Geology and History of the Copper Deposits at Mineral Creek, Pinal and Gila Counties, Arizona

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Cover image: Oblique view of the Mineral Creek (Ray) Mining District, looking north-northwest (photo from Google Earth)

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1 INTRODUCTION

Copper deposits in the Mineral Creek district are located in Pinal County, approximately 65 miles east-southeast of Phoenix, Arizona and about 65 miles north of Tucson, Arizona (Figure 1). Situated along a north-south trending drainage known as Mineral Creek, its principal mine, Ray is located 5 miles north of its confluence with the Gila River.

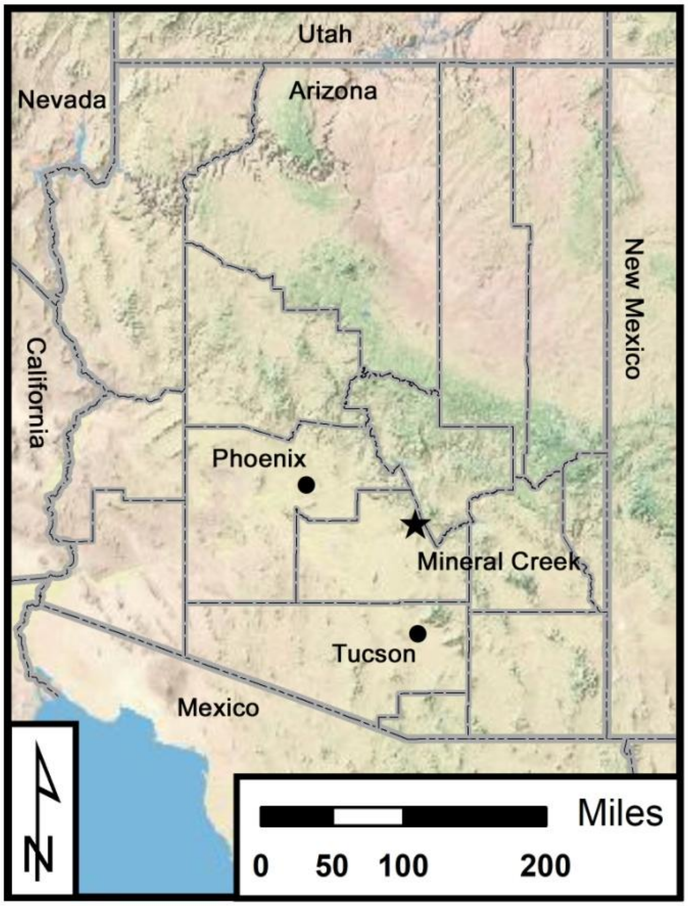


Figure 1. Location map showing counties of Arizona, Mineral Creek District and nearby Phoenix and Tucson.

1.1 Scope of Study

During the early 1980’s, geologists at the Arizona Bureau of Geology and Mineral Technology (now the Arizona Geological Survey) developed the concept of mineral districts. Unlike mining district, a term used to describe a geographically distinct location where mining took place; ore deposits grouped within mineral districts categorize mineralized areas based on geological criteria such as metals and alteration assemblages, age of mineralization, and ore forming processes (Keith et al., 1983).

The location of major deposits shown in Figure 2 includes three separate mineral districts (modified from Keith et al., 1983; and Grant et al., 2022). From southwest to northeast they include Pioneer-Alabama, Copper Butte, and Mineral Creek. Copper is the principal product recovered in these areas, where Laramide porphyry copper systems (i.e., Ray, Ray West, and Red Hills) and their associated vein/replacement occurrences are related to the emplacement of the late Cretaceous Granite Mountain Porphyry and Teapot Mountain Porphyry stocks. Associated exotic copper occurrences (i.e., Copper Butte, Buckeye East, Buckeye West, and Mineral Creek) were formed later by physical and/or chemical processes that transported and redeposited the copper at distant sites.

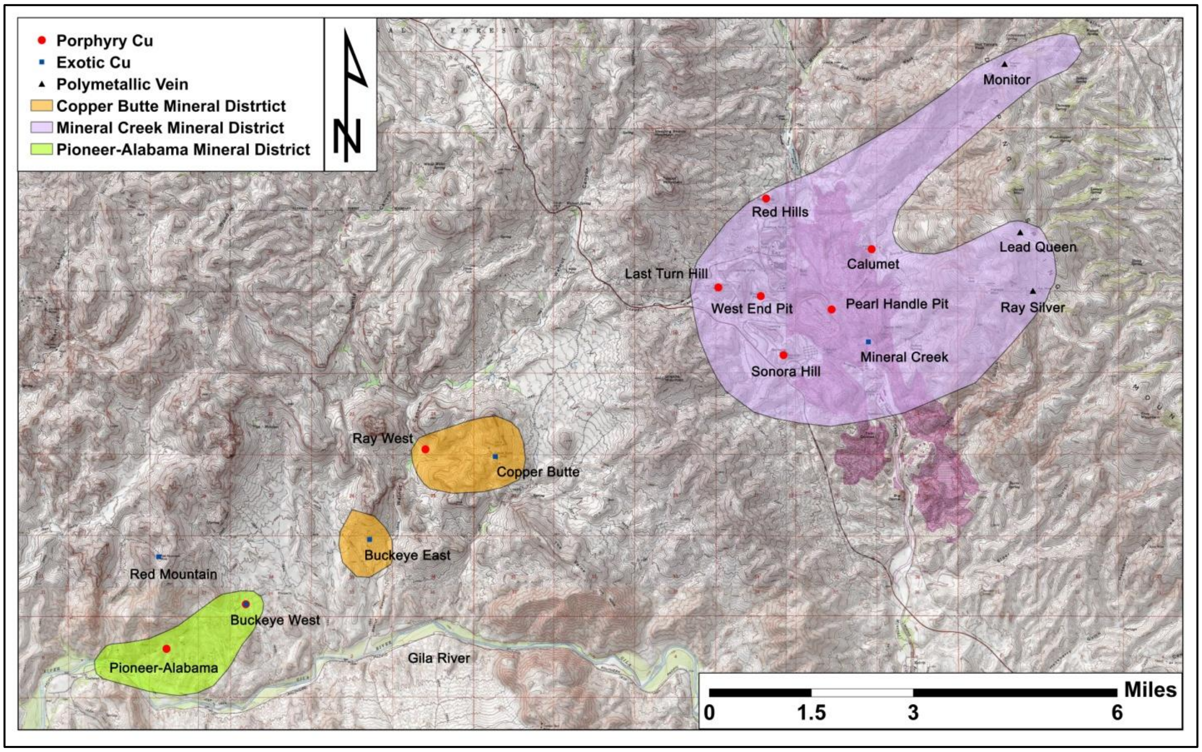


Figure 2. Major deposits located within Mineral Districts in the Mineral Creek area (modified from Keith et al., 1983; and Grant et al., 2022).

This paper summarizes the geology, structural setting, deposit types, and describes the major mineral deposits of the region, including recent geological models employed to explain the spatial and genetic relationships between mineral occurrences at Mineral Creek.

This is followed by comprehensive review of the region’s cultural and mining history, including its prehistoric indigenous inhabitants and the early mining communities of

Kelvin, Ray, Sonora, Kearny, and Hayden that supported operations at the area's mines and smelters. It also covers the discovery and development of the major ore deposits and the evolution of mining practices and technology that were employed over the life of the mining, processing, and smelting operations.

1.2 Production and Reserve Data

The Mineral Creek district is the seventh largest U. S. copper producer, yielding approximately 15.4 billion pounds of copper or about 5.6% of total U. S. historical production as of December 31, 2022 (Table 1). The majority of this production has been derived from the Ray copper mine.

Table 1. Production Data for Mineral Creek Mineral District.

Mine	Period	Ore Treated Short Tons	Cu lbs.	Pb lbs.	Zn lbs.	Mo lbs.	Au Troy Oz.	Ag Troy Oz.
Az. Hercules	1915-1920	374,235	9,188,769	0	0	0	0	16,635
Calumet	1907-1911	9,121	501,878	0	0	0	0	21
Copper Butte	1906-1971	156,396	9,252,199	26,212	0	0	75	4,655
Monitor	1944-1978	11,612	422,763	16,300	0	0	13	56,074
Ray	1881-2022	1,433,716,307	15,409,667,388	0	0	8,016,997	56,350	21,383,614
Ray Silver	1917-1960	25,304	87,791	11,171,931	285,290	0	1,637	58,898
Other (59)	1905-1975	6,725	441,367	933,319	0	0	833	9,615
Total	1881-2022	1,434,299,700	15,429,562,155	12,147,762	285,290	8,016,997	58,908	21,529,512

Note: Production data was compiled from the U.S. Bureau of Mines (1881-1981), Arizona Geological Survey (1881-1981), Arizona Department of Mines and Mineral Resources (1958-1992), and from various annual reports, 10-K reports and other regulatory filings (1982-2022).

As of December 31, 2022, reported proven and probable ore reserves at Ray (cut-off grade - 0.23% Cu) include 417.6 million short tons of mill ore, averaging 0.513% Cu and 80.8 million short tons of dump leach ore, averaging 0.384% Cu, an aggregate of approximately 4.9 billion pounds of copper (Table 2). The waste to ore (mill + leach) ratio is 1.95:1 (Grupo Mexico S.A. de C.V., 2023). The projected date of depletion of its remaining ore reserves is approximately 2057.

Table 2. Proven and Probable Ore Reserves for Ray as of December 31, 2022.

Ore Type	Tonnage Short Tons	Cu %	Contained Copper lbs.
Mill Ore	417,600,000	0.513	4,284,572,000
Dump Leach Ore	80,798,000	0.384	620,526,000
Total	498,398,000	0.492	4,905,098,000

As of December 31, 2022, reported proven and probable oxide reserves (cut-off grade - 0.10% Cu) at the Copper Butte and Buckeye East satellite deposits included 169.7 million tons oxide ore, averaging 0.389% Cu (Table 3). The waste to ore ratio is less than 0.87:1 for Copper Butte and 1:1 at Buckeye East (Grupo Mexico S.A. de C.V., 2023).

Table 3. Proven and Probable Oxide Ore Reserves for Copper Butte and Buckeye East as of December 2022.

Deposit	Tonnage Short Tons	Cu %	Contained Copper lbs.
Copper Butte	126,700,000	0.390	988,260,000
Buckeye East	43,000,000	0.385	331,100,000
Total	169,700,000	0.389	1,319,360,000

With combined historical production plus proven and probable copper reserves of approximately 21.7 billion pounds, Mineral Creek is the tenth largest copper mineral district in North America. Although it’s measured, indicated and inferred mineral resources have not been made public, Mineral Creek probably ranks in the top 20 largest copper districts in North America in terms of total copper endowment (i.e., historical production + reserves + resources).

2 REGIONAL SETTING

The state of Arizona straddles three main physiographic regions: the Colorado Plateau, the Southern Basin and Range Province, and the intervening Transition Zone. Mineral Creek is located in the northwest sector of the Mexican Highland sub-province of the Southern Basin and Range Province (Figure 3).

The Colorado Plateau of northern Arizona is characterized by an elevated region (4,900 to 9,200 feet) of extensive valleys with numerous low-relief plateaus that are locally disrupted by monoclonal uplifts and cut by deep canyons of the Colorado River system (Menges and Pearthree, 1989).

The Southern Basin and Range Province is characterized by discontinuous northwest and northeast-trending mountain ranges separated by alluvial valleys. It varies from broad, mostly undissected valleys and low mountain ranges of the southwestern Sonoran Desert sub-province to regions of greater altitude, local relief and basin dissection of the Mexican Highland sub-province in southeastern Arizona and the Mohave sub-province of northwestern Arizona. Most of the drainages of southern

Arizona are presently incorporated in the Gila River system (Menges and Pearthree, 1989).

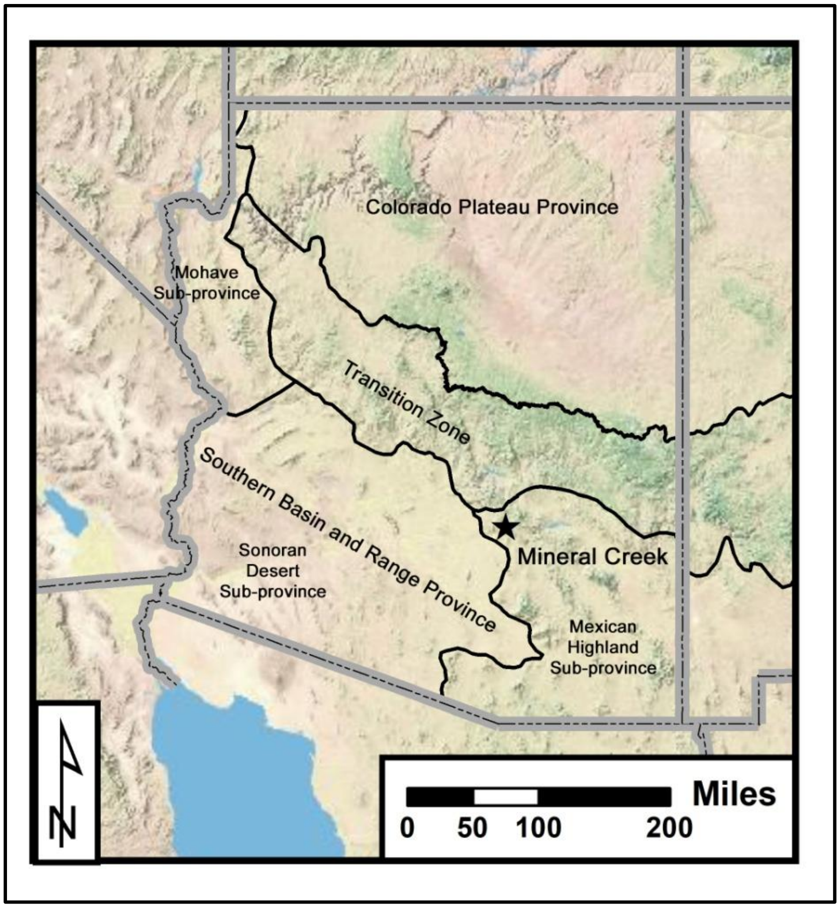
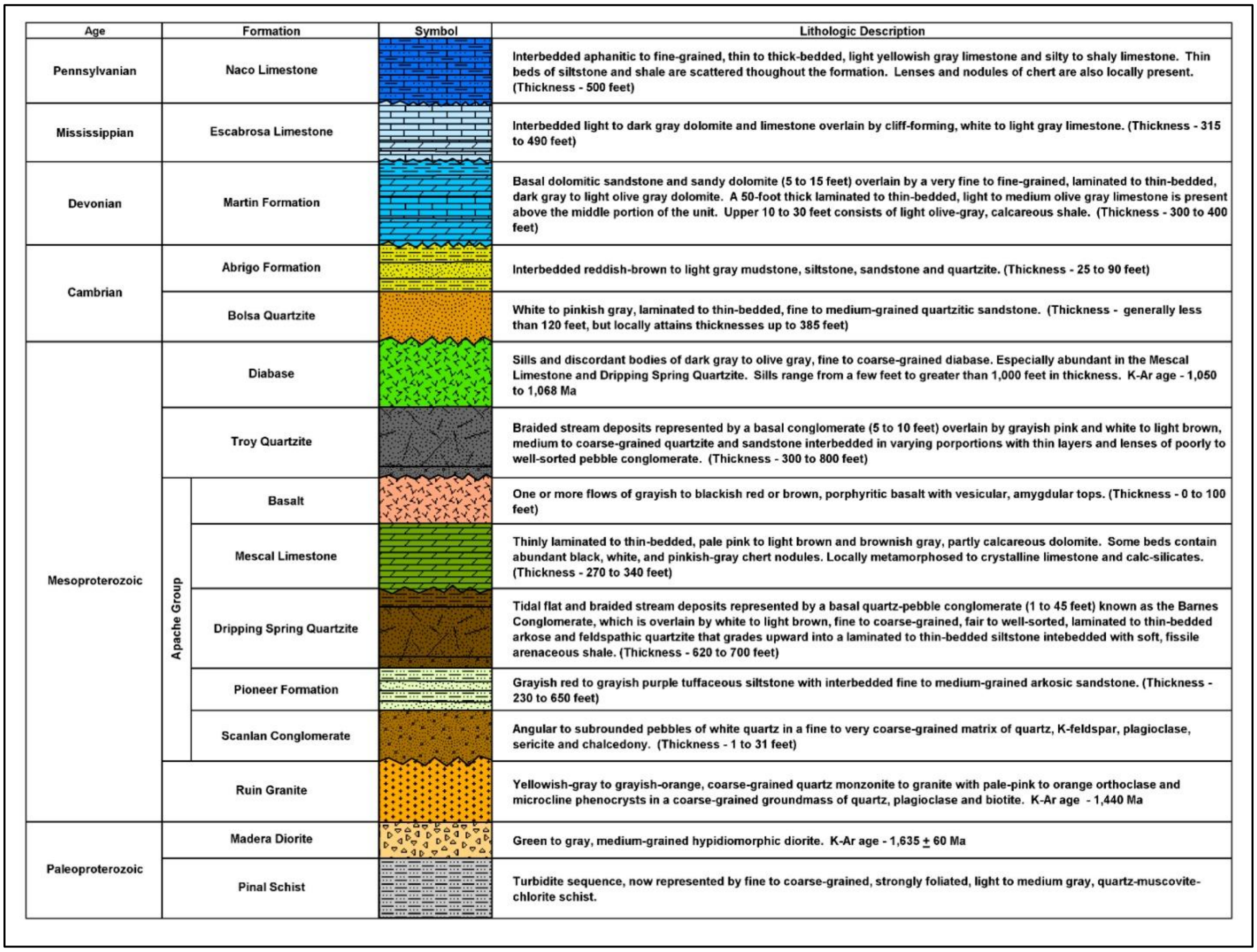


Figure 3. Physiographic Provinces of Arizona (modified from Menges and Pearthree, 1989).

Arizona's Transition Zone is characterized by a rugged landscape of variably dissected alluvial basins and large mountain ranges, which are capped by erosional remnants of the Colorado Plateau (Menges and Pearthree, 1989).

2.1 Stratigraphic Section

The oldest formation exposed in the Mineral Creek district is the Paleoproterozoic Pinal Schist, which is characterized by a turbiditic sequence of feldspathic sandstone, greywacke, siltstone, and shale (Figure 4). Deposited in the Pinal Basin approximately 1,710 to 1,675 million years ago, these strata were subsequently deformed during the Mazatzal Orogeny (1,675 to 1,625 Ma) and cut by the syntectonic Madera diorite (K-Ar age – 1,635 ± 60 Ma) and post-tectonic Ruin Granite (K-Ar age – 1,440 Ma) (Reynolds et al., 1986). Regionally metamorphosed under greenschist facies conditions, it is now represented by fine- to coarse-grained quartz muscovite schist with variable amounts of chlorite (Conway and Silver, 1989).

