The Colosseum Mine, in the Clark Mountain Mining District north of Mountain Pass at one time was the largest gold producer within the Eastern Mojave National Scenic Area (EMNSA) and, from 1987 to 1992, was the largest metals mine in operation. It produced about 2,188 kg Au and 938 kg Ag per year during peak years of operation. (From Theodore, 2007, p. 200-201).

Mine History

Colosseum Mine. This mine originally was comprised of 2 patented claims (Colosseum No. 1 and Colosseum No. 2), and 32 claims held by location, situated on the northwest slope of Clark Mountains, in sec. 19, T. 17 N., R. 13 and 14 E., SBM., 10 miles north of Valley Wells and 23 miles north of Windmill Station, on U. S. Highway 91 [now I-15]; elevation 5,500 to 6,100 feet. The owner was the Colosseum Mining & Smelting Corporation, C. W. Gowman, president, Earl Thomas, secretary, 7371 West Sunset Boulevard, Hollywood, California. The property was under option to Harold Chase and Walter Lineberger, of Santa Barbara, California, from February 1938 to November 1942. During this period, 5,000 feet of diamond-drill work was done to determine the extent of orebodies; also development on lower tunnel level on No. 2 orebody. These parties suspended operations in the latter part of 1942, surrendering their option. (From Tucker and Sampson, 1943, p. 128-129).

Since the Twenty-seventh Report of the State Mineralogist was issued (1931), the following development work has been done on the property, up to 1943: At an elevation of 5,700 feet, and 177 feet in elevation below upper tunnel, a lower tunnel has been driven N. 20° E. for 440 feet in granite, intersecting shaft at a depth of 200 feet; at 400 feet from the portal, it intersected a contact of granite and rhyolite porphyry. At 435 feet from the portal, a crosscut was run northwest 160 feet to west contact of No. 2 orebody, then drift along contact 160 feet in ore. The orebody developed along contact is 100 feet in length by 12 feet in width. Average value is reported to be $7.85 per ton. Upper tunnel is 800 feet in length; elevation 5877 feet. Upper tunnel level and intermediate tunnel level have developed No. 1 orebody which is 125 feet in length and 60 feet in width. Total amount of development is about 4,000 feet. Mine equipment consists of one 180-horsepower Fairbanks-Morse diesel engine; one 60 K.V.A. Fairbanks-Morse, 3-phase, 60-cycle, 460- volt generator; one 20-horsepower Westinghouse generator; one Ingersoll- Rand 2-stage (12- by 12-inch) (7-J- by 12-inch) air compressor; one Sullivan drill sharpener; mine cars and air drills. Mill equipment consists of concentration mill with a capacity of 50 tons per 24 hours; one 100-ton ore bin; one 3D Gates gyratory crusher; one Challenger ore feeder; one 24-foot bucket elevator; one 36- by 96-inch vibrating screen; one 5- by 4-foot Marcy type of ball mill; one 50-horsepower Westinghouse motor; one 18- by 48-inch trommel; one Cone classifier; 2 Wilflley tables; one 25-horsepower motor; 2 Groch flotation cells; one 12-foot rake classifier; one 16-foot conical settler; one 20-foot Dorr thickener; three 8-foot wood storage tanks; one 20- by 20- by 8-foot concrete water-storage tank, with a capacity of 35,000 gallons. From well on Mojave tungsten claim, water is pumped through 5,000 feet of 2-inch pipe line to water storage tank above mill. Previous to 1938, the mill was operated and produced 1000 tons of concentrates reported to have a value of $20 to $40 per ton in gold. (From Tucker and Sampson, 1943, p. 128-129 see also State Mineralogist's Reports XX, pp. 92-93; XXVII, pp. 291-292).
Production, initially begun in 1929, was shut down in 1939. During that time, 3016 tons of ore were produced yielding 615.43 ounces of gold, 115 ounces of silver, 285 pounds of copper and 285 pounds of lead. Run of the mine ore ran $7.00 per ton, while some high grade pockets produced $30.00 ore. From 1938 to 1942 approximately 5,000 feet of diamond drill holes were drilled in an extensive exploration program. However, War Production Board order L-208 shut the operation down and the mine was closed (Dobbs, 1961, p. 88).

The mine was reopened in 1987 as an open-pit operation. According to the U.S. Bureau of Mines (1990a), ore reserves in 1989 were estimated at 9.5 million tonnes (t), averaging 1.94 g Au/t. About 7 years of mine life were left as of February, 1990, at a production rate of about 219 kg/yr and a gold price of $400/oz (From Theodore, 2007, p. 200-201).

