville (Knoxville, Manhattan, Harrison, Soda Springs, Reed and Red Elephant mines) | T11, 12N, R4, 5W MDM                   | ▶ Generally, mercury deposits are confined to silica-carbonate rocks along northwest trending faults, which form the contact between serpentinite and sediments of the Great Valley sequence. At the Manhattan mine mercury ore occurs in altered Tertiary olivine basalt and tuff. Minerals reported from these mines include cinnabar, metacinnabar, pyrite, marcasite, stibnite, native mercury, copper oxides, gold, millerite (nickel sulfide) and redingtonite (hydrous chromium sulfate). Pyrite in the district shows traces of gold (Averitt, 1945, p. 78). Apparently minor leaching has occurred, yielding free gold as reported by Becker (1888, p. 282):<br>The surface soil here (the Manhattan mine) and also near the Redington (Knoxville) mine contains cinnabar, resulting from the erosion of croppings, and accompanying the cinnabar is free gold, which may be found by panning the soil.                            |
| Oat Hill  | Section 27, 28, 33, 34, T10 N, R6W MDM | ▶ The Oat Hill mine is one of several mercury mines situated along the crest of the broad eastward plunging Mayacmas anticline where the sandstone has been broken by northwest trending normal faults. At the Oat Hill mine the sandstone has been intensely kaolinized and the rock is cut by numerous dense quartz veinlets. Fine cinnabar crystals are disseminated through the altered sandstone, and are associated with calcite and pyrite. Assays of dump material at the Oceola workings were .06% mercury, 4.58% iron, .005 oz./ton gold and .02 oz./ton silver. The material contained an appreciable amount of hydrocarbons and 2-5% pyrite. The dump of the Eureka Workings contained a trace of gold (Yates and Hilpert, 1946, p. 260-262; Newmont, 1965).  |
| Palisades (Grigsby)   | Section 24, T9N, R7W MDM               | ▶ Two quartz veins which strike N 5°W and dip 70°W occur in extensively fractured, generally flat lying andesite flows and related pyroclastics. Ore minerals (in order of abundance) are chalcopyrite, pyrite, sphalerite, argentite, polybasite, galena, and cinnabar. Gangue minerals are quartz, adularia, and calcite. Marcasite, limonite, and selenite are products of supergene alteration. Cinnabar occurs in minute veinlets accompanied by pyrite and is of later origin than the base metal sulfides. According to Becker (1888, p. 370) assays of silver ore contained antimony and a trace of arsenic. The mine has also produced gold, although Crutchfield (1953, p. 45) was unable to observe any in polished section. He speculates the gold may be contained in the pyrite and chalcopyrite. Crutchfield (1953, figure 15), shows that gold was deposited simultaneously with the base metals, rather than the cinnabar. |
| Picacho   | Section 19, 20, T18S, R12E MDM         | ▶ Lenses and irregular bodies of silica-carbonate rock occur in a broad shear zone in serpentinite. The mercury ore has been produced from shallow open cuts. Becker (1888, p. 309) indicated that gold and silver were reportedly present (Averill, 1947, p. 59).  |

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|---|---|---|
| Shamrock  | Section 14, 23, T13N, R6W<br>MDM  | ▶ The Hunting fault, which separates serpentinite on the south from sediments of the Great Valley sequence on north, trends northwest across the Deep Shaft and Zodiac claims. The fault zone is expressed as a red clay gouge zone that contains sparse mercury values. The most significant mercury mineralization occurs in serpentinite which is altered to opalite, located south of the fault. The altered serpentine is mineralized with cinnabar, copper oxides, pyrite, and gold. Small amounts of gold have been recovered from the ore by the use of a shaker table. Placer gold, and a nugget which weighed .25 ounces, have been recovered from Rocky Creek. Reportedly, cinnabar crystals were found to have grown within one gold nugget. (M.C. Smith, personal communication, 1981; Lawton, 1956).  |
| Stayton (Quien Sabe, Blue Wing, Stayton, Yellow Jacket Gypsy, Shriver, Comstock, Mariposa, and Ambrose mines) | Section 5, 6, T12S, R7E,<br>Section 19-21, 28, 30-32, T11S<br>R7E MDM     | ▶ Antimony and mercury mineralization is confined to northwest trending faults. Stibnite bearing quartz veins occur in Tertiary basalt, and at the Ambrose mine in intrusive andesite. Cinnabar occurs as later encrustations and impregnations in fractured antimony veins, and fracture fillings in basalt. At the Comstock mine, cinnabar is confined to a fault zone in silica-carbonate rock. Ore minerals reported from the district include stibnite, cinnabar, metacinnabar, mercury "paint," and the antimony oxides of valentite, senarmonite, cervantite, and stibconite. Gangue minerals reported are eponite, melanterite, gypsum, barite, and jarosite (Bailey and Myers, 1949). Antimony veins at the Quien Sabe mine average about .02 oz./ton gold and from a trace to .5 oz/ton silver (Wiebelt, 1956). At the Shriver mine, Ireland (1890, p. 517) reported that small amounts of mercury ore were found near the surface, and assayed specimens of the antimony vein yielded \$25 in gold and \$17 in silver per ton.   |
| Sulphur Bank  | Section 6, T13N, R7W, MDM   | ▶ The oldest rocks present are sandstone and shale of the Franciscan assemblage. These rocks are partially unconformably overlain by Recent sediments which, along with the underlying Franciscan rocks, have been brecciated—probably in a landslide. An augite andesite flow overlies much of the earlier deposits. Prior to the commencement of mining, native sulfur occurred at the surface. Mercury was localized along faults below the water table. Metallic minerals include cinnabar, stibnite, and pyrite. Becker (1888, p. 257) reports that an assay of a sample of marcasite contained traces of copper and gold. He also reported small quantities of "bitumen." Sims and White (1981) report that mercury is presently being deposited by hot mineral charged water. (Everhart, 1946).  |
| Wilbur Springs  | Section 12, 13, T14N, R6W<br>Section 21, 28, 29, 31, 32,<br>T13N, R7W MDM | ▶ Three areas of mercury mineralization can be recognized in the vicinity of Wilbur Springs. The Wilbur Springs group of mines consists of the Wide Awake, Central and Empire mines located along a "dike" of detrital serpentinite and the Manzanita and Cherry Hill mines located in fractured sedimentary rocks of the Knoxville Formation. The Elgin mine group occurs in a body of silicified serpentinite and the Knoxville Formation. The Abbott mine group includes the Boggess, Abbott, and Turkey Run mines, which are located in silica-carbonate rock at the contact between the serpentine with Knoxville sediments. Minerals present in the Wilbur Springs district include cinnabar, metacinnabar, pyrite, marcasite, gold and minor calomel. At Wilbur Springs, mercury ore occurs in the same localities as the hot springs. Gold occurs at the Cherry Hill, Manzanita, Abbott, and Clyde mines (Logan, 1929). At the Abbott mine, traces of gold are present in the marcasite (Moisseeff, 1966, p. 85). Becker (1888, p. 367) noted the ore at the Manzanita mine consisted of:<br><p>...cinnabar and gold, which are sometimes in direct contact, and some metacinnabarite. These minerals are accompanied by pyrite and marcasite, chalcopyrite, stibnite, calcite, and quartz. The gold is often visible in feather-like, crystalline aggregates, sometimes in direct contact with cinnabar and sometimes deposited directly upon calcite...</p> <p>At this mine, Moisseeff (1966) described the occurrence of gold as specks or "sheets" in leached zones. The destruction of iron sulfides probably liberated the gold which then became scattered in the leached zones.</p> |

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