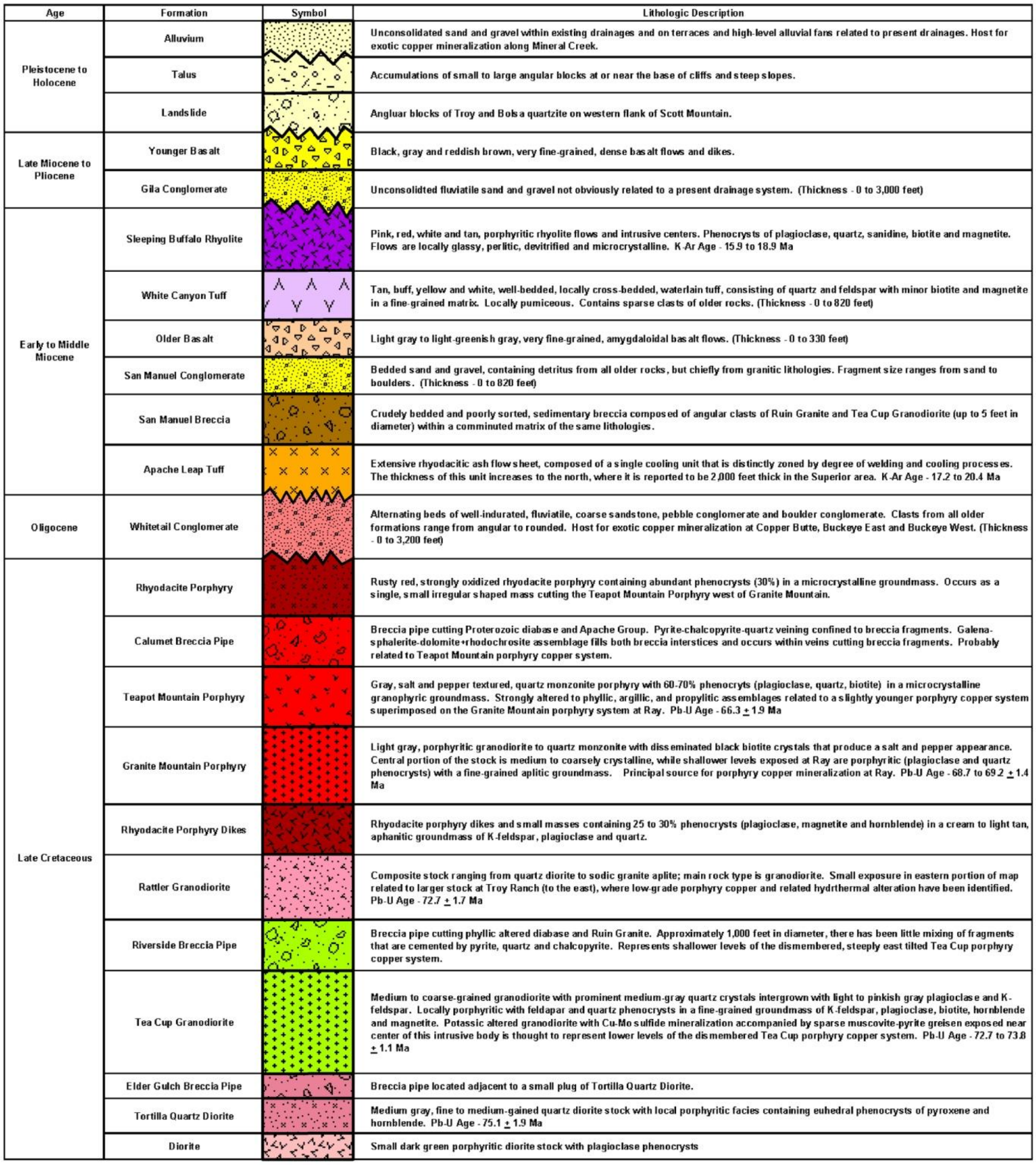


Age	Formation		Symbol	Lithologic Description
Pennsylvanian	Naco Limestone			Interbedded aphanitic to fine-grained, thin to thick-bedded, light yellowish gray limestone and silty to shaly limestone. Thin beds of siltstone and shale are scattered thoughout the formation. Lenses and nodules of chert are also locally present. (Thickness - 500 feet)
Mississippian	Escabrosa Limestone			Interbedded light to dark gray dolomite and limestone overlain by cliff-forming, white to light gray limestone. (Thickness - 315 to 490 feet)
Devonian	Martin Formation			Basal dolomitic sandstone and sandy dolomite (5 to 15 feet) overlain by a very fine to fine-grained, laminated to thin-bedded, dark gray to light olive gray dolomite. A 50-foot thick laminated to thin-bedded, light to medium olive gray limestone is present above the middle portion of the unit. Upper 10 to 30 feet consists of light olive-gray, calcareous shale. (Thickness - 300 to 400 feet)
Cambrian	Abrigo Formation			Interbedded reddish-brown to light gray mudstone, siltstone, sandstone and quartzite. (Thickness - 25 to 90 feet)
	Bolsa Quartzite			White to pinkish gray, laminated to thin-bedded, fine to medium-grained quartzitic sandstone. (Thickness - generally less than 120 feet, but locally attains thicknesses up to 385 feet)
Mesoproterozoic	Diabase			Sills and discordant bodies of dark gray to olive gray, fine to coarse-grained diabase. Especially abundant in the Mescal Limestone and Dripping Spring Quartzite. Sills range from a few feet to greater than 1,000 feet in thickness. K-Ar age - 1,050 to 1,068 Ma
	Troy Quartzite			Braided stream deposits represented by a basal conglomerate (5 to 10 feet) overlain by grayish pink and white to light brown, medium to coarse-grained quartzite and sandstone interbedded in varying porportions with thin layers and lenses of poorly to well-sorted pebble conglomerate. (Thickness - 300 to 800 feet)
	Apache Group	Basalt		One or more flows of grayish to blackish red or brown, porphyritic basalt with vesicular, amygdular tops. (Thickness - 0 to 100 feet)
		Mescal Limestone		Thinly laminated to thin-bedded, pale pink to light brown and brownish gray, partly calcareous dolomite. Some beds contain abundant black, white, and pinkish-gray chert nodules. Locally metamorphosed to crystalline limestone and calc-silicates. (Thickness - 270 to 340 feet)
		Dripping Spring Quartzite		Tidal flat and braided stream deposits represented by a basal quartz-pebble conglomerate (1 to 45 feet) known as the Barnes Conglomerate, which is overlain by white to light brown, fine to coarse-grained, fair to well-sorted, laminated to thin-bedded arkose and feldspathic quartzite that grades upward into a laminated to thin-bedded siltstone intebedded with soft, fissile arenaceous shale. (Thickness - 620 to 700 feet)
		Pioneer Formation		Grayish red to grayish purple tuffaceous siltstone with interbedded fine to medium-grained arkosic sandstone. (Thickness - 230 to 650 feet)
		Scanlan Conglomerate		Angular to subrounded pebbles of white quartz in a fine to very coarse-grained matrix of quartz, K-feldspar, plagioclase, sericite and chalcedony. (Thickness - 1 to 31 feet)
	Ruin Granite			Yellowish-gray to grayish-orange, coarse-grained quartz monzonite to granite with pale-pink to orange orthoclase and microcline phenocrysts in a coarse-grained groundmass of quartz, plagioclase and biotite. K-Ar age - 1,440 Ma
Paleoproterozoic	Madera Diorite			Green to gray, medium-grained hypidiomorphic diorite. K-Ar age - 1,635 ± 60 Ma
	Pinal Schist			Turbidite sequence, now represented by fine to coarse-grained, strongly foliated, light to medium gray, quartz-muscovite-chlorite schist.

Figure 4. Schematic Proterozoic and Paleozoic Stratigraphic section for the Mineral Creek District. For simplicity, intrusive relations are not shown (modified from Cornwall et al., 1971; and Creasey et al., 1983).

Following a period of uplift and erosion, these older units were unconformably overlain by the Mesoproterozoic Apache Group, a younger unmetamorphosed, dominantly clastic sequence comprising the Scanlan Conglomerate, Pioneer Formation, Dripping Spring Quartzite, and Mescal Limestone, which is capped by basaltic lava flows. The Apache Group is unconformably overlain by the Troy Quartzite. These units are cut by an extensive complex of Mesoproterozoic diabase sills and dikes (K-Ar age 1,068-1,050 Ma) (Reynolds, et al., 1986). Prominent exposures of these units are exposed in the Dripping Spring Range at the Ray copper mine as well as areas to the northwest of the Mineral Creek district. Erosional remnants of the Paleozoic stratigraphic section (i.e., Bolsa Quartzite, Abrigo Formation, Martin Formation, Escabrosa Limestone, and Naco

Limestone) are locally preserved above an unconformity developed above the Middle Proterozoic section.



Age	Formation	Symbol	Lithologic Description
Pleistocene to Holocene	Alluvium	▨	Unconsolidated sand and gravel within existing drainages and on terraces and high-level alluvial fans related to present drainages. Host for exotic copper mineralization along Mineral Creek.
	Talus	▨	Accumulations of small to large angular blocks at or near the base of cliffs and steep slopes.
	Landslide	▨	Angluar blocks of Troy and Bolsa quartzite on western flank of Scott Mountain.
Late Miocene to Pliocene	Younger Basalt	▨	Black, gray and reddish brown, very fine-grained, dense basalt flows and dikes.
	Gila Conglomerate	▨	Unconsolidted fluviatile sand and gravel not obviously related to a present drainage system. (Thickness - 0 to 3,000 feet)
Early to Middle Miocene	Sleeping Buffalo Rhyolite	▨	Pink, red, white and tan, porphyritic rhyolite flows and intrusive centers. Phenocrysts of plagioclase, quartz, sanidine, biotite and magnetite. Flows are locally glassy, perlitic, devitrified and microcrystalline. K-Ar Age - 15.9 to 18.9 Ma
	White Canyon Tuff	▨	Tan, buff, yellow and white, well-bedded, locally cross-bedded, waterlain tuff, consisting of quartz and feldspar with minor biotite and magnetite in a fine-grained matrix. Locally pumiceous. Contains sparse clasts of older rocks. (Thickness - 0 to 820 feet)
	Older Basalt	▨	Light gray to light-greenish gray, very fine-grained, amygdaloidal basalt flows. (Thickness - 0 to 330 feet)
	San Manuel Conglomerate	▨	Bedded sand and gravel, containing detritus from all older rocks, but chiefly from granitic lithologies. Fragment size ranges from sand to boulders. (Thickness - 0 to 820 feet)
	San Manuel Breccia	▨	Crudely bedded and poorly sorted, sedimentary breccia composed of angular clasts of Ruin Granite and Tea Cup Granodiorite (up to 5 feet in diameter) within a comminuted matrix of the same lithologies.
	Apache Leap Tuff	▨	Extensive rhyodacitic ash flow sheet, composed of a single cooling unit that is distinctly zoned by degree of welding and cooling processes. The thickness of this unit increases to the north, where it is reported to be 2,000 feet thick in the Superior area. K-Ar Age - 17.2 to 20.4 Ma
Oligocene	Whitetail Conglomerate	▨	Alternating beds of well-indurated, fluviatile, coarse sandstone, pebble conglomerate and boulder conglomerate. Clasts from all older formations range from angular to rounded. Host for exotic copper mineralization at Copper Butte, Buckeye East and Buckeye West. (Thickness - 0 to 3,200 feet)
Late Cretaceous	Rhyodacite Porphyry	▨	Rusty red, strongly oxidized rhyodacite porphyry containing abundant phenocrysts (30%) in a microcrystalline groundmass. Occurs as a single, small irregular shaped mass cutting the Teapot Mountain Porphyry west of Granite Mountain.
	Calumet Breccia Pipe	▨	Breccia pipe cutting Proterozoic diabase and Apache Group. Pyrite-chalcopyrite-quartz veining confined to breccia fragments. Galena-sphalerite-dolomite+rhodochrosite assemblage fills both breccia interstices and occurs within veins cutting breccia fragments. Probably related to Teapot Mountain porphyry copper system.
	Teapot Mountain Porphyry	▨	Gray, salt and pepper textured, quartz monzonite porphyry with 60-70% phenocryts (plagioclase, quartz, biotite) in a microcrystalline granophyric groundmass. Strongly altered to phyllic, argillic, and propylitic assemblages related to a slightly younger porphyry copper system superimposed on the Granite Mountain porphyry system at Ray. Pb-U Age - 66.3 ± 1.9 Ma
	Granite Mountain Porphyry	▨	Light gray, porphyritic granodiorite to quartz monzonite with disseminated black biotite crystals that produce a salt and pepper appearance. Central portion of the stock is medium to coarsely crystalline, while shallower levels exposed at Ray are porphyritic (plagioclase and quartz phenocrysts) with a fine-grained aplitic groundmass. Principal source for porphyry copper mineralization at Ray. Pb-U Age - 68.7 to 69.2 ± 1.4 Ma
	Rhyodacite Porphyry Dikes	▨	Rhyodacite porphyry dikes and small masses containing 25 to 30% phenocrysts (plagioclase, magnetite and hornblende) in a cream to light tan, aphanitic groundmass of K-feldspar, plagioclase and quartz.
	Rattler Granodiorite	▨	Composite stock ranging from quartz diorite to sodic granite aplite; main rock type is granodiorite. Small exposure in eastern portion of map related to larger stock at Troy Ranch (to the east), where low-grade porphyry copper and related hydrthermal alteration have been identified. Pb-U Age - 72.7 ± 1.7 Ma
	Riverside Breccia Pipe	▨	Breccia pipe cutting phyllic altered diabase and Ruin Granite. Approximately 1,000 feet in diameter, there has been little mixing of fragments that are cemented by pyrite, quartz and chalcopyrite. Represents shallower levels of the dismembered, steeply east tilted Tea Cup porphyry copper system.
	Tea Cup Granodiorite	▨	Medium to coarse-grained granodiorite with prominent medium-gray quartz crystals intergrown with light to pinkish gray plagioclase and K-feldspar. Locally porphyritic with feldapar and quartz phenocrysts in a fine-grained groundmass of K-feldspar, plagioclase, biotite, hornblende and magnetite. Potassic altered granodiorite with Cu-Mo sulfide mineralization accompanied by sparse muscovite-pyrite greisen exposed near center of this intrusive body is thought to represent lower levels of the dismembered Tea Cup porphyry copper system. Pb-U Age - 72.7 to 73.8 ± 1.1 Ma
	Elder Gulch Breccia Pipe	▨	Breccia pipe located adjacent to a small plug of Tortilla Quartz Diorite.
	Tortilla Quartz Diorite	▨	Medium gray, fine to medium-gained quartz diorite stock with local porphyritic facies containing euhedral phenocrysts of pyroxene and hornblende. Pb-U Age - 75.1 ± 1.9 Ma
	Diorite	▨	Small dark green porphyritic diorite stock with plagioclase phenocrysts

Figure 5. Schematic Mesozoic and Tertiary stratigraphic section for the Mineral Creek District. For simplicity, intrusive relations are not shown. (modified from Cornwall et al., 1971; Cornwall and Krieger, 1975a; Cornwall and Krieger, 1975b; Theodore et al., 1978; Creasey et al., 1983; and Richard and Spencer, 1997).

There is a large gap in the stratigraphic record from Pennsylvanian until late Cretaceous time, when the region experienced extensive intrusive activity and emplacement of a number of dioritic to quartz monzonitic intrusive stocks during the Laramide Orogeny, one of many mountain building episodes throughout Arizona's long geologic history (Grant, et al., 2022) (Figure 5). These intrusives include the Tortilla Quartz Diorite (U-Pb age – 75.1 ± 1.9 Ma), Tea Cup Granodiorite (U-Pb age – 72.7 to 73.8 ± 1.1 Ma), Rattler Granodiorite (U-Pb age – 72.7 ± 1.7 Ma), Granite Mountain Porphyry (U-Pb age – 68.7 to 69.2 ± 1.4 Ma), Teapot Mountain Porphyry (U-Pb age – 66.3 ± 1.9 Ma), and Rhyodacite Porphyry stocks and dikes (Seedorff et al., 2019).

During the ten-million-year period from 75 to 66 Ma a cluster of porphyry copper systems and related breccia pipes were formed in the vicinity of the Mineral Creek. Identified porphyry copper occurrences are related to the emplacement of the Tea Cup Granodiorite (i.e., Grayback, Tea Cup, Kelvin and Riverside), Rattler Granodiorite (i.e., Troy), Granite Mountain Porphyry (i.e., Ray and Ray West), and Teapot Mountain Porphyry (i.e., Red Hills) intrusive centers (Maher, 2008).

Following a period of uplift, erosion and oxidation/supergene enrichment of the primary copper ores at Mineral Creek, older units were unconformably overlain by several sequences of younger sedimentary and volcanic rocks that dominate the landscape in the vicinity of Teapot Mountain and a large north-south oriented Middle Tertiary basin situated west of Granite Mountain. Consisting of alternating beds of well-indurated, fluviatile, coarse sandstone and pebble and boulder conglomerate, the basal sedimentary sequence is represented by the Early to Late Oligocene Whitetail Conglomerate, which resulted from syntectonic deposition in local half-graben basins developed at the onset of extensional deformation. Interestingly, it locally contains abundant altered clasts eroded from nearby copper deposits as well as remobilized copper (i.e., exotic copper) from similar sources (John and Fountain, 1994; Dickinson, 1995; Dickinson, 2001; and Barton, et al., 2005).

The Whitetail Conglomerate is unconformably overlain by the southeastern-most exposures of the Early Miocene Apache Leap Tuff, an extensive rhyodacite ash flow sheet derived from a large caldera in the Superstition Mountains, located approximately 25 miles northwest of the Ray mine (Ferguson and Trap, 2001). The Apache Leap Tuff is reported to reach thicknesses up to 2,000 feet in the Superior area (Peterson, 1969).

Deposition of the Apache Leap Tuff was followed by a second period of clastic sedimentation and basaltic volcanism. Local deposition of a basal sedimentary breccia (i.e., San Manuel Breccia) is restricted to a small area immediately southwest of Copper Butte. It is characterized by crudely bedded, poorly-sorted breccia composed of large angular clasts up to 5-feet in diameter within a comminuted matrix of the same lithologies. This debris was derived from Proterozoic Ruin Granite and Late Cretaceous

Tea Cup Granodiorite, which are presently exposed along the Gila River to the south (Creasey, et al., 1983).

The basal sedimentary breccia is succeeded by sand and gravel detritus of the Miocene San Manuel Conglomerate, which was also largely derived from granitic terrains (Creasey, et al., 1983). Local occurrences of amygdaloidal basalt flows overlie the San Manuel Conglomerate, which are in turn succeeded by the White Canyon Tuff, a widespread sequence of waterlain felsic tuffs (Favorito and Seedorff, 2020).

The rhyolitic volcanic/intrusive complex of Middle Miocene Sleeping Buffalo Rhyolite occupies much of the western portion of the Middle Tertiary Basin, located west of Granite Mountain. It is characterized by numerous hypabyssal intrusive centers that were the source for its coeval porphyritic rhyolite flows (Creasey, et al., 1983; and Theodore et al., 1978). The Middle Miocene felsic volcanics were succeeded by a younger sequence of basin-fill clastics with locally intercalated basaltic flows of the Late Miocene to Pliocene Gila Conglomerate (Creasey, et al., 1983).

2.2 Structural Setting

The structural setting in and around the Mineral Creek district is quite complex. Over time as more has learned about this region, various geological models have been adapted to explain these observations and guide future exploration activities. The simplified geologic map shown in Figure 6 illustrates a recent model proposed by Nickerson, et al. (2010); Favorito and Seedorff (2020); and Cornoyer (2021). It employs one or more Laramide thrust faults (74 to 69 Ma) that pre-date mineralization and at least five sets of Late Oligocene to Recent extensional faults that post-date the porphyry copper emplacement in this region.

The oldest recognized faults in the region are represented by Late Cretaceous Laramide thrust faults; Telegraph Thrust, Kelvin Thrust, White Canyon Thrust, and Walnut Canyon Thrust. These compressional structures may actually represent segments of a much larger regional thrust sheet or possibly several thrust sheets that were subsequently cut, dismembered and rotated by younger extensional faulting since ~25 Ma (Favorito and Seedorff, 2020). Juxtaposing older formations over younger units, only short segments of these Laramide structures are presently exposed at the surface. Evidence for their existence is largely concealed by younger lithologies. Favorito and Seedorff (2020) postulate the Kelvin Thrust represents the southern extension of the Walnut Canyon Thrust.

Structural reconstruction of this region suggests the Laramide compressional structures (i.e., Telegraph Thrust, White Canyon Thrust, and Walnut Canyon Thrust) represent thick-skinned, basement cored uplifts that had moderate west dips of 35 to 38 degrees.

This interpretation is supported by the rigid and homogeneous nature of the crystalline basement lithologies involved with these structures and by associated fault propagation folds that are consistent with an east-directed thrust. Compressional shortening in this region during the Laramide event was estimated to be 98% (Favorito and Seedorff, 2020).

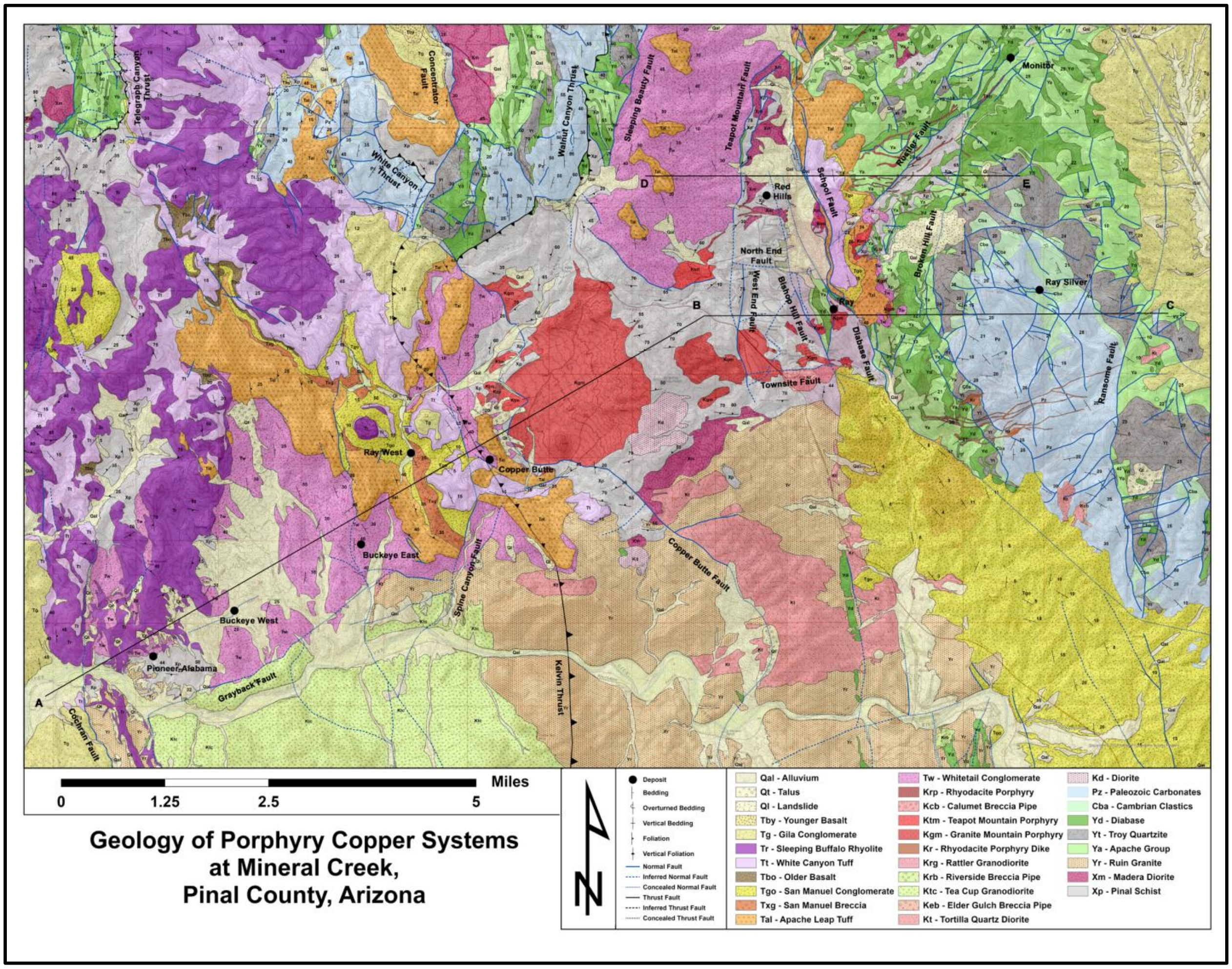


Figure 6. Simplified Geologic Map of the Porphyry Copper Systems at Mineral Creek and surrounding area showing location of principal mineral deposits (modified from Cornwall et al., 1971; Cornwall and Krieger, 1975a; Cornwall and Krieger, 1975b; Theodore et al., 1978; Creasey et al., 1983; Keith, 1983; Richard and Spencer, 1997; Maher, 2008; Favorito and Seedorff, 2020; and Cornoyer, 2021).