Area Geology
The area surrounding the Colesseum Mine contains hydrothermal mineral deposits where geologic data indicates that significant measured or indicated resources are present. It was given an (MRZ-2a(h-1) classification by Bezore and Josheph (1985) for high development potential. The deposit occurs in two hydrothermally altered 100 m.y. old (Mesozoic age) rhyolite breccia pipes that were intruded into crystalline Precambrian basement rocks and previously overlying, thrust faulted, Paleozoic sedimentary rocks (Sharp, 1984). The gold-silver-copper bearing mineralized rhyolite breccia pipes are approximately 500 feet wide by 700 feet long and connect at depth. The pipes also contain fragments of Bright Angel Shale, Tapeats Sandstone, Bonanza King carbonate rock, and epidote-garnet skarn which had collapsed into the vents from overlying Paleozoic sedimentary rocks. The breccia in the pipes are thought to have developed through fluidization and brecciation of rhyolite and older rock units. Gold mineralization occurs as disseminations within the breccia pipes and is closely associated with and deposited as fillings in fractured pyrite. The replacement of carbonate breccia fragments within the breccia pipe has increased the sulfide content and the gold mineralization in the vents as well. Thus, the richest gold mineralization is associated with the main portion of the rubble breccia. (From Bezore and Joseph, 1985, p. 44).

Mine Geology
In the immediate vicinity of the Colosseum mine there is a great anticlinal fold of thick beds of stratified rocks, consisting of sandstone, limestone, dolomite, and thin-bedded shales. These rest upon gneissoid granite. Into this formation, there has been thrust a large, dome-shaped mass of quartz monzonite. Probably following the granite replacement, an intrusion of rhyolite porphyry occurred, in a general N. 30° E. direction. Subsequent to the intrusion of the rhyolite, intensive fracturing occurred in the rhyolite plug, with minor faulting. The major fracture strikes N. 20° W. to N. 20° E. A general mineralization of the rhyolite plug exists along intersecting fractures, metallic minerals being pyrite and chalcopyrite. The pyrite is auriferous. There are two types of ore deposits. The first, No. 1 orebody, is a mineralized network of intersecting fractures within the highly altered rhyolite plug. The second, No. 2 orebody, is a contact deposit on contact of granite and rhyolite plug. The orebodies strike N. 60° E. and dip 80° SW. Estimated tonnage of ore developed in the two orebodies is reported (in 1943) to be 116,000 tons with an average value of $8 per ton in gold (From Tucker and Sampson, 1943).
Figure 2. Geology of the Colosseum Mine and surrounding area. From Hewett, 1957, Plate 1.
The Colosseum gold deposit, investigated in detail by Sharp (1984), is in a breccia-pipe complex that consists of two connected felsite breccia pipes and outlying felsite dikes in a horst block of Proterozoic younger undivided granitoids (unit Xg). The ore is primarily free gold that is disseminated at the micrometer scale in auriferous pyrite. Surrounding related mineralized rock includes vein silver-copper in brecciated dolostone, tungsten, and fluorite, described as “Silver-Copper Brecciated Dolostone,” “Tungsten Veins,” and “Fluorite Veins.” The following descriptive summary of the deposit largely is modified from Sharp (1984). Breccia-pipe gold has not been defined formally as a deposit type (Cox and Singer, 1986), and so characteristics of the Colosseum orebody cannot readily be compared with those of other deposits assigned to this specific type, although descriptions of some individual breccia-pipe gold deposits are available (Baker and Andrew, 1991). Sillitoe (1991) included the Colosseum deposit with six other breccia-pipe-hosted gold deposits he described. The overall range in contained gold in those seven gold-bearing breccia pipes is 9 to 101 tonnes Au, and their mean content of Au is about 44 tonnes. Thus, the Colosseum Mine, which has been shown to contain about 20 tonnes Au, is one of the smaller of such systems known. (From Theodore, 2007, p. 200-201)