Since Late Oligocene time (~25 Ma) this region experienced extensional deformation involving at least five sets of normal faulting exhibiting two major tilt domains that successively cut, dismembered and rotated the older geological units, Laramide thrusts, and porphyry copper systems as well as older sets of normal faulting to produce the complex structural setting we see today. Tertiary strata in the western domain dip to the east, while units of similar age in the eastern domain dip west (Maher, 2008).

Examples of down-to-the-west faults of the western tilt domain include the Diabase Fault, Bishop Hill Fault, Teapot Mountain Fault, Copper Butte Fault, Spine Canyon Fault, and Cochran Fault. Down-to-the-east faults of eastern tilt domain include the Sleeping Beauty Fault, West End Fault, Calumet Fault, and Broken Hill Fault (Favorito and Seedorff, 2020, and Cornoyer, 2021).

Located where the two major tilt domains overlap, the structural setting at the Ray mine is particularly complex (Figure 7). It is characterized by several sets of down-to-the-west normal faults of the western domain and at least two sets of down-to-the-east normal faults of the eastern domain.

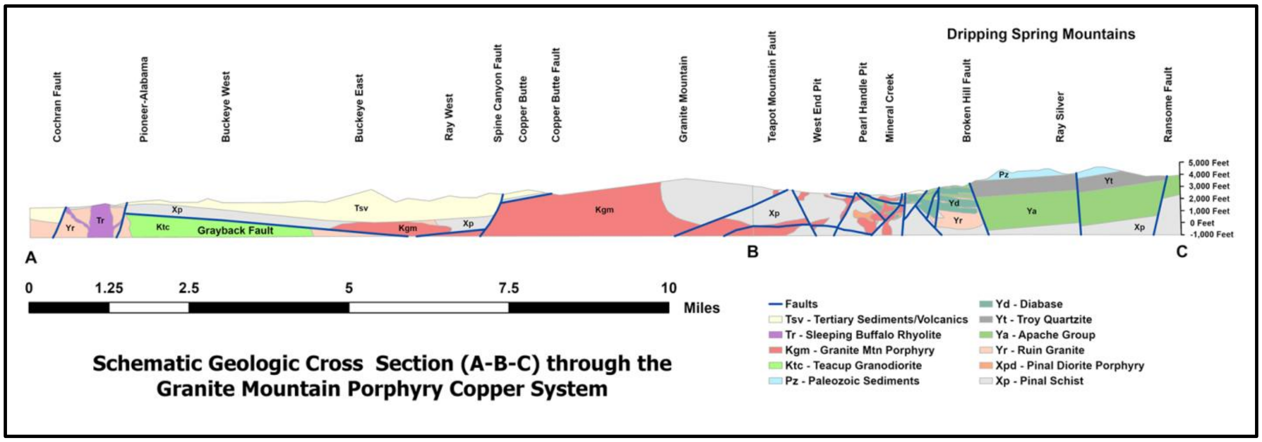


Figure 7. Schematic cross section (A-B-C) through the Granite Mountain Porphyry Copper System (modified from Maher, 2008 (A-B) and Cornoyer, 2021 (B-C)).

Late Tertiary extension (up to 275%) in the western tilt domain resulted in the progressive tilting of 65 degrees east in the area immediately southwest of Mineral Creek increasing to 90 degrees east tilting in the area along the Gila River near Buckeye East, Buckeye West, and Pioneer-Alabama (Nickerson et al., 2010; and Favorito and Seedorff, 2020). Extensional deformation of the eastern tilt domain exposed in the Dripping Springs Mountains is significantly less with post-mineral tilting of the Ray porphyry copper system of approximately 20 to 25 degrees east (John and Fountain, 1994).

The cumulative impact of post-mineral extensional deformation has tilted the dismembered porphyry system(s) related to the Granite Mountain stock to the northeast. Tilts of 20 to 25 degrees to the northeast are present within the footwall of the Diabase Fault at Ray. This increases to about 60 degrees in the Pearl Handle, West End Pit and Sonora Hill areas, which are located in the hanging wall of the Diabase Fault. Traversing further southwest, from Copper Butte to the Pioneer-Alabama areas, tilted fault segments of the Ray West porphyry copper system approach 90 degrees.

3 ECONOMIC GEOLOGY

Porphyry copper mineralization and alteration observed at Mineral Creek is related to two late Cretaceous intrusive centers; the Granite Mountain Porphyry (U-Pb age – 68.7 to 69.2 ± 1.4 Ma) and the Teapot Mountain Porphyry (U-Pb age – 66.3 ± 1.9 Ma) (Seedorff et al., 2019). These porphyry copper systems include related upper level, peripheral polymetallic vein deposits (i.e., Ray Silver and Monitor) as well as associated exotic copper deposits (i.e., Mineral Creek, Copper Butte, Buckeye East, and Buckeye West).

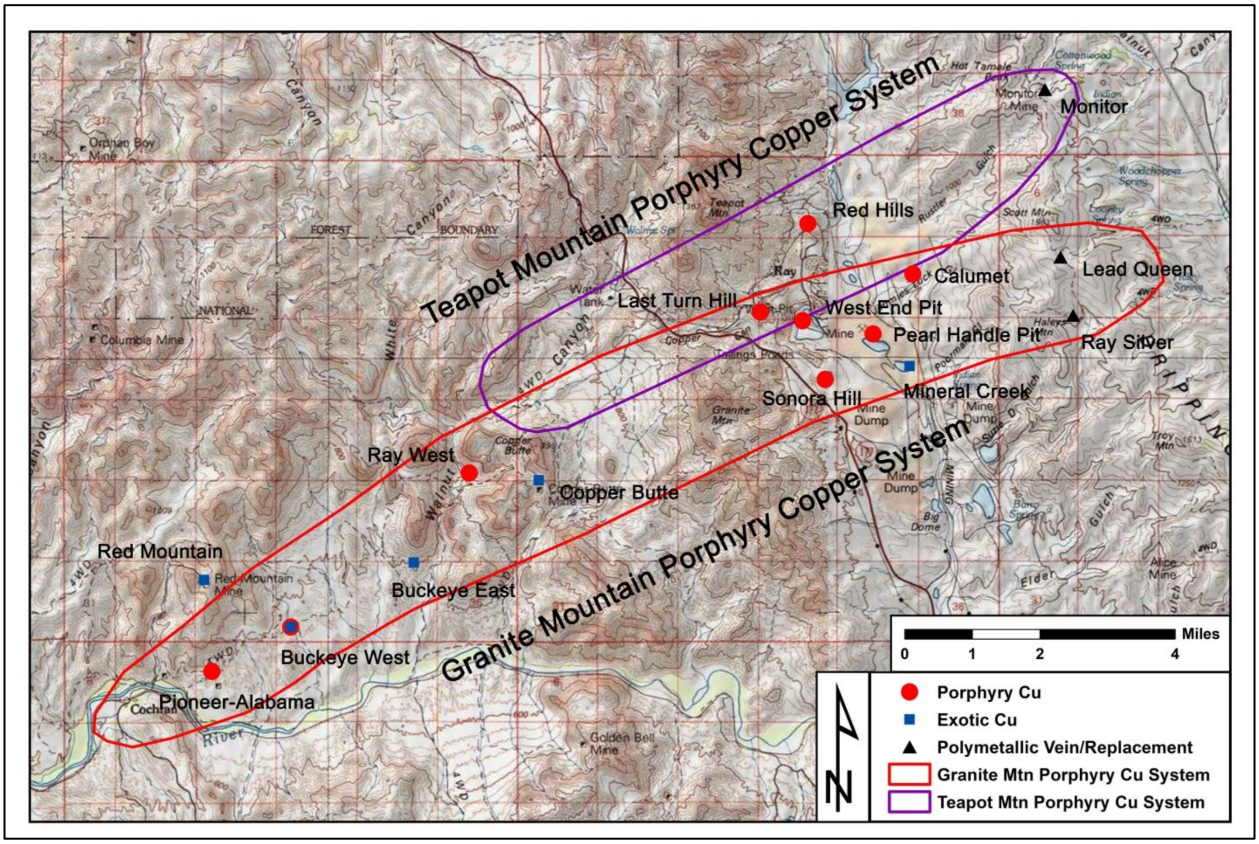


Figure 8. Extensional deformation has dismembered porphyry copper systems in the Mineral Creek district along a NE-SW extensional axis. Deposits have been classified by deposit type (modified from Maher, 2008).

As discussed in the previous section, post-mineral, normal faulting has cut and dismembered these porphyry copper systems, preserving portions of different levels of these hydrothermal deposits at the present erosional surface along a northeast-southwest trending extensional axis over a distance of about 15 miles (Figure 8).

At the northeast end of southern-most belt, small polymetallic veins hosted by late Proterozoic Troy Quartzite (i.e., Lead Queen), and lower Paleozoic sediments (i.e., Ray

Silver) occur above and peripheral to the upper levels of the northeast flank of the Granite Mountain stock at Ray. The most productive portion of the district is located along Mineral Creek at West End Pit, Pearl Handle Pit, Calumet, and Sonora Hill, which over time have coalesced into a single large open pit. Host lithologies include the Proterozoic Diabase, Pinal Schist, Granite Mountain Porphyry, and Ruin Granite.

At deeper levels, alteration in the Granite Mountain stock is characterized by a greisen (i.e., coarse-grained muscovite) assemblage, exposed along the western slope of Granite Mountain. It represents the root zone underlying the productive level of the porphyry system at Ray.

Displaced by the post-mineral Copper Butte Fault and related structures, the Pioneer-Alabama and Buckeye West may represent dismembered remnants of the phyllic (i.e., quartz-sericite-pyrite) alteration halo that originally surrounded the peripheral and upper levels of the Ray West porphyry copper occurrence situated along the southwestern flank of Granite Mountain stock.

Table 4. Summary of Host Lithologies, Alteration and Mineralogy at Various Localities in the Mineral Creek District (abbreviations for host units are shown in Figure 6, Kspar = K-feldspar, QSP = Quartz-Sericite-Pyrite, Py = Pyrite, Cpy = Chalcopyrite, and CC = Chalcocite) (modified from Maher, 2008; and Cook, 2024).

System	Locality	Host Lithology	Alteration Assemblage	Total Sulfide %	Mineralogy	Comments
Granite Mtn	Mineral Creek	Qal, Tw, Tal	Biotite, QSP in Clasts		CuOx	Exotic
Granite Mtn	Copper Butte	Tw	Biot, QSP, Silica-Pyrite in Clasts		Variable Py/Cpy Ratio to In-situ CuOx within Clasts of Altered Rx	Exotic
Granite Mtn	Buckeye East	Tw	QSP in Clasts		Py ≥ Cpy to In-situ CuOx within Clasts of Altered Rx	Exotic
Granite Mtn	Buckeye West	Tw	QSP in Clasts		Py ≥ Cpy to In-situ CuOx within Clasts of Altered Rx	Exotic
Granite Mtn	Red Mountain	Tw	QSP in Clasts		Py ≥ Cpy to In-situ CuOx within Clasts of Altered Rx	Exotic
Granite Mtn	Buckeye West	Xp, Yd	Weak to locally Strong QSP	1 to 5	Py>>Cpy to CC	Supergene
Granite Mtn	Pioneer-Alabama	Xp, Yd	Weak to locally Strong QSP	>5	Py>>Cpy to CuOx + CC	Oxide + Supergene
Granite Mtn	Ray Silver/Lead Queen	Pz, Yt			Polymetallic (Pb, Zn, Cu, Ag)	Veins/Replacement
Granite Mtn	Ray West	Xp	Moderate QSP	1 to 5	Py>Cpy	Hypogene
Granite Mtn	Last Turn Hill	Xp	Strong QSP	>5	Py>>Cpy to CC	Supergene
Granite Mtn	West Pit	Xp, Kgm	Strong QSP	>5	Py>Cpy to CC	Supergene
Granite Mtn	Pearl Handle	Xp, Kgm, Ya, Yd	Strong Biotite, Moderate QSP	1 to 5	Cpy≥Py	Hypogene
Granite Mtn	Sonora Hill	Xp, Kgm, Kt	Strong Biotite, Weak QSP	<1	Cpy>>Py	Hypogene
Granite Mtn	Calumet	Xp, Kgm, Ya, Yd, Yr	Moderate QSP/Biotite	1 to 5		Hypogene
Granite Mtn	Granite Mtn East Slope	Kgm, Xp	Moderate Kspar, Weak Biotite	<1	Cpy>Py to CuOx	Oxide
Granite Mtn	Granite Mtn West Slope	Kgm, Xp	Strong Greisen, Weak Kspar	<1	Py>Cpy	Hypogene
Teapot Mtn	Red Hills	Xp, Xm, Yd, Ktm	Strong QSP	1 to 5	Py ≥ Cpy	Hypogene
Teapot Mtn	Monitor	Ya, Yd			Polymetallic (Cu, Pb, Zn, Ag)	Veins

A similar relationship is observed at the Teapot Mountain Porphyry system with upper levels of the system hosted by late Proterozoic Apache Group and diabase (i.e, Monitor) and portions of its phyllic halo at Red Hills (Figure 8). Host lithology, mineralogy, total sulfide content, and alteration mineralogy of various portions of these systems are summarized in Table 4.

3.1 Porphyry Copper

Porphyry copper deposits are very large hydrothermal (i.e., hot water) systems, which occupy many cubic miles of rock surrounding and including intrusive bodies that were the source for the metals and served as the thermal engines that drove these systems (Guilbert and Park, 1986).

The term “porphyry copper” is derived from the texture of the igneous rock, which commonly forms the intrusive bodies associated with these mineral systems. At Mineral Creek this includes granodiorite and quartz monzonite porphyries, which contain plagioclase, quartz and biotite phenocrysts in a fine-grained to microcrystalline groundmass. Commonly occurring in intrusive bodies that have risen to a shallow level (i.e., 4,000 to 18,000 feet) in the earth’s crust, the larger phenocrysts formed as the intrusive body cooled slowly. At some point during the cooling process, the magma was rapidly chilled and crystallized, producing a fine to microcrystalline matrix surrounding the larger phenocrysts.

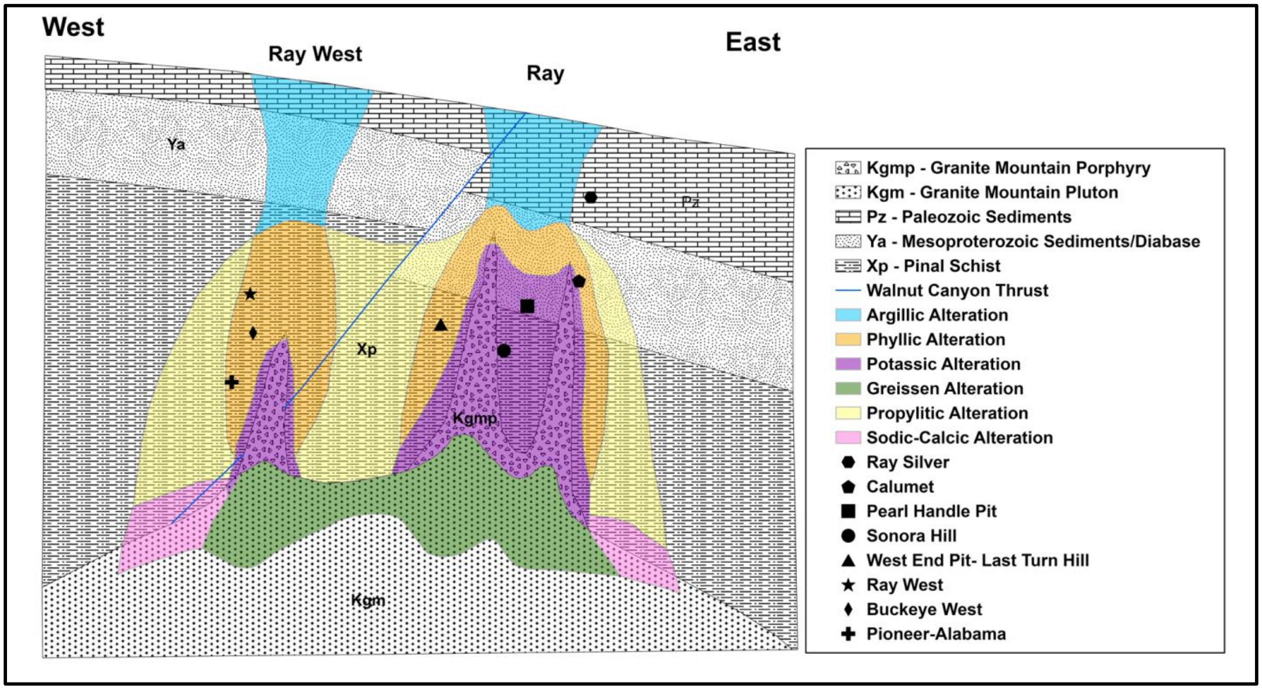


Figure 9. Schematic cross-section of the porphyry copper system(s) prior to mid-Tertiary dismemberment showing spatial distribution of various deposits to various alteration assemblages that formed about the Granite Mountain stock, which post-dated Laramide thrusting (modified from Maher, 2008).

As the Granite Mountain stock was emplaced, its upper and outer edges were the first to crystallize. This crystalline rind and surrounding baked zone of Pinal Schist, diabase and sediments of the Apache Group were repeatedly fractured and broken by metalladen hydrothermal fluids released from the crystallizing magma. These fluids reacted with the surrounding rocks to form a large zoned alteration halo within and around the Granite Mountain Porphyry stock.

A schematic cross-section of porphyry copper deposits (i.e., Ray and Ray West) related to the emplacement of the Granite Mountain stock prior to mid-Tertiary extensional dismemberment are shown in Figure 9. This large alteration halo is characterized by a deep-central zone of potassic alteration, enclosed by an outer propylitic zone, which is overlain and overprinted by phyllic zone.

Potassic alteration is characterized by the presence of quartz, secondary potassium feldspar, biotite (dark colored, shreddy mica), magnetite, and anhydrite. With a total sulfide content generally less than three volume percent, it typically contains minor amounts of chalcopyrite ($CuFeS_2$), bornite (Cu_5FeS_4), pyrite (FeS_2), and molybdenite (MoS_2). Intense biotite alteration is present in the barren core of the system exposed along lower portions of the eastern slope of Mineral Creek and along northeastern (i.e., Calumet/Ballpark) and southwestern flanks (i.e., Pearl Handle and Sonora Hill) of the southwest tilted and dismembered ore shell (Figure 10).

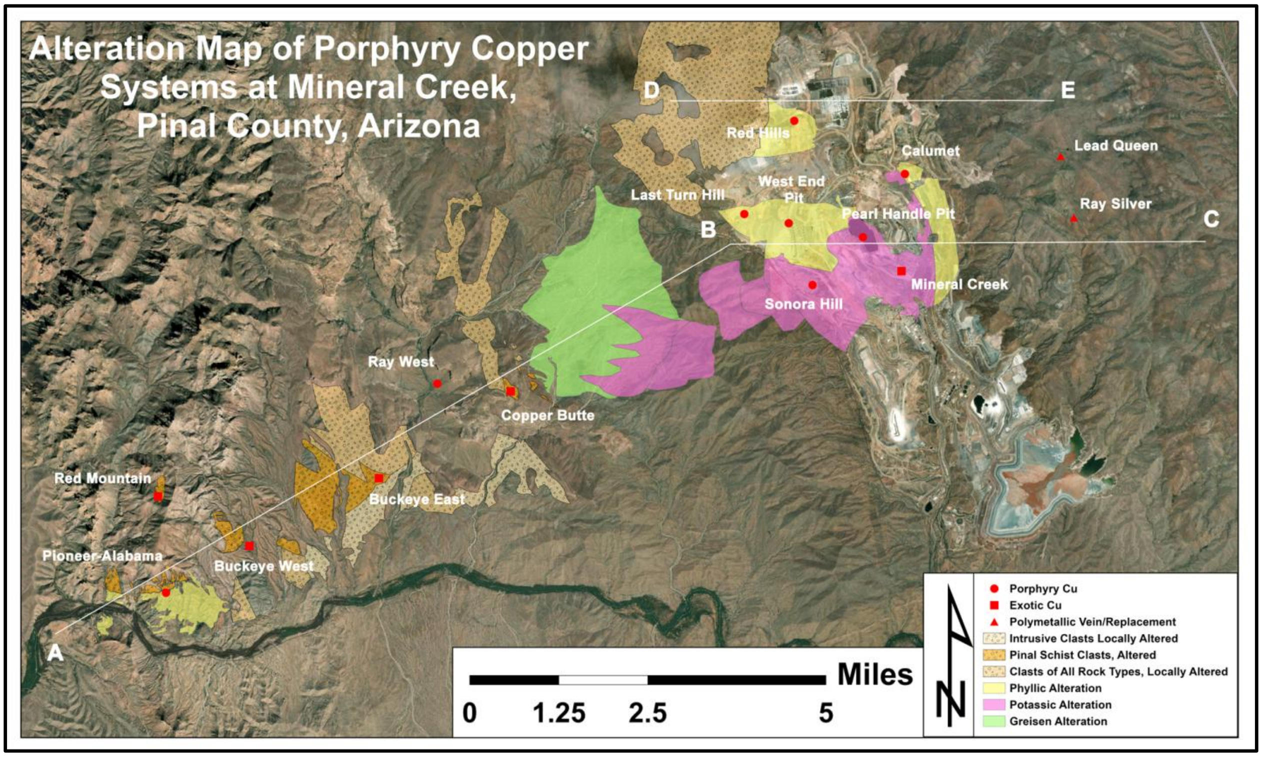


Figure 10. Alteration map showing distribution of altered clasts within the Whitetail Conglomerate and phyllic, potassic and greisen assemblages associated with porphyry copper systems at Mineral Creek (modified from Barton et al., 2005; and Maher, 2008).

Southwest of Sonora Hill, deeper levels of the Granite Mountain porphyry system exposed on the eastern flank of the Granite Mountain transition from porphyry to a fine- to medium-grained equigranular phase of the Granite Mountain pluton, where weak chalcopyrite mineralization is hosted by sheeted veins with minor potassium-feldspar and biotite envelopes (Barton et al., 2005; and Maher, 2008).

Minerals associated with the phyllic alteration include quartz and sericite (fine-grained colorless mica) with abundant pyrite in felsic and quartz-rich rocks. In more mafic lithologies, chlorite may substitute for sericite, producing a chlorite + pyrite ± quartz assemblage that is commonly observed in the Proterozoic Diabase at Ray. Sulfide content of the phyllic zone is generally high as observed above the western flank of the tilted ore shell (i.e., West End Pit and Last Turn Hill), where it constitutes more than 5 volume percent of the rock, with pyrite to chalcopyrite ratios much greater than 5:1 (Maher, 2008).

Propylitic alteration frequently gives the rock a greenish cast, as it is characterized by green-colored minerals, such as chlorite that replace mafic minerals and epidote, albite and calcite that replace plagioclase feldspar. Minor amounts of pyrite and hematite may also be present. A somewhat discontinuous zone of propylitized lithologies surrounds potassic and phyllic alteration assemblages at Ray (Metz and Rose, 1966).

A zone of advanced argillic alteration (quartz, clay, alunite, pyrophyllite, kaolinite, and pyrite) commonly overlies the central portion of many porphyry copper systems, but is absent at Ray (Maher, 2008). This is most likely due to rapid post-mineral erosion of the upper portions of this paleo-hydrothermal system.

Greisen occurs beneath the potassic zone, where it is characterized by coarse-grained hydrothermal muscovite that occurs as vein fillings with associated envelopes of quartz and K-feldspar (Maher, 2008). Widespread sulfide-poor greisen veins are observed within the main equigranular mass of the Granite Mountain stock along the western flank of Granite Mountain (Figure 10).

Sodic-calcic alteration assemblages are commonly localized in peripheral, deeper levels of many porphyry copper systems. These mineral assemblages are characterized by oligoclase, actinolite, sphene, and epidote. Silica is commonly leached resulting in a vuggy mass of quartz-poor rock (Maher, 2008). Although not recognized in porphyry copper systems related to the Granite Mountain Porphyry, well-developed sodic-calcic alteration assemblages are present within porphyry copper systems associated with the Tea Cup Granodiorite pluton, exposed south of the Gila River (Nickerson et al., 2010; and Maher, 2008).

The primary (i.e., hypogene) sulfide mineral assemblage includes chalcopyrite and bornite with minor molybdenite accompanied by minor to moderate amounts of pyrite. Copper ores typically occupy a bell-shaped zone of stockwork veining and disseminated mineralization that straddles the boundary between the potassic and phyllic alteration zones, which surround a low-grade potassic core, located at the center of the porphyry copper system.

The observed distribution of hypogene alteration assemblages and sulfide mineralization of the Granite Mountain porphyry system at Ray has been modified by post-mineral events. Approximately two to three million years following the emplacement of the Granite Mountain Porphyry (Pb-Ag age – 68.7 to 69.2 ± 1.4 Ma), its accompanying alteration/mineralization halo was partially overprinted by similar assemblages related to the Teapot Mountain Porphyry system (Pb-U age – 66.3 ± 1.9 Ma). Both systems were subsequently disrupted and rotated by normal faulting, which began in late Oligocene time and continues today.

3.1.1 Ray Copper Deposit

The Ray copper deposit is genetically related to smaller shallow level porphyry stocks located along the eastern flank of a larger intrusive body of equigranular granodiorite, exposed along the western flank of Granite Mountain (Figure 6). The most-productive portions (i.e., Pearl Handle Pit, West End Pit, Calumet and Sonora Hill) of this tilted and structurally dismembered hydrothermal deposit lie along the Mineral Creek drainage. Small polymetallic vein and replacement deposits along the crest of the Dripping Spring Mountains represent the uppermost, preserved levels of the porphyry copper system at Ray (Figure 8).

In addition to Granite Mountain Porphyry, copper ores are mainly hosted by the Pinal Schist and an extensive network of Proterozoic diabase dikes and sills that cut the Middle Proterozoic Apache Group (Figure 11). Hypogene sulfide minerals include pyrite and chalcopyrite with minor amounts of bornite and molybdenite (Metz and Rose, 1966). The best primary ore grades occur within diabase, a particularly receptive host due to the reactive nature of its mineralogy.

Over time as erosion exhumed primary copper ores at Ray, a leached cap and secondary enrichment blanket was formed above the primary sulfide zone as a result of oxidation and weathering. During this process any iron contained in these minerals was transformed into red, reddish brown, orange or yellow colored iron oxides, while sulfur reacted with groundwater to produce a weak sulfuric acid solution. Any copper contained within the rock was dissolved by these acidic solutions, which percolated down to the water table, where reducing conditions allowed the copper to precipitate out on primary sulfides as chalcocite (Cu_2S), forming a thick, copper-rich, supergene blanket-shaped zone. Located above primary sulfide (i.e., hypogene) mineralization, the enrichment blanket at Ray ranged from 40 to 400 feet in thickness (averaged 120 feet) and was overlain by 40 to 600 feet of barren leached cap.

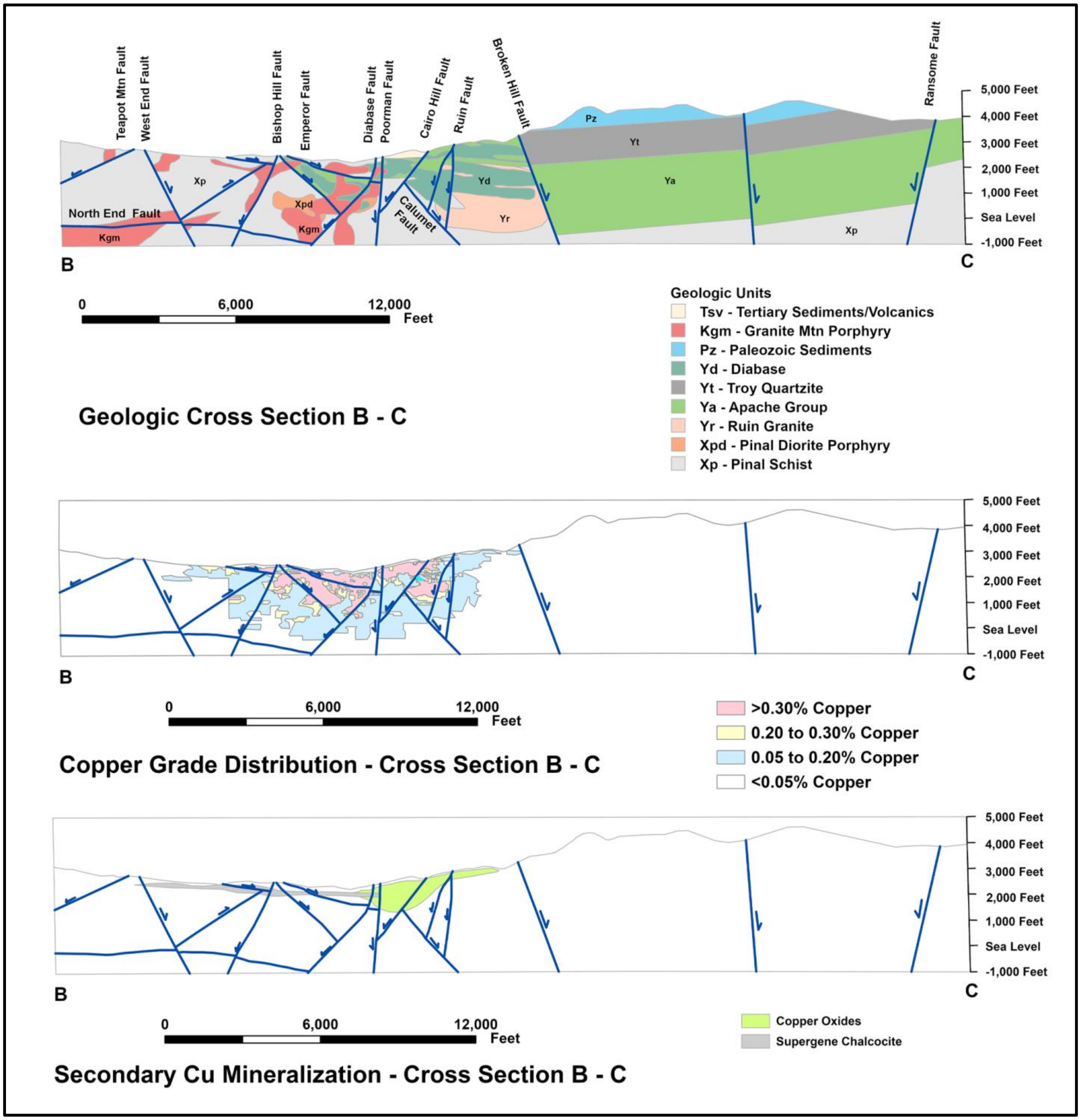


Figure 11. Cross Section (B-C) of the Ray Copper Deposit showing Geology, Copper Grade Distribution and Secondary Copper Mineralization (modified from Cornoyer, 2021).

The distribution of the secondary enrichment blanket observed at Ray is controlled by the abundance of sulfides and host rock lithologies (Figure 11). The best areas of secondary enrichment occur within the phyllic alteration halo developed within the Pinal Schist (i.e., West End Pit), where sufficient acid was generated to remobilize the copper (John, 1994). Locally containing ore grades as great as 10% Cu, initial mining activities began in these areas, which were the source for most of the district's production prior to the early 1960s (Metz and Rose, 1966).

Exposed along the eastern bank of Mineral Creek, the sulfide content of the barren core of the Ray porphyry copper system was not sufficient to remobilize the copper. Likewise, the acid neutralizing capacity of reactive hosts also impeded development of secondary enrichment blankets in regions underlain by diabase (Figure 11). In these areas, hypogene sulfides were oxidized in place to produce native copper and copper-bearing silicates, oxides and carbonates. Recovery of copper from these ores began in 1969.

3.1.2 Displaced Mineralization Related to Granite Mountain Porphyry

Large zones of phyllic alteration in Pinal Schist are concealed by post-mineral Whitetail Conglomerate and younger Tertiary cover at Ray West and Buckeye West and occur along the Gila River at Pioneer-Alabama, northeast of Cochran (Figure 6). Reported results from deep exploration drilling confine these weakly mineralized zones to portions of the hanging walls of the Copper Butte and Grayback fault zones (Figure 7).

Centered approximately one mile west of Copper Butte, the Ray West porphyry copper occurrence is concealed by approximately 1,800 to 2,000 feet of Tertiary sedimentary and volcanic cover located in the hanging wall of the north-striking Spine Canyon Fault (Sell, 1974a). Pre-mineral lithologies include the Pinal Schist, Ruin Granite (?), Diabase, and Granite Mountain Porphyry that are weakly to moderately altered to phyllic and propylitic assemblages and weakly mineralized (<0.05% Cu) (Sell, 1974b, and Maher, 2008).

Located approximately 4.3 miles southwest of Copper Butte, Pinal Schist at Buckeye West is concealed by approximately 550 feet of Oligocene Whitetail Conglomerate, which has been cut by Miocene porphyritic rhyolite dikes (Figure 6). The Pinal Schist occupies the brecciated hanging wall of the northeast-striking Grayback Fault (located at a depth of about 1,476 feet), which dips to the northwest at about 20 degrees. A zone of weak supergene enrichment in phyllic (i.e., quartz-sericite-pyrite) altered Pinal Schist containing 2 to 5 % pyrite and 0.02 to 0.44% copper underlies about 150 feet of oxidized leached cap beneath the Middle Tertiary unconformity. The footwall of the Grayback Fault contains weakly propylitized Tea Cup Granodiorite (Hoelscher, 1973).

In the Pioneer-Alabama area, Proterozoic Pinal Schist and Ruin Granite are exposed along the Gila River, northeast of Cochran, where it has been unconformably overlain by the Oligiocene Whitetail Conglomerate and cut by an intrusive complex of Miocene Sleeping Buffalo Rhyolite (Figure 6). The Pinal Schist is weakly to locally intensely altered to a quartz-sericite-pyrite assemblage containing copper oxides and supergene chalcocite (Maher, 2008).

This alteration and its related copper mineralization appear to have been formed about an apophysis of Granite Mountain porphyry above the western flank of the Granite Mountain pluton (Figure 9). Subsequently dismembered, rotated and displaced by middle to late Tertiary extensional faulting, much of the alteration halo and accompanying copper mineralization related to this apophysis appears to have been removed by erosion, leaving only isolated faulted remnants of the western flank of its phyllic and propylitic halo preserved beneath Tertiary cover at Ray West and Buckeye West and outcropping at Pioneer-Alabama.

Widespread exotic copper mineralization hosted by the Oligocene Whitetail Conglomerate in the late to middle Tertiary basin west of Granite Mountain may have been derived from mineralized erosional debris shed from the western apophysis of Granite Mountain Porphyry at Ray West.

3.1.3 Red Hills

Located north and partially overprinting the northern edge of the Granite Mountain porphyry copper system (i.e., Ray) is a younger hydrothermal system that is related to small stocks and dikes of Teapot Mountain Porphyry (Maher, 2008). Only small portions of this system are presently exposed at Red Hills (Figure 6).

North of the Ray pit, exploration drilling encountered significant copper mineralization within a large phyllic halo in the footwall of a low-angle, post-mineral fault at Red Hill (Figure 12). Altered clasts as well as strongly mineralized clasts observed within pebble dikes associated with Teapot Mountain Porphyry may suggest the presence of a concealed target at depth. Pyritically altered dikes of Teapot Mountain Porphyry also cut mineralization associated with the older Granite Mountain porphyry system exposed in the Ray pit.

The fault block containing the Red Hills occurrence is bounded on the east and west by the Ruby Fault and Teapot Mountain Fault, respectively (Figure 12). Concealed portions of the Teapot Mountain Porphyry system probably underlie post-mineral cover exposed in the hanging walls of these major structures. Small polymetallic vein occurrences (i.e., Monitor) along the northeast-trending dike swarm of Teapot Mountain Porphyry likely represent the upper levels of this system (Figure 8).

Understanding the genesis of the Calumet breccia pipe (Figure 6) was made difficult by supergene processes, which overprinted primary alteration and mineralization in the upper levels of this structure. However, two periods of mineralization have been recognized in lower levels, where hypogene mineralization and alteration are better preserved.

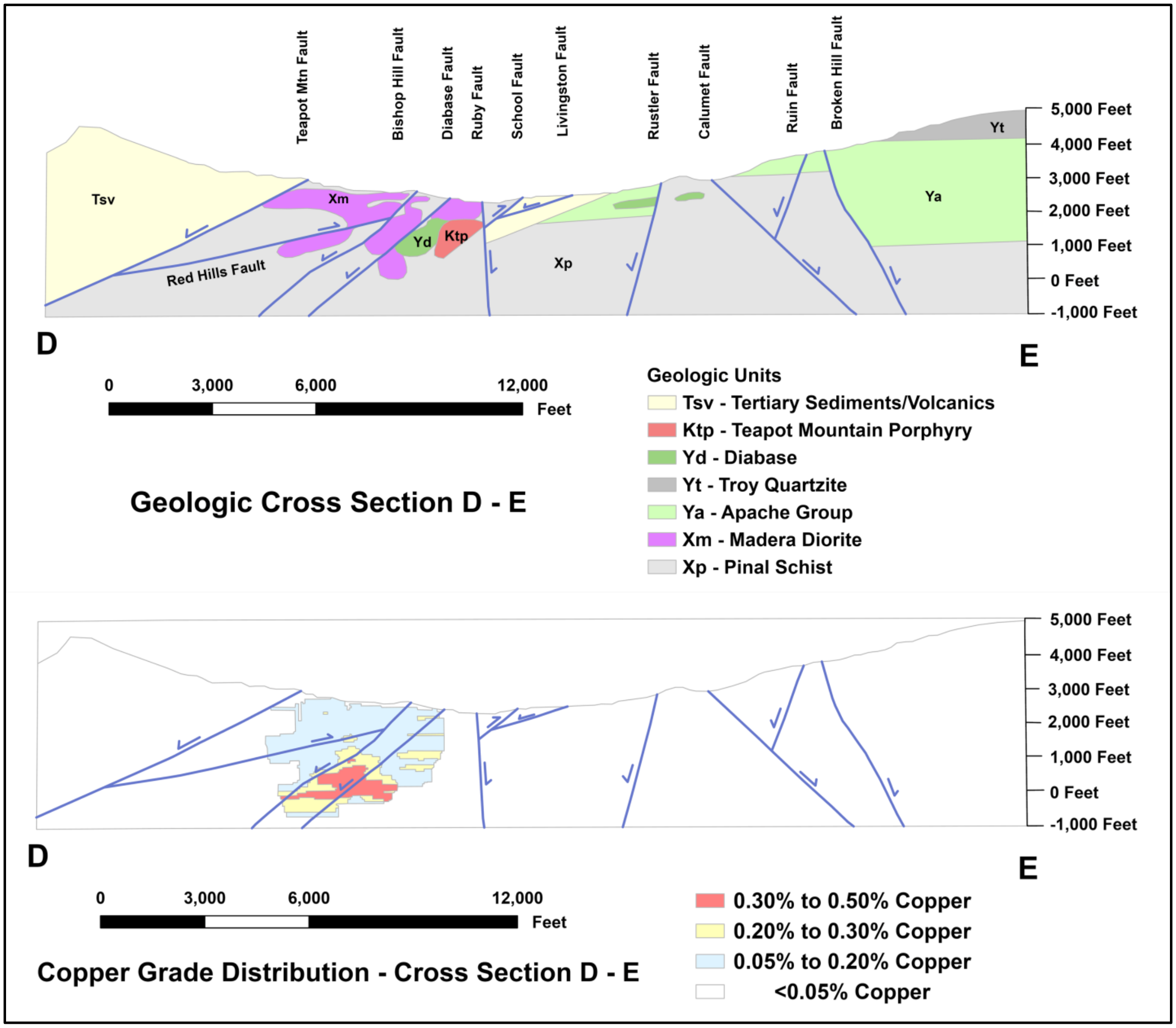


Figure 12. Cross Section (D-E) of the Red Hills Copper Deposit showing Geology, and Copper Grade Distribution (modified from Cornoyer, 2021).

The initial period is related to the Granite Mountain porphyry copper system. It is characterized by pyrite-chalcopyrite-quartz veining, which is confined to the breccia fragments within breccia pipe. The second period of mineralization consists of a galena-sphalerite-dolomite±rhodochrosite assemblage, which fills both breccia interstices and occurs within veins cutting breccia fragments. This sequence of events suggests the Calumet breccia pipe post-dates the Granite Mountain porphyry copper system and is possibly related to younger, peripheral mineralization associated with the Teapot Mountain event (Gambell, 1977).

3.2 Exotic Copper

Exotic copper occurrences are a type of secondary copper mineralization formed when copper from nearby oxidizing primary copper deposits is transported laterally prior to re-depositing it at a favorable site downstream. This can involve either physical or chemical processes or a hybrid of both methods (Seedorff et al., 2019).

Classic exotic deposits in the Andes (i.e., Exotica) appear to have formed by chemical processes, when migrating meteoric water containing dissolved iron, copper and manganese from an actively weathering porphyry system is transported laterally before precipitating it at a favorable site. Chemically formed deposits exhibit mineral zoning, ranging from a proximal zone of hematitized or leached cap clast gravel, through an intermediate zone of copper-manganese wad with kaolinized clast gravel to a distal zone of chrysocolla-atacamite with unaltered clast gravel. A similar zoning pattern is also observed in bedrock underlying the mineralized gravels, ranging from proximal chalcocite-turquoise in propylitized lithologies to more distal chrysocolla in unaltered lithologies. In some instances more distal or overlying zones of ferricrete and manganocrete may also be present (Munchmeyer, 1996).

Chemical processes formed large exotic copper deposits at the Ray mine, which are hosted by the Whitetail Conglomerate and vitrophyric horizons in the Apache Leap Tuff, located in the half graben on the east side of Mineral Creek (Cook, 2024). Smaller occurrences of exotic copper are also present in unconsolidated to semi-consolidated Holocene stream gravels (Figure 8) along the Mineral Creek drainage (Phillips et al., 1971).

Exotic copper deposits are formed by physical processes where altered and mineralized erosional debris derived from a nearby porphyry copper system was deposited at a distal site. Commonly formed in areas of crustal extension, this type of exotic copper occurrence can be associated with large-scale landslide avalanches (i.e., Cactus-Carlota) or wet debris flows of alluvial fan or fluvial systems that formed over time. Physical processes related to the deposition of wet debris flows appear to have formed the Buckeye East and Buckeye West deposits, which are associated with altered and mineralized clasts of Pinal Schist within Whitetail Conglomerate (Arnold, 1972; and Maher, 2008).