The breccia pipes and associated felsite dikes, which are exposed as resistant knobs enclosed within the Proterozoic gneisses, are each about 170 by 235 m wide at the surface, elongated to the northeast-southwest, and connected by a narrow dike. The pipes represent multiphase brecciation events, including significant collapse, and the lithologies within them indicate the composition of the overlying Paleozoic sedimentary rocks and the height of stoping during the development of the breccia. Overlying rocks included the Cambrian Tapeats Sandstone, Cambrian Bright Angel Shale, and Late Cambrian to Devonian dolomite units (included in units_d and PDI). The Colosseum orebody is in the western pipe, but both pipes are mineralized. Each pipe consists of early felsite that is disrupted by later igneous breccia; however, the western pipe also contains abundant clasts of the structurally higher Paleozoic rocks that had been thrust over the Proterozoic rocks before onset of breccia-pipe emplacement. The abundance of sedimentary rocks as clasts indicates that the western pipe stoped through the Tapeats Sandstone and Bright Angel Shale, well into the overlying dolomite, whereas the eastern pipe, predominantly containing basement rocks and felsite igneous breccia, did not invade the Paleozoic sedimentary rocks significantly. Height above the current surface that was subjected to stoping was at least 430 to 460 m. Gold is disseminated in breccia and associated closely with pyrite, commonly filling fractures in pyrite. Highest concentrations of gold are in the western pipe where pyrite has replaced carbonate-breccia fragments, greatly increasing the overall concentration of sulfide minerals. Metal zoning in this part of the Clark Mountain Mining District (fig. 95) is apparently related spatially and genetically to breccia-pipe mineralization. The gold zone is restricted to a circular area around the breccia pipes, in addition to a crescent-shaped area west of and bounded by the Clark Mountain fault. Within the breccia pipes, gold is associated mainly with sulfide minerals, primarily pyrite, whereas outside the pipes, gold is a constituent of quartz-barite and quartz-pyrite veins and veinlets that form a complex network surrounding felsite dikes. Silver is present predominantly in a broadly concentric zone west of, and bounded by, the Keystone thrust fault; the veins make up the Ivanpah Mining District, which had significant production into the early part of the 20th century. Tungsten is found predominantly in a broad northwest-trending belt, which intersects a part of the gold zone and is bounded on the west by the Clark Mountain fault. Field inspection of the regional distribution of tungsten veins suggests that some of the tungsten veins in the Proterozoic granitoids to the south-southeast of the Colosseum Mine may not be related to the emplacement of the gold-bearing breccia pipe at the mine (pl. 2), inasmuch as known tungsten veins are present in Proterozoic granitoids as much as 6.5 km southeast of the mine. Nonetheless, felsite dikes related to the emplacement of the breccia pipes extend from Clark Mountain to Mountain Pass, a distance of 11 km (Sharp, 1984). Within the gold zone, tungsten is present as wolframite and scheelite in Proterozoic rocks. Fluorite is in veins and shear
zones associated with the Keystone and Mesquite Pass thrust faults west of the silver zone. Sharp (1984) attributed these spatial relations to development of a single hydrothermal system, which was initially stacked vertically but was subsequently displaced by gravity gliding (detachment faulting) on the then-extant Keystone thrust fault and by high-angle normal faulting on the Clark Mountain fault. Epithermal-vein silver, originally closest to the surface in the system, is now horizontally juxtaposed with the deeper gold-rich breccia-pipe complex. Thus, the district zoning from west to east represents the displaced slices of once-vertical zones, the vein silver in the silver-copper brecciated-dolostone occurrences being found at the top (Theodore, 2007, fig. 95). As will be described later in this section, scanning electron microscope (SEM) studies have established the presence of tungsten in ore at the Colosseum Mine, and the presence of tungsten apparently in distal parts of the mineralized system here can only be attributed to mobility of tungsten in a hydrothermal environment, as was documented by Bateman (1965) in some of the retrograde parts of the Pine Creek, California, tungsten-skarn system. Alternatively, the Colosseum Mine may represent the superposition of a Cretaceous gold breccia pipe onto an environment already enriched in tungsten during a previous episode of tungsten mineralization. (From Theodore, 2007, p. 200-201)

Felsite, dated at 99.8±4 to 102±4 Ma, is the oldest rock in the breccia pipe (K-Ar dates by Geochron Laboratories, as quoted in Sharp, 1984) and consists of equal parts of quartz, K-feldspar, and sericite, plus secondary siderite; carbonate content is about 6 volume percent. The second phase of intrusion caused brecciation of the felsite, producing the igneous breccia that consists mainly of felsite matrix and minor quartzite, granite, gneiss, and andesite clasts. A third phase occurred in the western pipe, producing collapse-rubble breccia that is the most intensely mineralized rock type of the entire breccia-pipe complex. Dolomite breccia fragments are replaced by disseminated pyrite and are accompanied by sphalerite, siderite, and chalcopyrite that hosts gold and silver. As of 1984, commercial values of disseminated gold had been found as deep as 170 m below the surface. (From Theodore, 2007, p. 200-201)