3.2.1 Copper Butte

Located approximately 5 miles southwest of the Ray open pit, Early Miocene Apache Leap Tuff capping a small mesa (i.e., Copper Butte) overlies a thin section of Oligocene Whitetail Conglomerate, which in turn overlies Pinal Schist exposed in the hanging wall of the gently southwest dipping Copper Butte Fault.

Confined to the Whitetail Conglomerate, historically mined exotic copper ores at this locality were mainly derived from shallow pits situated along the southwestern flank of Copper Butte (Figure 13). Subsequent exploration drilling shows much of the resource remaining at Copper Butte is concealed beneath Apache Leap Tuff to the northeast. Exotic copper mineralization at Copper Butte is bounded on the southwest by a northwest striking normal fault, which has down-dropped the mineralized horizon in its southwest hanging wall (Phelps, 1946).

The Whitetail Conglomerate is composed of erosional debris chiefly composed of clasts of altered Pinal Schist with locally abundant quartzite, limestone, diabase, and Granite Mountain Porphyry, which are cemented in a sandy/clay matrix (Phelps, 1946; and Maher, 2008). Phelps (1946) noted that copper oxides ores are preferentially hosted by gray to brownish gray conglomerate, while red to reddish brown conglomerate contain little copper.

Figure 13. Chrysocolla and Azurite-Bearing Ore hosted by Whitetail Conglomerate at Copper Butte (photo from Mindat.org).

While quartz-sericite-pyrite is the dominant alteration assemblage observed in clasts contained within the Whitetail Conglomerate at Copper Butte, less common potassic biotite as well as silica-pyrite assemblages have also been reported (Maher, 2008).

Furthermore, the original sulfide (pyrite, chalcopyrite) content varies from clast to clast, suggesting the source for the erosional debris contained within the Whitetail Conglomerate was derived from different portions of a nearby porphyry system (i.e., presumably Ray West). Ore minerals include chrysocolla, malachite, black or brown wad and copper-bearing jarosite/goethite that coats the rock clasts, replaces some limestone clasts and occurs within interstitial matrix (Dickinson, 2001).

Observations of the copper mineralization at Copper Butte posed interesting questions about the how the deposit was formed. One theory implied the copper was transported to the site within mineralized rock clasts contained within the Whitetail Conglomerate and was subsequently redistributed by acid generated from residual pyrite following its deposition. While a second theory suggests the copper was chemically leached from a distant source and transported to its present location in solution (Arnold, 1972).

John and Fountain (1994) suggest the copper was remobilized from clasts contained within the reddish to reddish brown debris flows that underlie the Apache Leap Tuff and deposited within the underlying horizons of gray to brownish gray conglomerate. In contrast, Phillips (1976) concluded the large amount of copper hosted by the Whitetail Conglomerate at Copper Butte requires significant lateral groundwater transport of copper from some distant source. This is supported by the presence of oxide copper as mainly clasts coatings or within interstitial matrix as well as vein fillings, which implies partial lithification of the Whitetail Conglomerate prior to mineralization (Dickinson 2001). Exotic copper mineralization at Copper Butte probably represents an example of a hybrid deposit, formed mainly by chemical processes with a lesser physical component (Seedorff et al., 2019).

3.2.2 Buckeye East

Situated approximately 7.5 miles southwest of the open pit at Ray, exotic copper mineralization at Buckeye East is also hosted by the Oligocene Whitetail Conglomerate. This project lies within the western hanging wall of the north-south trending Spine Canyon Fault (Figure 6).

Exotic copper mineralization at this locality is present in two separate rock types. The upper unit is characterized by a hematite flooded, coarse-grained conglomerate that only contains clasts of strongly silicified Pinal Schist. It is believed to represent erosional debris derived from a phyllic halo associated with a porphyry copper system (i.e., Ray West). Copper mineralization in the lower unit is associated with a medium- to coarse-grained, poly-lithic unit containing neither pervasive iron staining nor silicified Pinal Schist. Limestone clasts are noticeably absent (Armstrong, 1994).

Unlike, Copper Butte, oxide copper mineralization (i.e., chrysocolla) at Buckeye East is mainly confined to clasts and rarely fills open spaces within the conglomerate (Arnold, 1972; and Maher, 2008).

3.2.3 Buckeye West

Located approximately 10 miles southwest of the Ray copper mine, exotic copper mineralization is also present within the Whitetail Conglomerate at Buckeye West, an area where weakly mineralized Pinal Schist is also reported at depth (Figure 6). Similar to Buckeye East, oxide copper mineralization (i.e., chrysocolla) is also localized within clasts of Pinal Schist, which are altered to a quartz-sericite-pyrite assemblage (Armstrong, 1994; and Maher, 2008).

4 EARLY HISTORY OF THE MINERAL CREEK REGION

Evidence from archaeological sites along the middle Gila River Valley and its tributaries indicates this region was occupied by members of the Hohokam/Salado cultures from A.D. 200 until A.D. 1450. Flourishing for more than a millennium, they established large agricultural communities, where dry farming techniques and extensive networks of canals were excavated along streams to irrigate their crops (Meserve, 2003).

The Hohokam/Salado cultures began to decline around A.D. 1300 before disappearing entirely by A.D. 1450 (Meserve, 2003). While scholars have hypothesized many reasons for their demise, it is interesting to note that this decline coincided with the onset of the Little Ice Age (A.D. 1300-1850). Climate conditions during this time were characterized by extended periods of drought with intermittent severe flooding (Huckleberry et al., 2018). When combined with the possible salinization (i.e., overabundance of salt) of their irrigated fields, these conditions made it impossible to sustain their large communities. Successfully adapting their lifestyle to meet these challenges, their descendants, the Tohono O’odham (i.e., Papago) and Akimel O’odham (i.e., Pima) continue to reside in these lands today (Meserve, 2003).

4.1 Yavapai and Western Apache

Mineral Creek lies near the boundary of the region that was later occupied by the Yavapai and Western Apache, which had two distinct ancestral lineages, but similar lifestyles (Figure 14). Both of these groups appear to have migrated to this region between A.D. 1200 and A.D. 1600, either displacing the Hokokam/Salado or settling lands recently abandoned by them (Laylander, 2014; Tagg, 1985; and Goodwin, 1969).

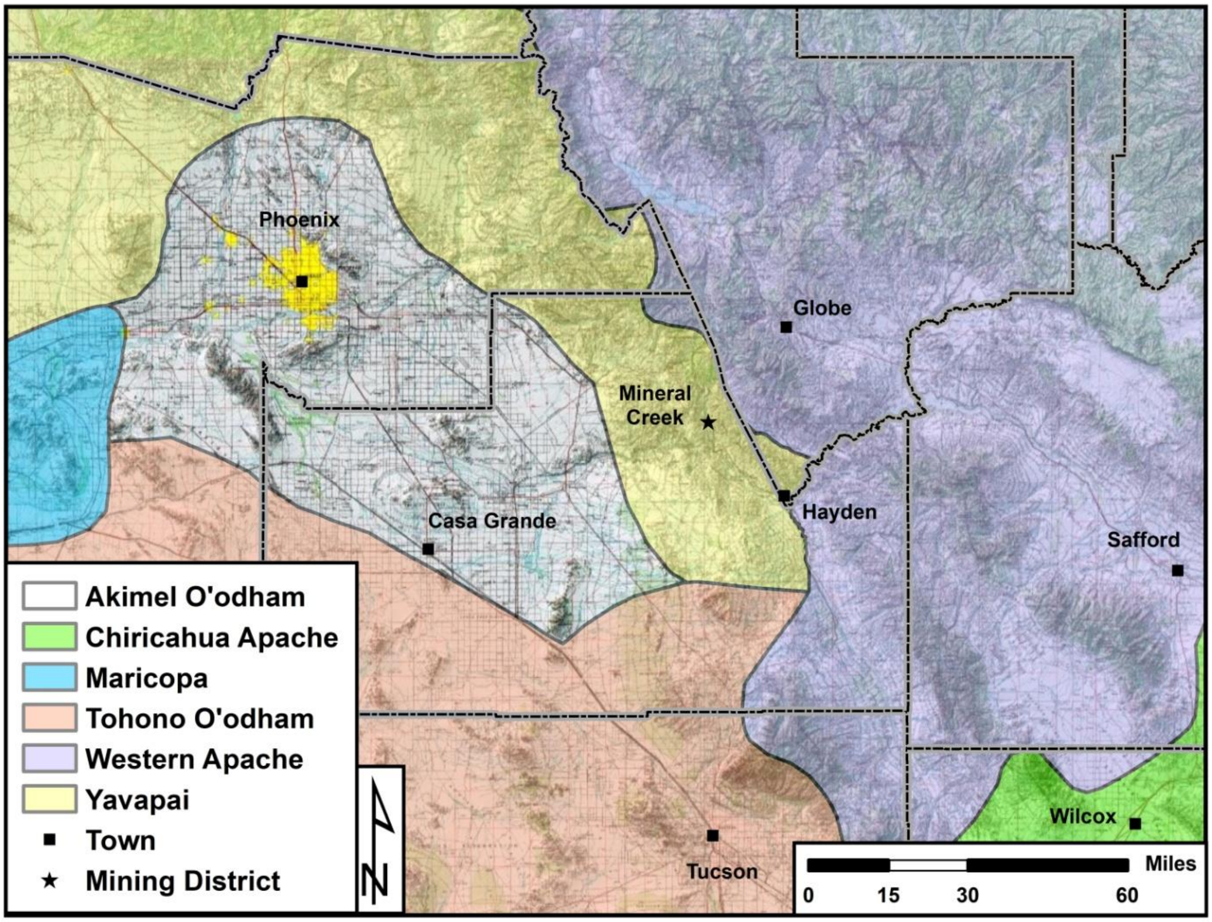


Figure 14. Pre-reservation homeland of the Yavapai, Western Apache and neighboring tribes in the vicinity of the Mineral Creek mining district, circa 1850 (modified from Goodwin, 1969).

Recent linguistic research, suggests the Yavapai are related to the Yuman Group of Native Americans, who inhabited the Lower Colorado River Valley and adjacent areas around B.C. 500 and spread north along the Colorado River and northeast along lower Gila River by A.D. 500. By A.D. 800, members of this group residing in the northern portion of the Lower Colorado River Valley split to form the Upper Yuman Sub-group (i.e., Hualapai, Havasupai and Yavapai), who settled portions of western and central Arizona after A.D. 1200 (Laylander, 2014).

The Apache are an Athapaskan culture that originated in the Canadian Yukon. Their migration south began in response to a major volcanic eruption at Mount Churchill in the Saint Elias Mountains of southeastern Alaska around A.D. 803. Archeological evidence suggest small groups migrated south along the eastern flank of the Rocky Mountains over the next six to seven centuries before arriving in New Mexico, Arizona and Texas (Lewandowska, 2020). The western-most tribe of the Apache is the Western Apache, who settled the headwaters of the Salt and Gila River systems of east-central Arizona sometime between A.D. 1400 and A.D. 1600 (Tagg, 1985; and Goodwin, 1969).

Arriving in the region during the early years of the Little Ice Age, both the Yavapai and Western Apache were a nomadic people, who were well adapted for the climatic conditions of this period. They lived in small isolated groups, who subsisted on small-scale cultivation, gathering wild plant foods and hunting game. Both supplemented their lifestyles by raiding and to a lesser extent through commerce with neighboring tribes (Goodwin, 1969).

Relations between the Western Apache and the Yavapai were generally peaceful. On occasion, intermarriage between members of the two groups resulted in spouses residing in the other's camp. The Yavapai and some bands of the Western Apache allied themselves against a common foe (e.g., Tohono O'odham and Akimel O'odham as well as the Spanish and later Mexicans) (Goodwin, 1969).

4.1.1 Prehistoric Indigenous Mining Activity

The only reported evidence of mining activity at Mineral Creek by Native Americans was a small chrysocolla quarry, located approximately one mile east of the former Ray town site, which now lies within the footprint of the open pit operation. It is thought to have been excavated by the Hokoham/Salado, who used this colorful mineral to make jewelry and possibly for ceremonial or medicinal purposes. Several dozen stone tools (i.e., grooved mauls, hammerstones, and broken axes) made from diabase employed in this mining activity have been found in the vicinity of this site (Sense, 1967).

4.2 Discovery

The earliest Europeans arrived in the area around Rio Puerco (now known as Mineral Creek) during the sixteenth and seventeenth centuries (McCarty and Bufkin, 1976). These generally small groups primarily consisted of Spanish prospectors in search of gold and silver or were a part of organized expeditions to deal with Apache depredations on their outlying settlements in southern Arizona and northern Sonora. The first Americans to venture into the region were trappers from Santa Fe and Taos, New Mexico. Arriving during the mid-1820s, they trapped beaver along the Gila and San Pedro Rivers (Walker and Bufkin, 1986).

Following the on-set of the Mexican-American War on April 25, 1846, General Stephen W. Kearny (Figure 15) departed Fort Leavenworth, Kansas on June 30, 1846 with approximately 1,800 men, consisting of Missouri Volunteers and a portion of his regiment of dragoons with orders to seize control of Santa Fe, New Mexico and proceed to California. After a march of 1,000 miles, they entered Santa Fe on August 18, 1846, without firing a shot (Porter, 1909).

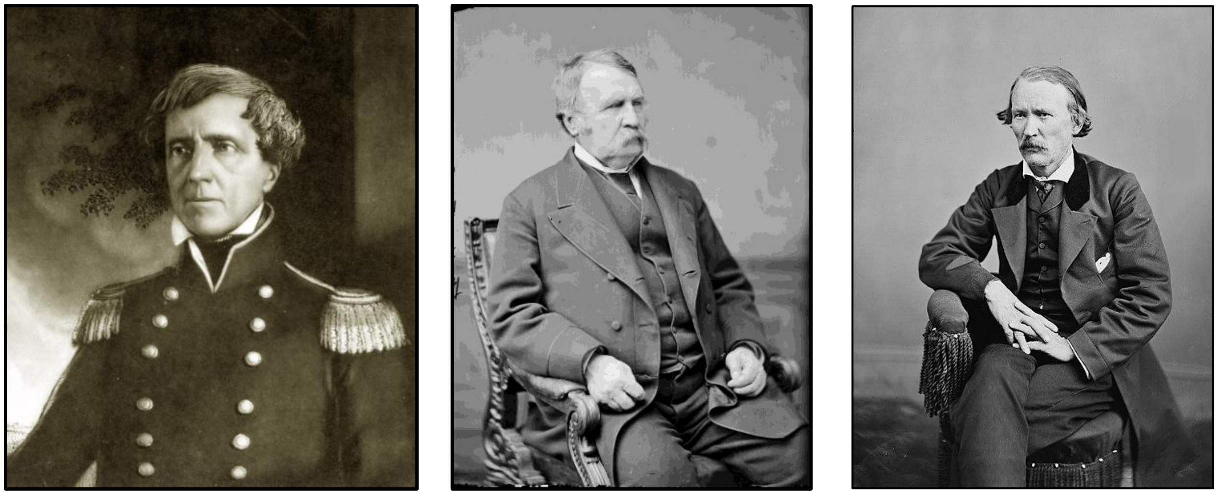


Figure 15. General Stephen W. Kearny (1794-1848) (left), Lt. William Emory (1811-1887) (middle) and Christopher "Kit" Carson (1809-1868) (right) (photos from Library of Congress).

After remaining in Santa Fe for about a month to assure a peaceful transition to a civil territorial government, Kearny split his force sending approximately 1,000 men south to join the war in Mexico. He departed Santa Fe for California with 300 troops on September 25, 1846. Among those who accompanied him was Lt. William Emory (Figure 15), a topographical engineer, who surveyed the route (Jonas, 2004).

Initially traveling south along the Rio Grande River, they reached Socorro on October 6, 1846, where they met Christopher "Kit" Carson (Figure 15) and a party of 15 men, who were on the way to Washington D.C. to inform President Polk that the U. S. Navy under the command of Commodore Robert Stockton had taken Monterrey and San Diego, California.

Upon learning of this news, Kearny ordered Carson to guide him back to California. Thomas Fitzpatrick relayed the news about California to Washington. As Kearny continued south along the Rio Grande River, Kit Carson advised him that very rough terrain made it virtually impassible for wagons. The general decided to proceed to California with a smaller occupation force of 140 troops and sent all of the wagons and remaining troops back to Santa Fe. Provisions were transferred to pack mules and they continued south along the Rio Grande with the only wheeled vehicles being two mountain howitzers (Ruhlen, 1957).

Figure 16. Map showing the Route the Kearny Expedition through Arizona and Mineral Creek.

The expedition left the Rio Grande River around Truth or Consequences on October 14, 1846, traveling overland, reaching the Gila River at the mouth of Mangas Creek on October 20, 1846. From there, they followed the Gila River west through Arizona

(Figure 16), reaching to the Colorado River at Yuma on November 25, 1846 and finally arriving in San Diego, California on December 12, 1846 (Ruhlen, 1957).

During this trek they camped along a creek located approximately 13 miles downstream from confluence of the Gila and San Pedro rivers on November 7, 1846. Noting the presence of copper in this area, Lt. William Emory named this drainage Mineral Creek (Seefeldt, 2005).

4.3 Early Mining Activity (1878-1886)

Although Mineral Creek was among the region’s earliest copper discoveries, several decades passed before prospectors ventured into this remote locality, which was vigorously defended by indigenous tribes (i.e., Western Apache and Yavapai) (Goodwin, 1969). Established near the confluence of Mineral Creek and Gila River in 1877, the community of Riverside served as a stage-stop between Globe and Florence, providing limited access to the area. Tom Haley and William Souffrien organized the Mineral Creek mining district in 1878 (Seefeld, 2005).

Figure 17. Financial backers of early efforts at Mineral Creek included Louis Zechendorff (1838-1937) (left, photo from Anonymous, 1901) and Albert Steinfeld (1854-1935) (right, photo from Arizona Historical Society #12608).

Formed in December 1880 by New York capitalists, the Pinal Copper Company commissioned a 30-ton water-jacketed blast furnace near the confluence of Mineral Creek and Gila River in May 1881. Feed for this furnace was reported to be carefully cobbled native copper and enriched chalcocite ores that assayed between 50 to 60% copper (Rickard, 1987).

Reorganized as the Ray Copper Company in 1883, work continued developing a substantial resource assaying between 7 to 15% copper. Prominent Tucson merchants (Figure 17), Louis Zeckendorff and Albert Steinfield were among the financial backers of this early activity (Rickard, 1932). Confronted by overwhelming engineering challenges, this effort achieved little as the price of copper declined to 9.5 cents/lb. in 1886, when all mining activities ceased (Tenney, 1927-1929).

4.3.1 Ray Copper Mines Ltd. (1898-1904)

After a prolonged period of idleness, Globe Mines Exploration Company Ltd. of London, England acquired an option to purchase the Ray, Taylor and Innes claim groups for £210,000 in October 1898. This option was exercised in June 1899. Largely financed by British capital, Ray Copper Mines Ltd. was incorporated to develop and operate its holdings. At the time of its acquisition, a resource of 190,000 tons, assaying 4 to 5% copper was reported at the site (Ransome, 1919).

Over the next year, Ray Copper Mines invested £117,465 in development and equipment. They founded the town of Kelvin in 1899, where they erected a 250-ton/day gravity concentrator, shops, office, mercantile, and other supporting infrastructure (Ransome, 1919). Kelvin’s population peaked at around 1,000 (Seefeldt, 2005).

Grading of the Mineral Creek Railroad (also known as the Ray Copper Mines Railroad), (Figure 18), a 5.5-mile narrow gauge line, connecting their mine and Kelvin began along the eastern bank of Mineral Creek during October 1899 (Irvin, 1987). In early 1900, the company’s working capital was increased by £200,000 and a smelter was built at Kelvin. However, this facility was never placed in operation. It was later destroyed by fire in March 1906 (Ransome, 1919).

At the mine, the Ray Shaft was sunk to a depth of 344 feet and ore delineated on three levels by a rectangular grid of drifts and cross-cuts, with the ultimate goal of extracting it by a caving method. Ray Copper Mines also sank the Sharkey, Humboldt and Tribunal shafts on promising sites on their large land holding (Ransome, 1919).

A 60-mile wagon road was established from Kelvin to the nearest railhead at Red Rock on the Southern Pacific Railroad, over which all fuel and other supplies were hauled to Kelvin by steam-powered traction engines (Ransome, 1919).

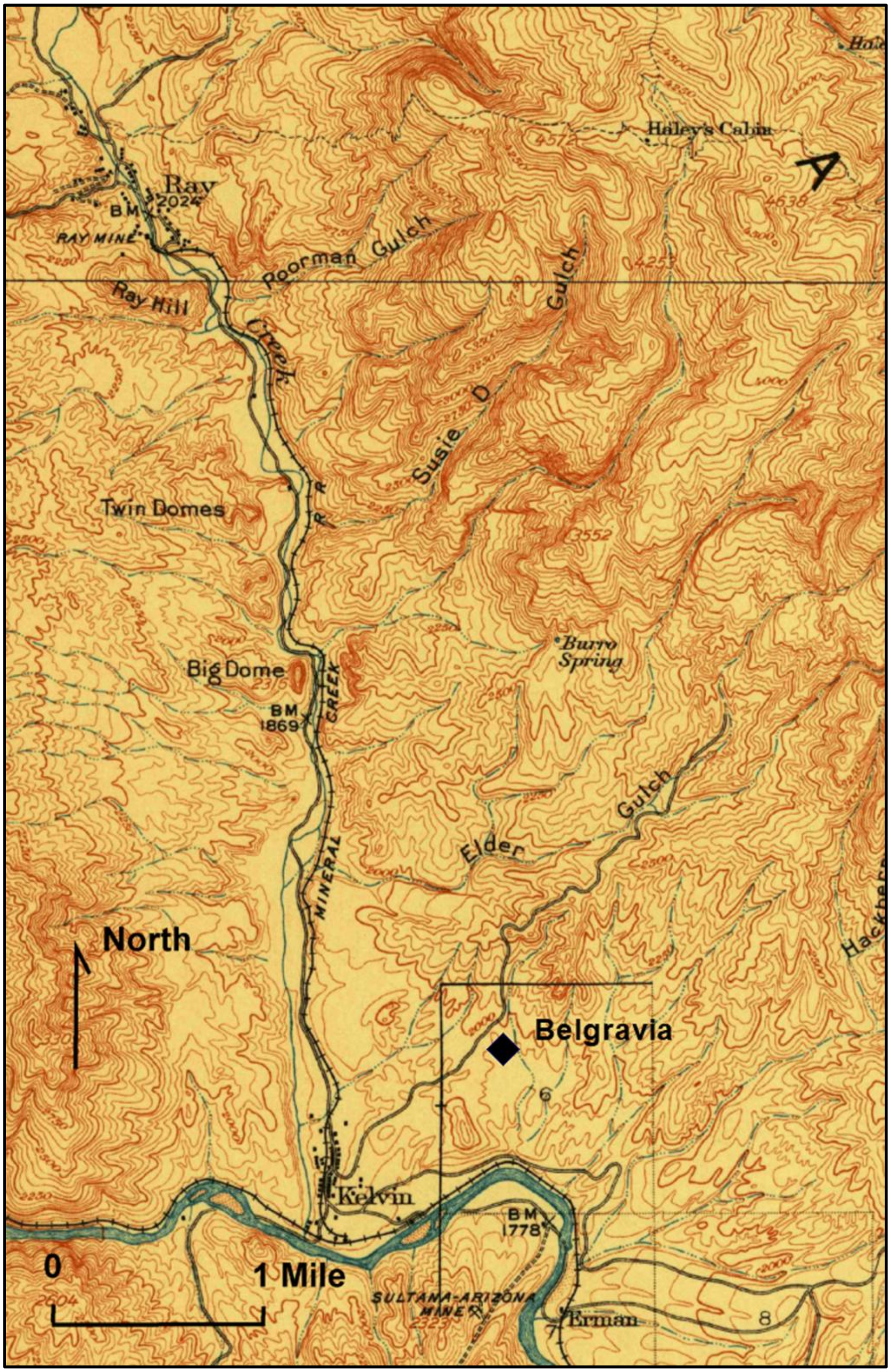


Figure 18. Topographic of Ray Mine, Kelvin, Belgravia, and Mineral Creek Railroad (photo from U. S. Geological Survey 1:62,500 Topographic Map of Ray Quadrangle, 1908).

The first shipment of crushed ore from the mine was delivered to the Kelvin concentrator on May 14, 1900. By the December 1900, only 480,000 lbs. of copper had been recovered from 16,000 tons of ore, assaying less than 2% copper. Operations were suspended in early 1901 and its assets placed into receivership (Ransome, 1919). Renewed efforts to resume production ceased in May 1902 (Seefeldt, 2005).

This early operation failed for several reasons. Inadequate supervision by qualified personnel resulted in poor sampling procedures during the development of the mine; leading to predicted ore grades of just less than 5% copper, compared to the actual tenor of the ore mined of slightly more than 2% copper. The second mistake was erecting a mill before an adequate reserve had been established. Its location, approximately 60-miles from the nearest rail head also significantly increased shipping costs to and from this remote site. Finally, large sums of capital were squandered on non-essential support infrastructure that could have better spent elsewhere (Parsons, 1933).

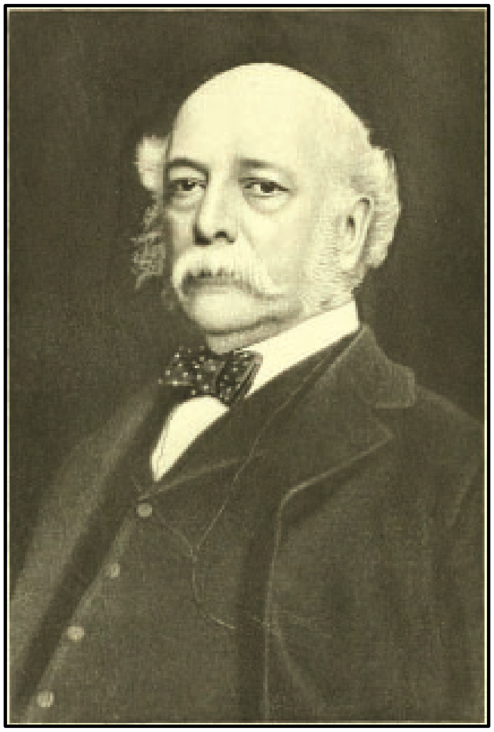


Figure 19. James D. Hague (1836-1908) (photo from North Star House).

James D. Hague, a well-known American mining engineer (Figure 19) was retained by the receivers of Ray Copper Mines Ltd. to examine the project. After a careful evaluation, he concluded the property had considerable potential. Although the tenor of the mineralization (2 to 3%) at Ray was less than could be economically extracted under existing conditions, he predicted improvements in processing technology would make it profitable at some point in the future (Ransome, 1919).

4.3.2 Renewed Interest (1904-1912)

Incorporated in August 1901 by Frank Murphy interests, the Phoenix and Eastern Railroad originally intended to build a standard gauge line east from Phoenix to Benson, Arizona, along the Gila and San Pedro river valleys. Soon after construction began in October 1902, the Atchison, Topeka and Santa Fe Railroad acquired control of its assets. By January 1904, the Phoenix and Eastern Railroad had reached Florence, Arizona, located 65 miles southeast of Phoenix (Irvin, 1987).

Serving southern Arizona since 1880, the Southern Pacific Railroad became aware that a competitor was encroaching on its territory. It organized the Arizona Eastern Railroad in February 1904, which filed plans to construct their line along the same route on the northern bank of the Gila River in March 1904. This resulted in litigation over who controlled the right to construct a railroad along an 18-mile section connecting Kelvin and Winkelman, Arizona (Figure 20). Pending outcome of this legal battle, the Phoenix and Eastern Railroad completed construction of its line to Winkelman in September 1904 and commenced operations further supporting its legal right to serve communities along this route.

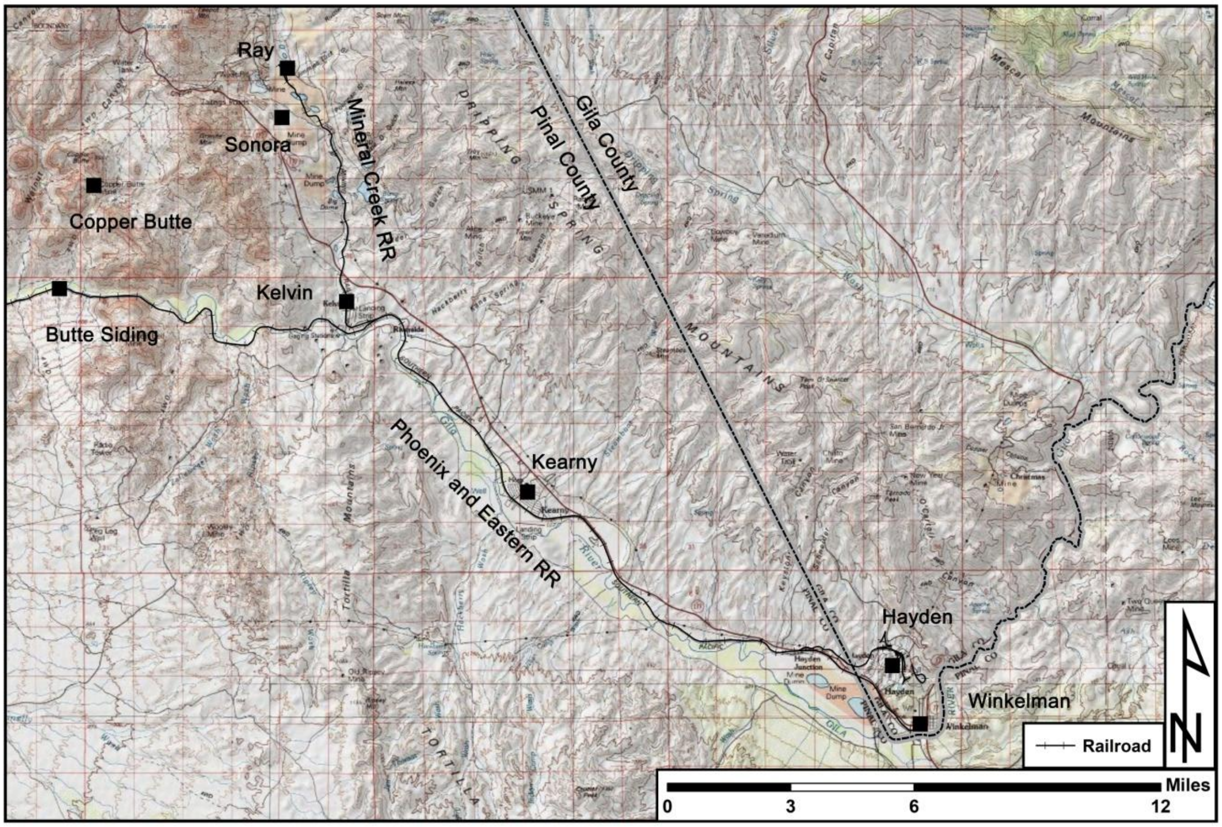


Figure 20. Major towns and transportation infrastructure at Ray and Hayden, Pinal and Gila Counties, Arizona.

However, spring flooding along the Gila River in March 1905, destroyed portions of the Phoenix and Eastern's rail line at several locations in the Gila River Canyon, halting all operations and caused unanticipated legal difficulties. Recognizing an opportunity to gain leverage in its on-going legal battle, the Southern Pacific Railroad constructed a new 0.77-mile segment that by-passed the damaged segment of track and agreed to permit Phoenix and Eastern to operate its trains over this small, but strategic section of the contested route.

In February 1906, the Secretary of the Interior, Ethan A. Hitchcock, determined the Phoenix and Eastern Railroad controlled the legal construction and operating rights along the Gila River between Florence and Winkelman. This decision was promptly appealed to the U.S. Supreme Court. However, before the Supreme Court was able to rule on this matter, litigation was settled in December 1906. As a part of this agreement, which also included resolution of other disputed holdings in Northern California, Arizona and New Mexico; the Atchison, Topeka and Santa Fe Railroad sold the Phoenix and Eastern Railroad to Southern Pacific in March 1907.

In March 1910, the Phoenix and Eastern Railroad was leased to the Arizona Eastern Railroad, who purchased the short line in October 1945. The Southern Pacific Railroad reacquired this asset through a merger in September 1955 and controlled it until June 1986, when it sold the Arizona Eastern Railroad to the Rail Management Corporation, which formed the Copper Basin Railway (ASARCO, Inc., 2023).

4.3.3 Anglo-American Copper Company (1904-1907)

The arrival of the Phoenix and Eastern Railroad at Kelvin in June 1904, spurred interest in the copper resources along Mineral Creek by a number companies, including Anglo-American Copper Company, Ray Central Copper Mining Company, Arizona Hercules Copper Mining Company, Gila Copper Company, and the Ray Consolidated Copper Company (Figure 21).

In late 1904, Anglo-American Copper Company acquired an option to purchase the former Ray Copper Mines' property from its receivers. William Y. Westervelt, a consulting engineer for Anglo-American, recognized the property's potential (Figure 22). Measuring approximately 8,000 feet by 4,000 feet, the copper-bearing zone had the potential of being much larger than Utah Copper's Bingham Canyon, which began production in July 1904. On the advice of William Westervelt, the existing system of horizontal underground drifting employed in exploratory work was replaced with vertical diamond drill holes (Anonymous, 1920).

Figure 21. Claim map of the Mineral Creek mining district, circa 1905-1910. Note: Prior to 1907, the holdings of Ray Consolidated Copper Company and Gila Copper Company were controlled by the Anglo-American Copper Company (modified from Ransome, 1919).

Figure 22. William Y. Westervelt (1872-1958) (photo from Anonymous, 1920).

Metallurgical testing showed not much more than 60% of the copper could be recovered using existing technology, making it unattractive considering its ore grade (2.5% copper) and the price of copper at the time (13 cents per pound). During 1905, under the guidance of Westervelt, Anglo-American Copper conducted experimental leach tests with a hot acid solution of ferric sulphate, followed by electrolytic precipitation of the dissolved copper. Achieving an 80% recovery, this procedure proved to be both feasible and economical. The recovery process employed so successfully at Inspiration Consolidated Copper's mine at Miami two decades later was largely modeled from this early research (Parsons, 1933).

4.3.4 Ray Central Copper Mining Company (1905-1912)

The Big Lead Mining and Smelting Company was organized by H. B. Twitchell in 1905, to develop a group of claims that adjoined the former holdings of Ray Copper Mines Ltd. Limited production was achieved from shallow surface cuts during 1906 (Tenney, 1927-1929).

The Calumet Copper Company also began shipping 40 tons of high-grade (~3% Cu) ore per day from its mine along Calumet Gulch on the east side side of Mineral Creek during 1906 (Ransome, 1919).

Calumet Copper Mining Company, Big Lead Mining and Smelting Company, and the Kelvin Reduction Company were merged in July 1907 to form the Kelvin-Calumet Copper Mining Company. They erected a 35-ton leach plant, designed to recover copper from oxide ores by a secret process invented by H. P. McIntosh. Limited testing commenced in September 1907. Achieving only limited production, this venture was not a financial success (Stevens, 1908).

The Ray Central Copper Mining Company was incorporated in January 1909 under the laws of Delaware with a capitalization of $6 million at $5 per share. Ray Central acquired the assets of Kelvin-Calumet Copper Mining Company in April 1909, exchanging 1 share of Ray Central for 5 shares of Kelvin-Calumet (Stevens, 1909).

Lewisohn interests through the General Development Company acquired an option to purchase a substantial equity interest in Ray Central through financing development activities. However, they relinquished their option in October 1910 on the advice of J. Parke Channing after spending approximately $300,000 (Stevens, 1911).

The assets of the Ray Central Copper Mining Company were acquired by the Ray Consolidated Copper Company through a merger in April 1912, exchanging one share of Ray Consolidated Copper for eight shares of Ray Central (Weed, 1916).

4.3.5 Arizona Hercules Copper Mining Company (1906-1927)

In September 1906, the Arizona Hercules Copper Mining Company was incorporated in the territory of Arizona with capitalization of $10 million at $10 per share. They controlled a 248-acre claim block along the east side of Mineral Creek (Stevens, 1911). In 1910 they began a 27-hole drill program, which delineated a resource of approximately 3 million tons. No further work was performed until August 1915, when the property was reorganized as the Ray Hercules Copper Company (Tenney, 1927-1929).

An examination of the property was performed by Henry Krumb, who reported an ore reserve of 3.43 million tons assaying 2.36% copper in September 1915. Between September 1915 and February 1917, additional drilling was completed, delineating 9.5 million tons, averaging 1.77% copper (Heikes, 1921).

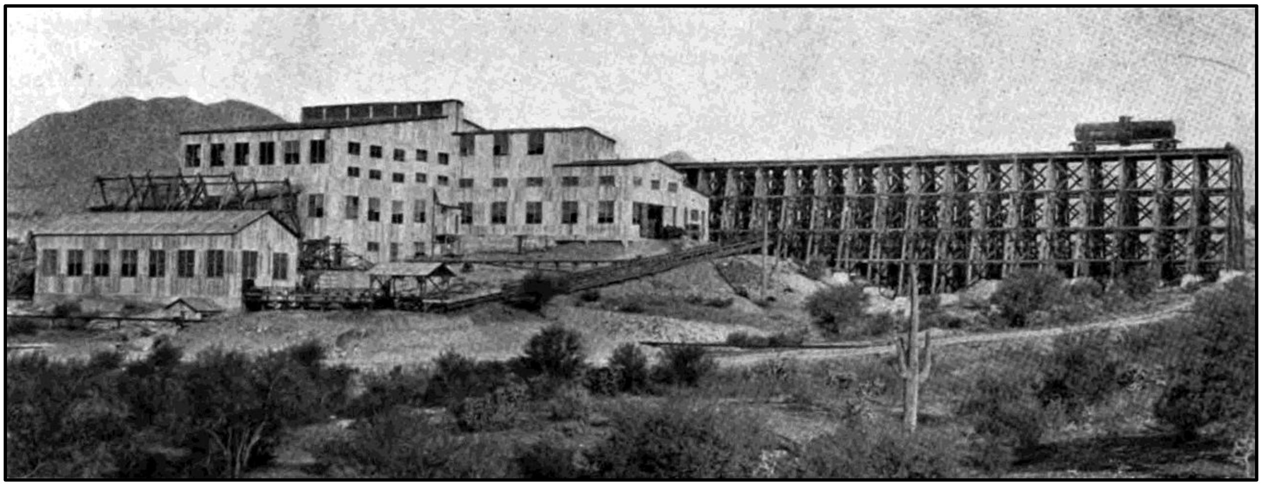


Figure 23. Ray Hercules Concentrator, circa 1920 (photo from Shimmin, 1920).

Efforts to bring the property into production commenced in 1916. Underground development began and a 1,200-ton per day concentrator (Figure 23) was erected at the small settlement of Belgravia (Figure 18), located approximately 0.5 miles north of the Gila River. A 2.2-mile railroad spur was constructed connecting with the Ray and Gila Valley Railroad at Hercules Junction north of Kelvin and a diesel-powered electric power plant was erected with transmission lines linking the mine and concentrator (Tenney, 1927-1929).

Ray Hercules Copper Company achieved production in August 1918. The ore was initially crushed to minus 3-inches at the mine site prior to being transported 5.5-miles via rail to the concentrator. The crushed ore reported to a primary grinding circuit employing 8-foot by 6-foot Marcy ball mills that were operated in closed circuit with a Dorr classifier. The Dorr classifier undersize reported to a combination of flotation

(Callow-type flotation cells) and gravity circuits (jigs and Deister tables) to produce a final concentrate product that was dewatered and shipped to a smelter (Anonymous, 1919).

Intermittent operations continued until May 1920, recovering approximately 7.8 million pounds of copper from 360,400 tons of ore, when high production costs combined with declining copper prices halted all operations (Tenney, 1927-1929). Commencing production too late to take advantage of the high copper prices during World War I, this venture was not a financial success.

In February 1922, the Ray Hercules Copper Company was reorganized as the Ray Hercules Mines, Inc. and resumed production in March 1923 after increasing the capacity of its concentrator to 1,800-tons per day. However, this effort was short-lived with all mining activities being suspended in August 1923 (Tenney, 1927-1929).

The Ray Hercules Mines, Inc. declared bankruptcy and its assets were sold to a stockholder’s protection committee at a sheriff’s sale in November 1924. Nevada Consolidated Copper Company ultimately acquired these assets in February 1927 (Tenney, 1927-1929).

4.3.6 Copper Butte (1900-1971)

Initially evaluated for silver between 1879 and 1881, mining activity at Copper Butte remained idle until July 1900, when the Arizona Copper Mountain Mining Company was organized by Minneapolis interests to develop the property (Figure 20). It had an initial capitalization of $6 million at $10 per share. The Arizona Copper Mountain Mining Company changed its name to Copper Butte Mines in June 1904 (Stevens, 1906).

Early development of the Copper Butte property included approximately 20 small open cuts, six shallow shafts ranging from 30 to 60 feet deep, two deeper shafts (175 and 465 feet deep) and six tunnels ranging up to 300 feet in length. Early development blocked out approximately 5 million tons of ore (Stevens, 1906). After acquiring additional capital during the spring of 1906 production commenced in late 1906 or early 1907. However, operations were halted in October 1907, following the collapse of the price of copper (Stevens, 1909).

Copper Butte Mines patented eight lode claims (June Bug, Cochise, and Butte 1-6) at the site in March 1909. In response to the increased wartime demand for copper, F. C. Armstrong resumed shipments of high-grade oxide ores in 1917. These ores were hauled by truck over a 3-mile dirt road to the Butte Siding (Figure 20) on the Phoenix and Eastern Railroad (now operated by Arizona Eastern Railroad), located on the south side of the Gila River for trans-shipment to American Smelting and Refining's smelter at Hayden (Phelps, 1946). Production at Copper Buttes ceased in January 1919 (Stevens, 1909).

In 1941, Fred Mitchell purchased the Copper Butte property at a tax sale and resumed production from underground workings in February 1942, initially shipping the ore to the International smelter in Miami. Later ore shipments derived from shallow open cuts began in August 1943. These flux ores were hauled by truck to a rail siding at Ray Junction, where it was dumped directly into railroad cars for transport to American Smelting and Refining's smelter at Hayden (Phelps, 1946).

Between October 1944 and April 1945, the U.S. Bureau of Mines completed nine drill holes, totaling 1,274 feet, which was a part of a program designed to improve utilization of natural resources (Phelps, 1946). During 1948, the Walnut Canyon Mining Company drilled eleven holes immediately south of the Copper Butte mine, which encountered erratic copper mineralization, ranging from 1 to 3% Cu that was unprofitable to develop at the time (John and Fountain, 1994).

Intermittent shipments of copper flux ores to ASARCO's Hayden smelter continued until March 1957. After a brief hiatus, lessees resumed intermittent production at Copper Butte, shipping flux to Magma Copper's Superior smelter. Production ceased in May 1971, when the property was sold to the Kennecott Copper Corporation (John and Fountain, 1994).

Table 5. Production data for Copper Butte Mine from 1906-1971 (U. S. Bureau of Mines data).