The breccia pipes appear to have been emplaced by fluidization, carbon dioxide being the dominant fluidizing agent (Sharp, 1984). Carbonate content increases with each stage of fluidization and intrusion (6 volume percent in the felsite, 20 volume percent in the igneous breccia, and 30 volume percent in the rubble breccia), indicating that increasing amounts of carbonate rocks were assimilated by the intrusion and incorporated into the breccias as they reached progressively higher levels of stoping into the Late Cambrian to Devonian dolomites. Fluid-inclusion studies of a 751-m-deep drill hole into the breccia-pipe complex indicated that the lower 250 m of the drill hole is dominated by CO2-rich fluids (Cook and others, 1992). These studies also suggested that the minimum lithostatic trapping pressures required to yield the observed fluid-inclusion relations range from 2.1 to 3.1 kilobars (kb). These pressures correspond to paleodepths of 7.9 to 11.7 km at the time of emplacement of the breccia-pipe complex, and they are remarkably consistent with the overburden estimated by Hewett (1956) at the time of breccia-pipe development. (From Theodore, 2007, p. 200-201)

Gold mineralization in the breccia pipes is present in an irregular vertical cylinder surrounding a barren core (Sharp, 1984). Depth of oxidation is about 100 m, and degree of oxidation is about 80 percent. Supergene enrichment, however, is of no mineralogic or economic importance. The barren core in the interior of the rubble-breccia pipe is devoid of gold but contains minor to major amounts of pyrite, zinc, and copper in well-silicified impervious rocks. Late gold-bearing fluids were unable to percolate through this impermeable unit to reach the favored sulfide sites for gold deposition. Gold content varies directly with depth, and gold is commonly alloyed with silver (as electrum) as fracture fillings in pyrite or along grain boundaries. According to Sharp (1984), Au/Ag ratios averaged 1.5 to 1, in marked contrast to the
Au/Ag ratios found in the surrounding vein deposits. Gangue minerals, in order of decreasing abundance, are siderite, goethite, quartz, and sericite. Pyrite is the most susceptible host for precipitation of gold, apparently because of its ease of fracturing (Sharp, 1984). (From Theodore, 2007, p. 200-201)

The four principal vein types in the ore at the Colosseum Mine are quartz-pyrite, quartz-barite, calcite-barite, and calcite-dolomite, in addition to occasional veins of unknown source and genetic significance that contain lead, antimony, tungsten, and zinc, as well as minor silver. According to Sharp (1984), mineral paragenesis and sequence of events took place in the following stages: (1) early, coarse-grained, barren pyrite and minor quartz; (2) coarse-grained, second-stage pyrite that has gold, chalcopyrite, sphalerite, bornite(?), and pyrrhotite; (3) shattering and fracturing of coarse-grained pyrite; (4) major phase of gold mineralization, which filled fractures and interstices in pyrite, accompanied by apparently stable sphalerite, chalcopyrite, and galena; (5) fine-grained, barren pyrite; (6) siderite replacement and flooding of the breccia matrix; and (7) localized veining by quartz and fine-grained pyrite. Gold is disseminated throughout the deposit; electrum mineralization was later paragenetically than the main-stage sulfide mineralization and its accompanying major amounts of gold. (From Theodore, 2007, p. 200-201)

Two examples of gold included in pyrite were identified in SEM micrographs, which were obtained from one polished thin section of felsite breccia from the Colosseum Mine (Theodore, 2007 fig. 96A,B,D), and also were verified by an X-ray spectrogram (fig. 96C). The largest grain of gold (about 7–8 μm; see fig. 96B) was clearly deposited along a fracture and possibly represents the major gold-mineralizing phase (stage 4) of Sharp’s (1984) paragenetic sequence. The smaller grain (about 4 μm; see fig. 96D) may represent the second phase (Sharp’s (1984) stage 2) of included gold associated with pyrrhotite. Examination by SEM also revealed grains of monazite and other rare earth element minerals that have been localized in cracks between euhedral pyrite crystals (Theodore, 2007, figs. 96E,F). Additional minerals identified within pyrite include the following: small grains of wolframite (Theodore, 2007, fig. 96A); bismuth and silver tellurides (Theodore, 2007, fig. 96G); possibly resorbed chalcopryite, pyrrhotite, and sphalerite (Theodore, 2007, fig. 96H); and sphalerite that has small euhedral pyrite inclusions and conspicuous replacement rim of covellite surrounded by feldspar (fig. 96I). The relation shown in figure 96A seems to confirm the genetic gold-tungsten association in the ore-forming system at the Colosseum Mine. (From Theodore, 2007, p. 200-201)
Figure 96. Scanning electron micrographs of gold-bearing breccia pipe at the Colosseum Mine, East Mojave National Scenic Area, California (fig. 94). Abbreviations: Ag, silver; AgTe, silver telluride; Au, gold; BiTe, bismuth tellurides; (Ce,La,Nd)PO₄, monazite; cpy, chalcopyrite; CuS, covellite; (Fe,Mn)WO₃, wolframite; FeS, pyrrhotite (queried where uncertain); FeS₂, pyrite; Kf, K-feldspar; Py, pyrite; SiO₂, quartz; ZnS, sphalerite. A, General morphology of pyrite hosting various minerals, including gold. B, Enlargement of part of 96A, showing argentiferous gold along microcrack in pyrite; some possible pyrrhotite also in the field of view. C, Energy-dispersive X-ray spectra of argentiferous gold grain in 96B. D, Gold associated with pyrrhotite in pyrite. E, Euhedral outlines of pyrite (py) crystals, common throughout sample. F, Enlargement of part of 96E, showing monazite crystals along margins between pyrite crystals. G, Silver tellurides and bismuth tellurides in pyrite. H, Enlargement of part of 96A, showing clot of chalcopyrite, pyrrhotite, and sphalerite in pyrite. I, Sphalerite surrounded by covellite in K-feldspar.