Period	Ore Treated Short Tons	Cu lbs.	Pb lbs.	Zn lbs.	Mo lbs.	Au Troy Oz.	Ag Troy Oz.
1906-1971	156,396	9,252,199	26,212	0	0	75	4,655

Most of the historic production from Copper Butte was derived from shallow open cuts. Total reported copper production from 1906 through 1971, was about 9.25 million pounds from approximately 156,400 tons of ore (Table 5).

4.4 Ray Consolidated Copper Company (1907-1926)

By 1906, the Mineral Creek mining district had attracted considerable attention among the mining community. In November 1906, J. Parke Channing examined the district's potential for the General Development Company, who had acquired an option to purchase Ray Copper Mines' former holdings from the Anglo-American Copper Company (Figure 21) (Parsons, 1933).

Organized in January 1906, the General Development Company had been formed by Adolph Lewisohn for the purpose of acquiring and developing promising mineral properties, especially those having a potential for low-grade, bulk-tonnage copper deposits. Concerned the presence of substantial amounts of oxide copper minerals mixed with chalcocite would make it difficult to process the ore, Channing advised General Development to allow its option to lapse (Parsons, 1933).

Seeley Mudd and Philip Wiseman negotiated an option on Ray Copper Mine's former holdings from Anglo-American Copper Company in December 1906, and took the property to Sherwood Aldrich of Colorado Springs. Through Aldrich, Daniel Jackling, Charles MacNeill, Spencer Penrose, and others (Figure 24), who had been involved with the development of the Utah Copper Company, formed the Ray Consolidated Copper Company and the Gila Copper Company, which acquired the former holdings of Ray Copper Mines Ltd.

Figure 24. Daniel C. Jackling (1869-1956) (left, photo from Parsons, 1933), and Spencer Penrose (1865-1939) (right, photo from Wikipedia).

The Gila Copper Company was organized in February 1907, to purchase a number of mining claims that the English owners declined to sell to Ray Consolidated Copper until certain stipulations had been carried out. In May 1910, more than 97% of its outstanding stock was exchanged for stock of Ray Consolidated Copper Company at an exchange rate of three shares of Gila Copper for one share of Ray Consolidated (Ransome, 1919).

Ray Consolidated Copper Company was organized in May 1907 under the laws of Maine with an initial capitalization of $6 million at $10 per share (Stevens, 1909). Its capitalization was subsequently increased to $8 million in August 1908, $10 million in July 1909, $14 million in May 1910, and $16 million in March 1912 (Ransome, 1919).

Unwilling to make the same mistake that befell Ray Copper Mines Ltd., this effort arranged the first $250,000 of their investment be used for mine development. An underground mine development program under the direction of Seeley Mudd began during the summer of 1907. Initial efforts employed as many as 600 miners to sink shafts and drive adits. However, none of this activity had penetrated the barren leach cap and reached ore before the Panic of 1907, which resulted in a temporary halt of all development activity in October 1907.

At this time, management began seeking more economical ways to explore its holdings. Having had experience with churn drilling on porphyry copper deposits near Ely, Nevada during 1906, Seeley Mudd acquired two Keystone drills in early 1908 (Parsons, 1933). Underground exploration activities were subsequently discontinued and by June 1908, approximately 3 million tons of ore, assaying 2.4% copper had been delineated (Ransome, 1919).

A churn drill is a type of percussion drill, which was employed to bore a vertical hole in relatively soft rock. Powered by steam or gasoline, it was composed of a string of tools, consisting of a tempered steel bit attached to a heavy stem, which was attached to a rope or wire cable that was repeatedly raised and allowed to drop, pulverizing the rock in the bottom of the hole with successive blows. Capable to drilling to depths of up to 1,500 feet, samples in the form of sludge were bailed or pumped out at 5-foot intervals to determine rock type, mineralogical composition, and tenor of the ore (Parsons, 1933).

Concerned about the objectivity of the property evaluation, Seely Mudd and Daniel Jackling decided that the sampling of the deposit and ore reserve estimation by churn drilling should be supervised by an independent outside engineer. Henry Krumb was placed in charge of the Ray exploration program in August 1908 (Parsons, 1933).

The churn drilling program was laid out in a checkerboard fashion with drill holes located at the corners of 200-foot squares. As of November 1910, 353 drill holes, totaling 147,449 feet were completed, delineating 77,314,470 tons of ore, averaging 2.17% copper (Ray Consolidated Copper Company, 1912). This was the first time churn-drilling and churn drill samples were employed as the principal basis to estimate the size and grade of a major copper ore body (Parsons, 1933).

Ray Consolidated Copper Company erected offices, a boarding house and other dwellings on its property to accommodate its operating staff as well as approximately 100 other workers (Ray Consolidated Copper Company, 1910). The existing Ray Copper Mines' concentrator at Kelvin was refurbished and enlarged to 300-tons per day. It was employed to gather metallurgical data from processing developmental ores that was used to design their commercial facility (Rickard, 1932).

The search for a potential site suitable for a commercial concentrator began during 1909. Two major criteria used to make this selection were an ample supply of water and an adequate area for the disposal of 100 million tons of mill tailings, neither of which was present at the mine site. After evaluating potential sites up and down the Gila River as far west as Florence, a site near Winkelman was selected (Parsons, 1933). Located thirteen miles up the river from Kelvin, Ray Consolidated Copper purchased approximately 4,000 acres of land for its mill and smelter (Ray Consolidated Copper Company, 1909). At this location, the company town of Hayden was established to provide housing and infrastructure for workers at its milling and smelting facilities (Figure 20).

The existing narrow gauge rail line from Ray to Kelvin was replaced by a standard gauge line over a new route using 80-pound rail in December 1909 (Ray Consolidated Copper Company, 1909). Ray Consolidated Copper Company's wholly-owned subsidiary, Ray and Gila Valley Railroad was organized in June 1910 to operate the 6.5-mile segment connecting the mine and Ray Junction (formerly Kelvin). In July 1910, an agreement was reached with the Arizona Eastern Railroad to handle ore cars from Ray Junction to Hayden Junction. From that point, another 2.5-mile segment owned by the Ray and Gila Valley Railroad provided access to the concentrator and smelting facility (Irvin, 1987).

In early 1910, Louis S. Cates was transferred from Utah Copper to Ray to organize its operating staff (Figure 25). Initially serving as superintendent of mines, he became the general manager in 1913. One of his first tasks was to develop a suitable method of mining the ore. Like early operations at Miami and Inspiration, the barren leach cap at Ray was too thick to be economically removed by open pit methods. It was decided to use a combination of shrinkage and caving methods to recover the ore. While caving techniques had been employed previously at Bingham Canyon and Morenci, Ray was the first porphyry copper operation to produce 8,000-tons of ore per day using caving methods (Parsons, 1933).

When construction began, Ray Consolidated Copper Company had planned to treat concentrates from Ray at its own smelter, which it planned to erect adjacent to its concentrator at Hayden. However, after the first section of the 8,000-ton/day Hayden concentrator was commissioned in March 1911, an agreement was reached that transferred the Hayden smelting operations to the American Smelting and Refining Company (ASARCO). Copper concentrates from Ray were shipped to ASARCO's smelter in El Paso, Texas until its Hayden smelter was commissioned in May 1912. After that date, its copper concentrates were smelted at the Hayden facility on a toll basis under a very favorable long-term contract (Parsons, 1933).

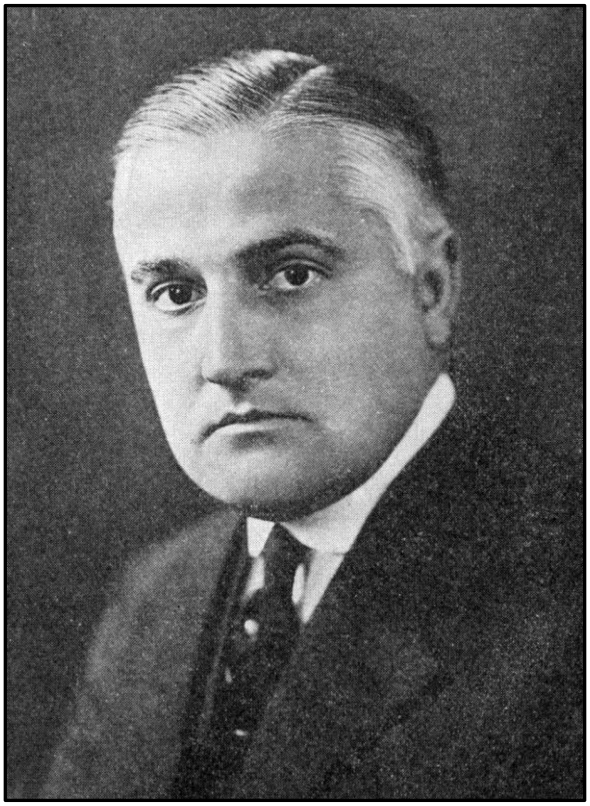


Figure 25. Louis S. Cates (1881-1959) was the general manager at Ray from 1913 until 1919, and later became president of Phelps Dodge Corporation (1930-1947) (photo from Parsons, 1933).

As of December 31, 1911, expenditures on property and development totaled approximately $14.6 million. This included the original property acquired from Ray Copper Mines Ltd. in 1907 ($5.2 million), Gila Copper property acquired in 1910 ($1.9 million), refurbishing and enlarging the existing concentrator at Kelvin ($0.6 million), equipment and construction expenditures at the Ray site ($1.3 million), capital and deferred charges for mine development ($2.1 million) and equipment and construction costs at the Hayden plant site ($3.2 million) (Ray Consolidated Copper Company, 1912).

In June 1912, Ray Consolidated Copper Company acquired the assets of the Ray Central Copper Mining Company, including an ore reserve of 5,590,000 tons, assaying 2.51% copper. Of this total, 446,000 tons was relatively higher grade, averaging 5.3%

copper. This transaction consolidated all of the properties in the Mineral Creek mining district under a single management, except those held by Arizona Hercules Copper Mining Company (Ray Consolidated Copper Company, 1913).

4.4.1 Underground Mining Operation

The initial production was derived from a relatively flat-lying, blanket-like zone of secondary enrichment that straddled Copper Canyon. Measuring 7,000-feet long by 1,500-feet wide, the ore body ranged from 40- to 400-feet in thickness (averaged 120-feet) and was overlain by 40- to 600-feet of barren leached cap. It occurred within two connected lobes with 40% of the reserves in the eastern mine accessed by the Ray No. 1 shaft and 60% in the western mine accessed by the Ray No. 2 shaft (Figure 26) (Thomas, 1929).

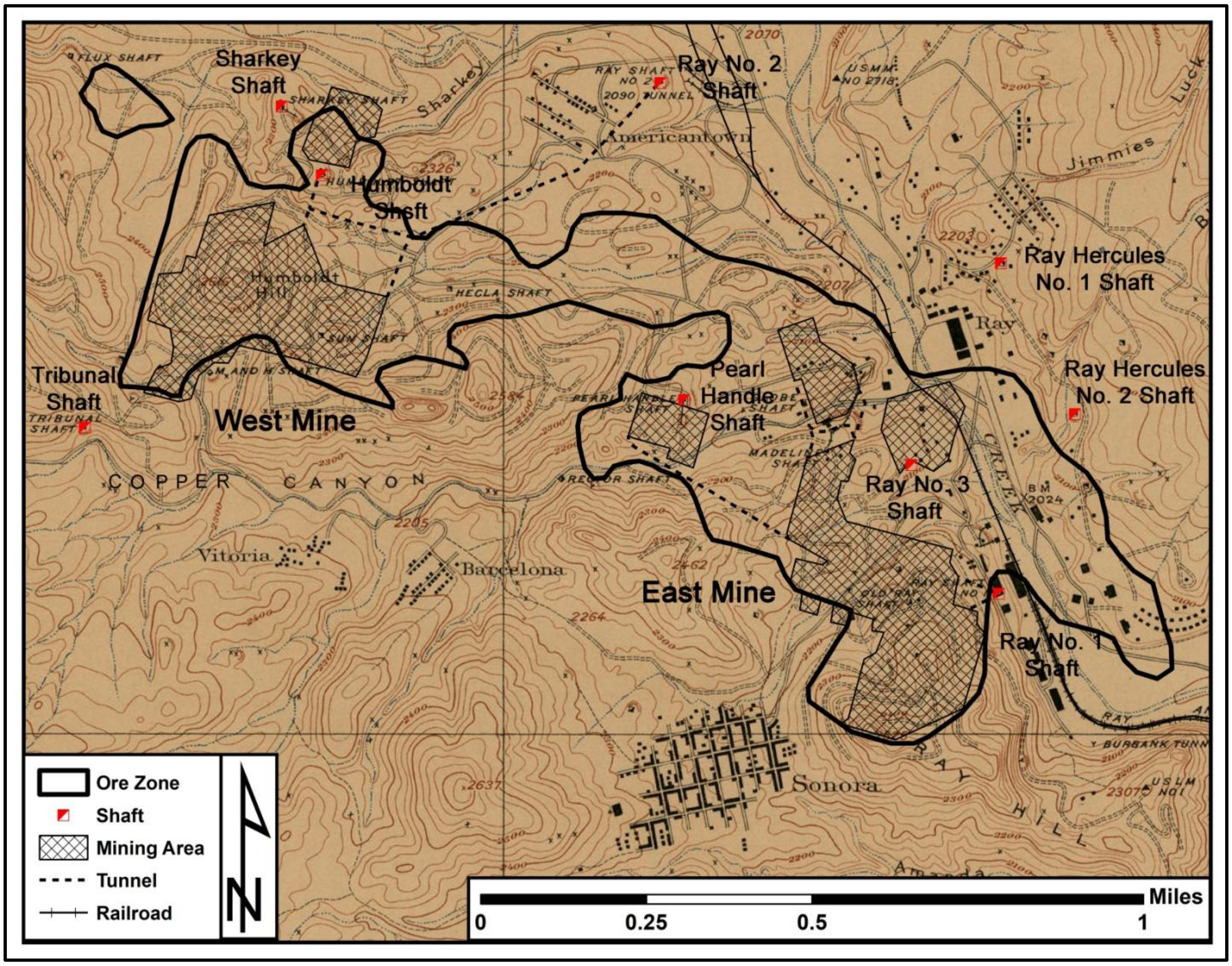


Figure 26. Topographic map showing the enriched ore body, underground mining areas, major shafts, railroad, and mining camps (modified from Ransome, 1919).

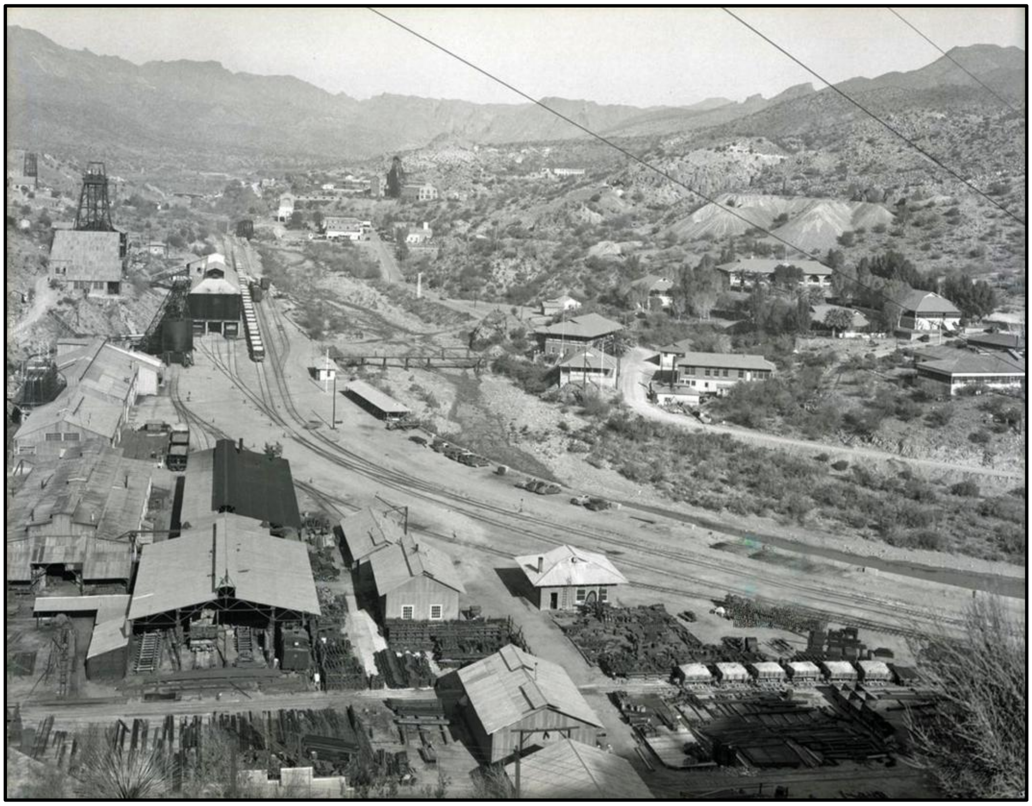


Figure 27. Headframe, crusher, ore bins, warehouses, and support facilities at the Ray No. 1 mine, looking north with town of Ray in the distance, circa 1930's (photo from Arizona State University Library Digital Repository).

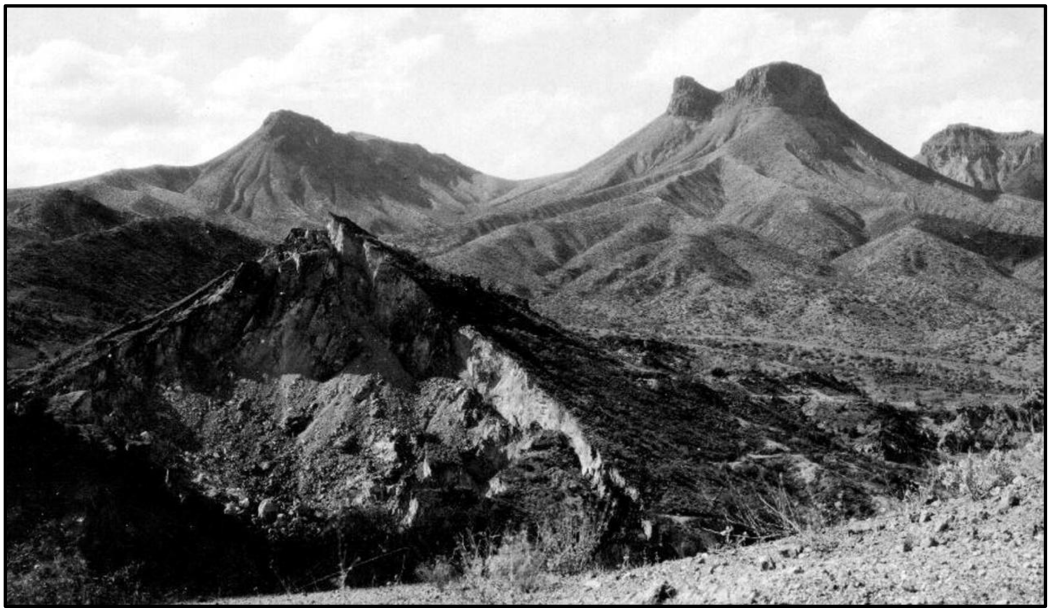


Figure 28. Humboldt Hill viewed from the south shows effect of block caving operation with Teapot Mountain in background, circa 1912-1916 (photo from U. S. Geological Survey).

Most of the underground ore production was hoisted through two concrete-lined, vertical production shafts. Located along the eastern edge of the ore zone, the 400-foot, three-compartment Ray No. 1 shaft had four levels at 171-feet, 221-feet, 271-feet, and 321-feet (Figure 27). Located approximately 4,000-feet north of the Ray No. 1 shaft, the 359-foot two-compartment Ray No. 2 shaft was used to develop the western ore body. Limited high-grade ore production was also hoisted by the Ray No. 3 shaft. Each production shaft was equipped with an electric hoist that employed two 12.5-ton skips operated in counter-balance. A 30-degree inclined three-compartment shaft, located adjacent to each production shaft, was used for handling men, equipment and supplies. Additional shafts were employed for ventilation and other purposes (Stevens, 1911).

Employing an undercut block-caving method to extract ores (Figure 28), the Ray Consolidated Copper mine was the first operation in the southwest to employ a caving system of mining on a large scale (Thomas, 1929). High-grade ores accessed by the Ray No. 3 shaft were extracted by more labor intensive square-set stoping methods (Ransome, 1919).