Figure 3. From Theodore, 2007, p. 226
Silver-Copper Brecciated Dolostone associated with the Colosseum orebody, Clark Mountains

Silver veins in the Clark Mountain Mining District are categorized as silver-copper brecciated dolostone; they are peripheral to the gold breccia pipes of the Colosseum orebody which was emplaced in Proterozoic rocks to the east of the silver veins (pl. 2). The veins are restricted to Late Cambrian to
Devonian dolomite, which was downdropped to the west from its earlier overthrust position above the Proterozoic rocks (pl. 1).

According to the U.S. Bureau of Mines (1990a), the veins are present in fractured, sheared, and brecciated zones in gray-yellow dolostone. Ore mineralization is reported as stromeyerite [ideally, \((\text{CuAg})_2\text{S}\)] in pods and blebs that contain minor azurite and malachite, and a gangue of calcite-dolomite and quartz (Hewett, 1956). Most individual vein systems strike northwestward and dip steeply to the northeast. More than $4$ million in silver was produced from the Clark Mountain Mining District in the late 1800s, primarily from the Beatrice, Monitor, Stonewall, and Lizzie Bullock Mines (Sharp, 1984); production from the Monitor Mine continued until 1942.

The U.S. Bureau of Mines (1990a) analyzed 92 samples from the silver-copper brecciated-dolostone deposits. Maximum Ag content was 3,080 ppm; maximum Au, 946 ppb. In 32 samples, Cu content was well over 1,000 ppm, and was greater than 10,000 ppm in 11 of them. Forty-seven samples contained more than 1 ppb Au and more than 1 ppm Ag; the average Ag/Au ratio was 4,660, which is notably high and contrasts with the Ag/Au ratio of approximately 0.67 at the Colosseum gold deposit. Zinc content was greater than 10,000 ppm in only three samples and greater than 1,000 ppm in 18 samples. Lead content was greater than 10,000 ppm in four samples and was 1,000 ppm or greater in 32 samples.
Sharp (1984) developed an intriguing hypothesis for the origin of the Ivanpah silver deposits, relating them genetically to the gold mineralization of the Colosseum breccia pipe. By this hypothesis, silver-bearing hydrothermal fluids accompanying the felsite breccias rose through the Proterozoic granitoid rocks, in which the gold orebodies are now present, into the overthrust Paleozoic sedimentary rocks. The fluids stopped upward well into the Cambrian to Devonian dolomite units; height of stoping is demonstrated by the presence of abundant carbonate fragments within the Colosseum breccia pipe. Mesothermal gold mineralization is richest in this pipe because of selective massive replacement of carbonate minerals by sulfide minerals. Epithermal-vein silver, however, emplaced in the overlying dolomite, was subsequently downdropped to the west along high-angle normal fault(s) and low-angle detachment fault(s) during a postmineralization extensional event localized along a preexisting thrust plane. Thus, the breccia pipe was effectively decapitated, juxtaposing the silver-copper occurrences in the dolomite on the west with the gold mineralization in lower parts of the pipe to the east (fig. 97). The mineral zoning and fault pattern as described by Sharp (1984) fit this explanation.

Although not exact analogues, the silver-copper deposits in the Ivanpah Mining District exhibit some characteristics of polymetallic-vein and polymetallic-replacement occurrences, which generally are related to felsic igneous intrusions (Cox and Singer, 1986). They are particularly common in areas of high permeability, such as breccia veins and pipes, and may form replacement bodies in carbonate rocks. It seems unlikely that economic, large-tonnage deposits of a type similar to the silver veins of the Ivanpah Mining District will be discovered in the EMNSA. (From Theodore, 2007, p. 201-202)