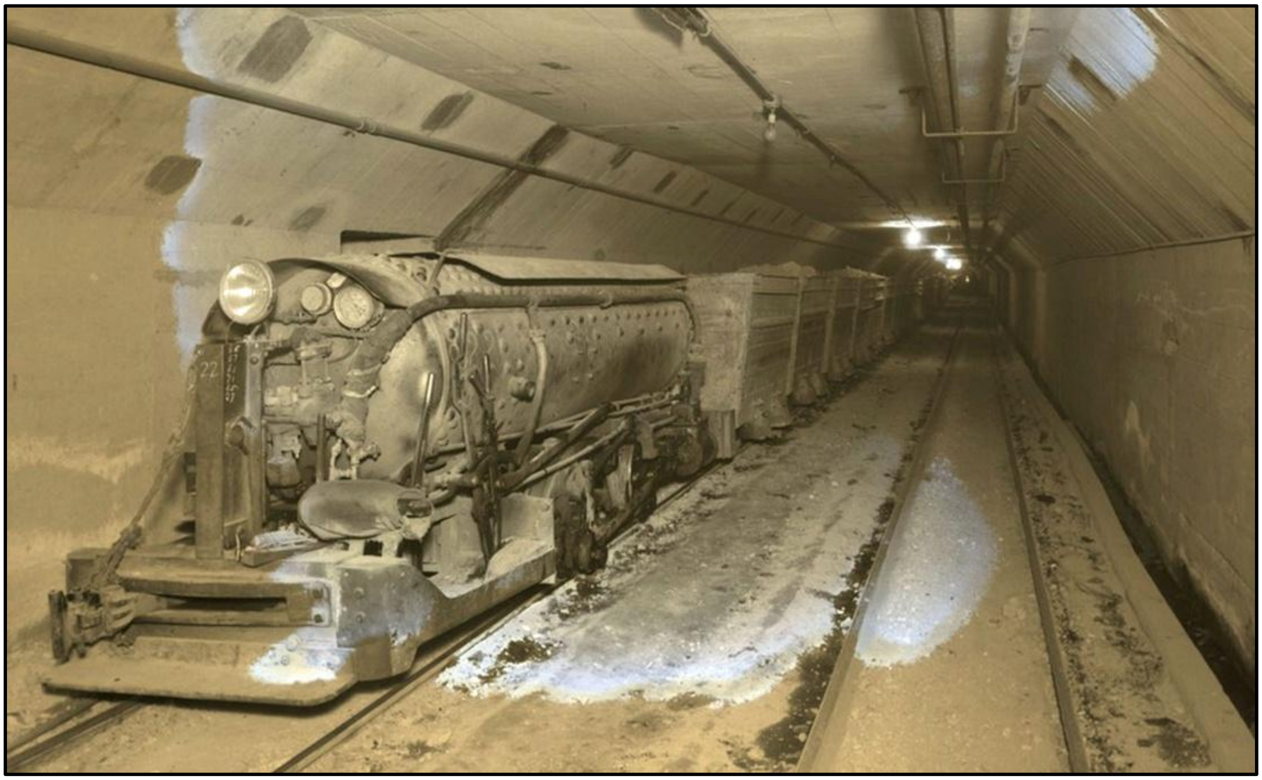


Figure 29. Compressed air locomotive and ore train at Ray, circa 1930s (photo from Arizona State University Library Digital Repository).

Caving operations at Ray experienced several problems related to the inconsistent competency of the ore. Portions of the ore body were unusually hard, making it difficult to cave, requiring mine workings that were larger and more numerous to achieve proper caving. In other areas softer ores caved well, but had a tendency to swell when exposed to air. Added expense of repeatedly replacing timbers in drifts, where pressure became excessive, lead to the extensive use of reinforced concrete to support permanent haulage ways (Parsons, 1933).

Underground haulage employed trains consisting eight-ton compressed air locomotives with twenty to twenty-five 4.5-ton ore cars that transported the ore to a storage bin, located adjacent to the production shaft (Figure 29) (Thomas, 1929).

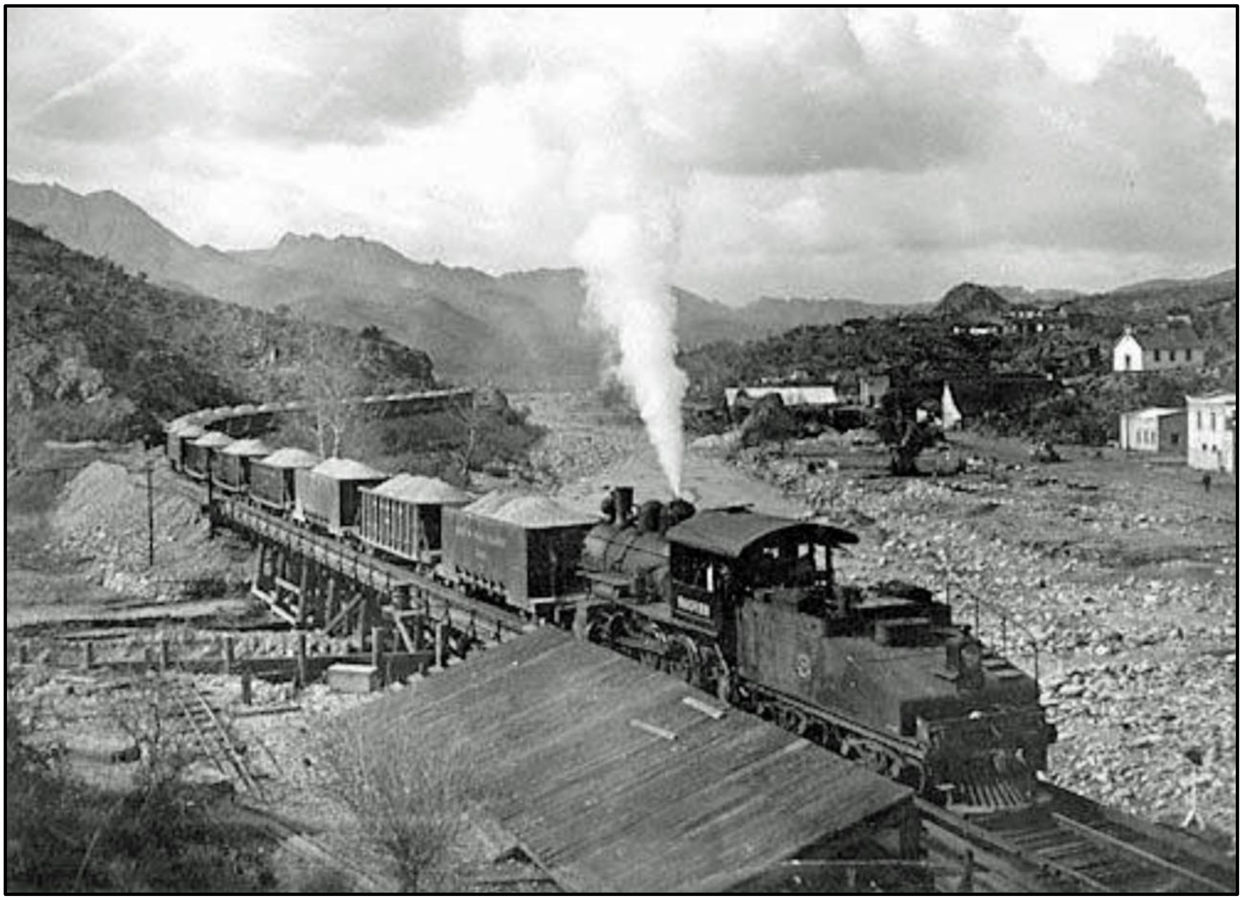


Figure 30. Crushed ore shipment leaving Ray for the Hayden concentrator, circa 1915 (photo from Northern Arizona University, Colorado Plateau Digital Collections).

At the surface, self-dumping skips delivered the ore to a 400-ton steel ore bin, which fed primary crushing plants that were located adjacent to the each of the production shafts (Figure 27). The crushed ore (minus 1-inch) reported to a 12,000-ton crushed ore bin from which it was loaded into 60-ton rail cars for transport to the Hayden concentrator, a distance of approximately 20 miles (Figure 30) (Thomas, 1929).

4.4.2 Hayden Concentrator

As of December 31, 1911, 5 of the 8 sections of the 8,000-tons/day Hayden concentrator were in operation (Figure 31). Over the next 18 months, production slowly rose with the seventh and final sections of the mill completed in January 1913 and October 1913, respectively, bringing the facility to full capacity (Heikes, 1914).

Milling operations at the Hayden concentrator initially employed a fine crushing circuit (16 sets of 10-inch Garfield rolls) followed by a single-stage grinding circuit, consisting of twenty-four 6-foot diameter Chilean mills. Ground ore was passed through a gravity circuit (i.e., Garfield roughing tables, Wilfley tables, Frue vanners and horizontal-motion suspended vanners) to produce a final copper concentrate (Stevens, 1911). Overall copper recovery was approximately 65 to 70% (Garms, 1930).

Figure 31. Hayden Concentrator, circa 1911 (photo from Edholm, 1911).

Increasing copper prices resulting from the rising demand for copper following the onset of World War I in July 1914, spurred production at Mineral Creek. Ray Consolidated Copper increased the capacity of its Hayden concentrator to 10,000-tons/day during the fall of 1915 (Ray Consolidated Copper Company, 1916).

In 1914, modifications to the milling process included the introduction of Janney mechanical flotation cells to treat tails from the gravity circuits, raising copper recoveries to 75%. Thickeners and vacuum filters were installed to dewater the flotation concentrates. Lengthy litigation with the Minerals Separation North American Corporation, who held patents on this process, was settled in 1922 (Parsons, 1933).

Ore production peaked during the summer of 1917. The addition of ball mills to augment the existing grinding circuit during 1918 further improved extraction (Figure 32) (Garms, 1930). During 1920, an alkaline circuit, employing soda ash and trona was introduced to protect milling equipment from corrosion by copper sulphate (Parsons, 1957).

With the signing of the Armistice in November 1918, the demand for copper abruptly declined. In order to avoid a large surplus of unsold copper, Ray Consolidated Copper reduced production and operations approximately 50% in January 1919 (Weed, 1922). This resulted in a sharp decline in copper production from 84.7 million pounds during 1918 to 46 million pounds in 1919.

Over the next two years, the price of copper fell from 20 cents per pound in January 1919 to 12.5 cents per pound, when production was suspended during the first week in April 1921. Although the mine and mill facilities were well maintained during this shutdown, the company was forced to lay off much of its experienced workforce during the closure.

Figure 32. Ball mill grinding circuit at Hayden concentrator, circa 1930s (photo from Arizona State University Library Digital Repository).

On resumption of operations in April 1922, Ray Consolidated Copper Company had to rebuild its workforce and restore the efficiency of the mine and milling operation (Ray Consolidated Copper Company, 1923). Copper production was further impacted by the oxidation of broken ore within mine during the shutdown, making it less amenable to recovery by flotation (Parsons, 1933). Copper recoveries gradually improved as the partially oxidized ore was mined and processed over the next several years.

Figure 33. Flotation circuit at Hayden concentrator, circa 1930s (photo from Arizona State University Library Digital Repository).

Ore production rose steadily as additional improvements were made to the Hayden concentrator. The Garfield and Wilfley concentrating tables and Chilean mills were replaced by Deister concentrating tables and ball mills, increasing production capacity of the facility from 10,000- to 12,000-tons/day in 1924. By 1926, all gravity concentrating equipment had been replaced with Chino flotation cells (Figure 33). Lime was substituted for soda ash and crude trona as an alkalizing agent. This reduced the amount of pyrite contained within the final concentrate product, increasing its copper content (Parsons, 1957).

Table 6. Ray Consolidated Copper Company production data from 1909-1926 (U. S. Bureau of Mines data)

Period	Milled & Direct Smelting Ore Short Tons	Cu %	Cu in Concentrate & Direct Smelting Ore lbs.	Precipitate Cu lbs.	Total Cu lbs.	Au Troy Oz.	Ag Troy Oz.
1909-1926	35,184,315	1.65	839,406,412	0	839,406,412	11,093	827,909

In June 1926, the Nevada Consolidated Copper Company acquired the Ray property through its merger with Ray Consolidated Copper Company. As of June 1926, approximately 35.2 million tons of ore, assaying 1.65% copper was mined at Ray, recovering about 839.4 million pounds of copper (Table 6).

4.5 ASARCO’s Hayden Smelter

When Ray Consolidated Copper Company decided to proceed with the development of its Ray property, it envisioned erecting a smelter to treat the copper concentrates from its Hayden concentrator (Parsons, 1933). The proposed facility was initially designed to employ two to three 500-ton water-jacketed blast furnaces to treat coarse ores and five or more 300-ton reverberatory furnaces to treat fine concentrates. An intermediate matte product, containing about 40% copper was planned to be upgraded to a nearly pure blister product by Peirce-Smith converters (Edholm, 1911).

American Smelting and Refining Company, who treated Utah Copper’s concentrates at its Garfield smelter, expressed an interest in assuming control of the smelting operations at Hayden. After a long period of negotiations, they reached an equitable agreement with Ray Consolidated Copper. Under the terms of this agreement, concentrates were treated on a “cost plus” basis, with the smelter’s profits based on a certain fixed margin over and above cost. The copper was smelted on a toll basis, where the refined copper is sold for the account of Ray Consolidated Copper as opposed to the ordinary custom basis under which the concentrate was sold to the smelter at the current market price for the metal (Parsons, 1933).

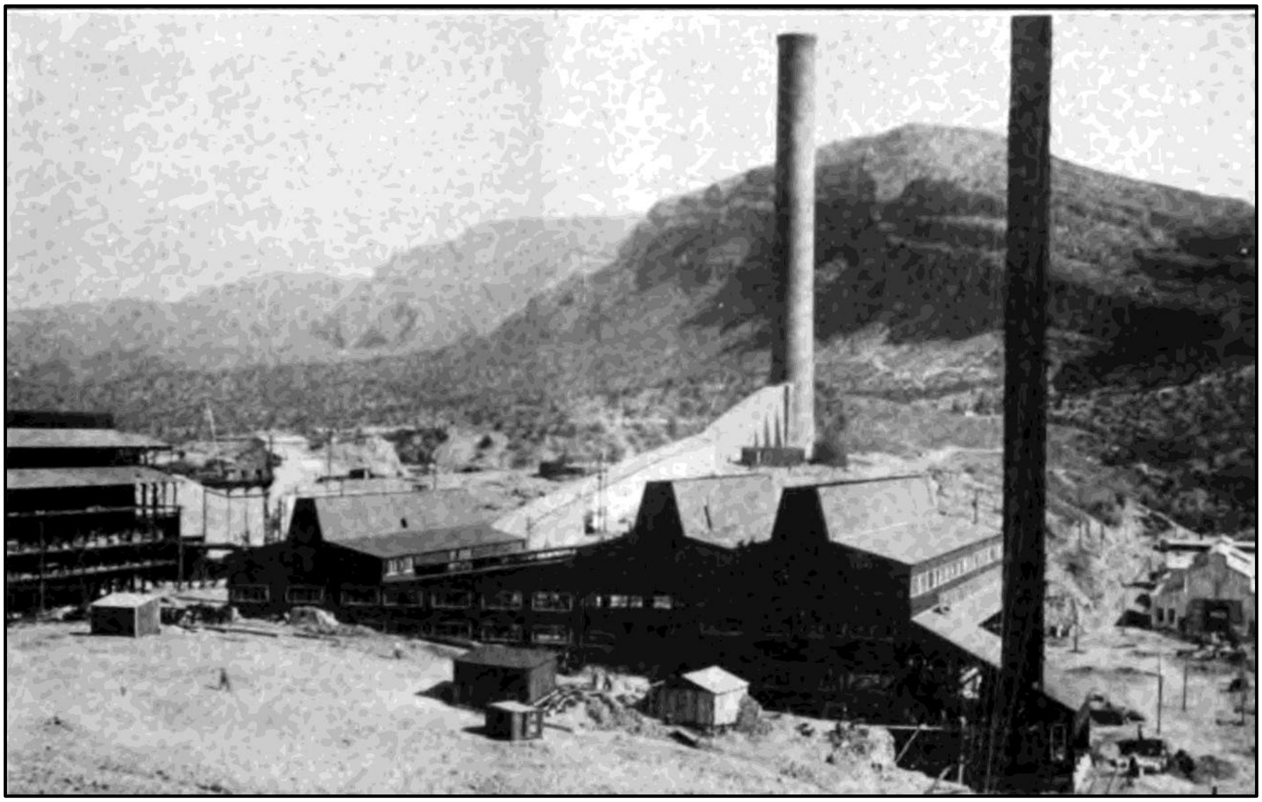


Figure 34. ASARCO’s Hayden smelter, circa 1912 (photo from Clifford, 1912).

Smelter construction began in September 1911. The Hayden smelter was commissioned in May 1912 at a cost of $1.6 million (Figure 34). Designed to treat concentrates from the Ray mine, this facility included eight 24-foot McDougal roasting furnaces, two 20-foot by 112-foot, oil-fired, reverberatory furnaces, and two 25.8-foot long by 10-foot diameter Pierce-Smith converters (Clifford, 1912). It was the first smelter to be constructed in Arizona without a blast furnace. Its main stack, measuring 300 feet high by 25-foot in diameter, was designed to handle emissions from the reverberatory furnaces and roasters (Vail, 1914). A second 250-foot stack was added to the facility in 1918 to discharge converter gases (CH2MHILL, 2008).

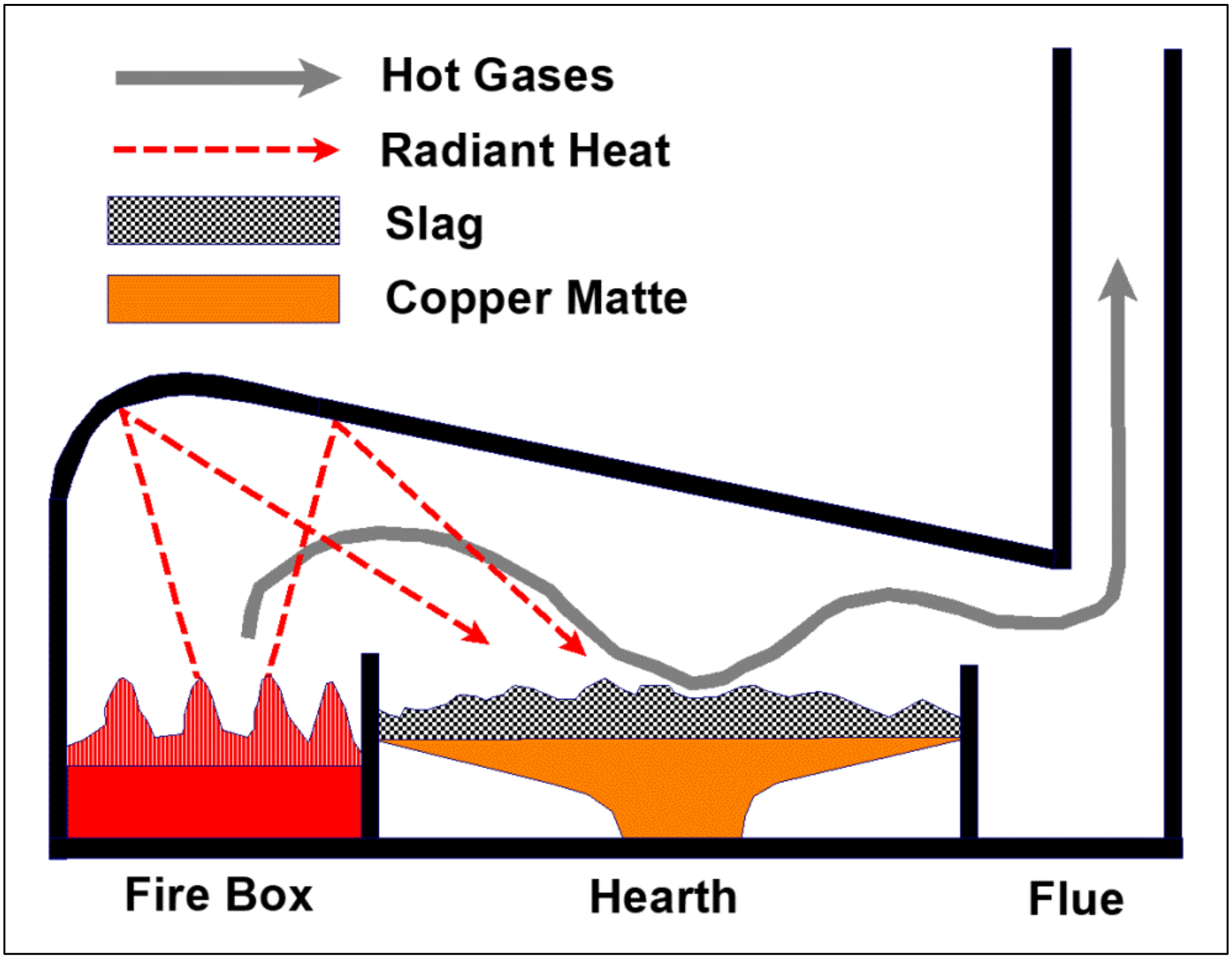


Figure 35. Simplified Schematic Sketch of a Reverberatory Furnace (modified from Anonymous, 2005).

First employed in England during the late 17th century, reverberatory smelting was initially introduced to the North American copper industry at Butte, Montana around 1880. Initially fired by wood, these furnaces were later modified to use coal, oil and natural gas. During the early 1900s reverberatory smelting replaced the blast furnaces that had been previously employed at many Arizona mines. It was found to be better suited to process the fine copper concentrates being recovered at that time (Rickard, 1987).

Copper concentrates from the Hayden concentrator were initially treated in eight roasting furnaces to produce a calcine product, prior to being fed with fluxing agents to two oil-fired reverberatory furnaces. Unlike, blast furnaces, where the fuel was combined with the ore and fluxing agents, it was kept a separate compartment within reverberatory furnaces (Figure 35). Radiant heat from the fire box melted the smelter charge in the hearth, producing copper-rich (i.e., matte) and copper-poor (i.e., slag) fractions. The denser matte fraction sinks to the bottom of the hearth, while the lighter slag fraction floats on top of the denser matte. The slag was disposed of, while the copper matte was further upgraded in a converter.

Figure 36. Molten copper from the converter was poured into the casting wheel to produce 275- to 300-pound ingots of unrefined blister copper, circa 1930s (photo from Arizona State University Library Digital Repository).

ASARCO’s Hayden smelter produced an unrefined blister copper product (~98% copper) that was cast into 275- to 300-pound ingots (Figure 36) that were shipped to electrolytic refineries in Baltimore, Maryland and Maurer, New Jersey.

5 EARLY COMPANY TOWNS AT MINERAL CREEK (1906-1965)

Both the Ray Consolidated Copper Company and Arizona Hercules Copper Mining Company established town sites on company-owned lands adjacent to active mining areas, where businesses that supported the community and workers resided (Figure 37).

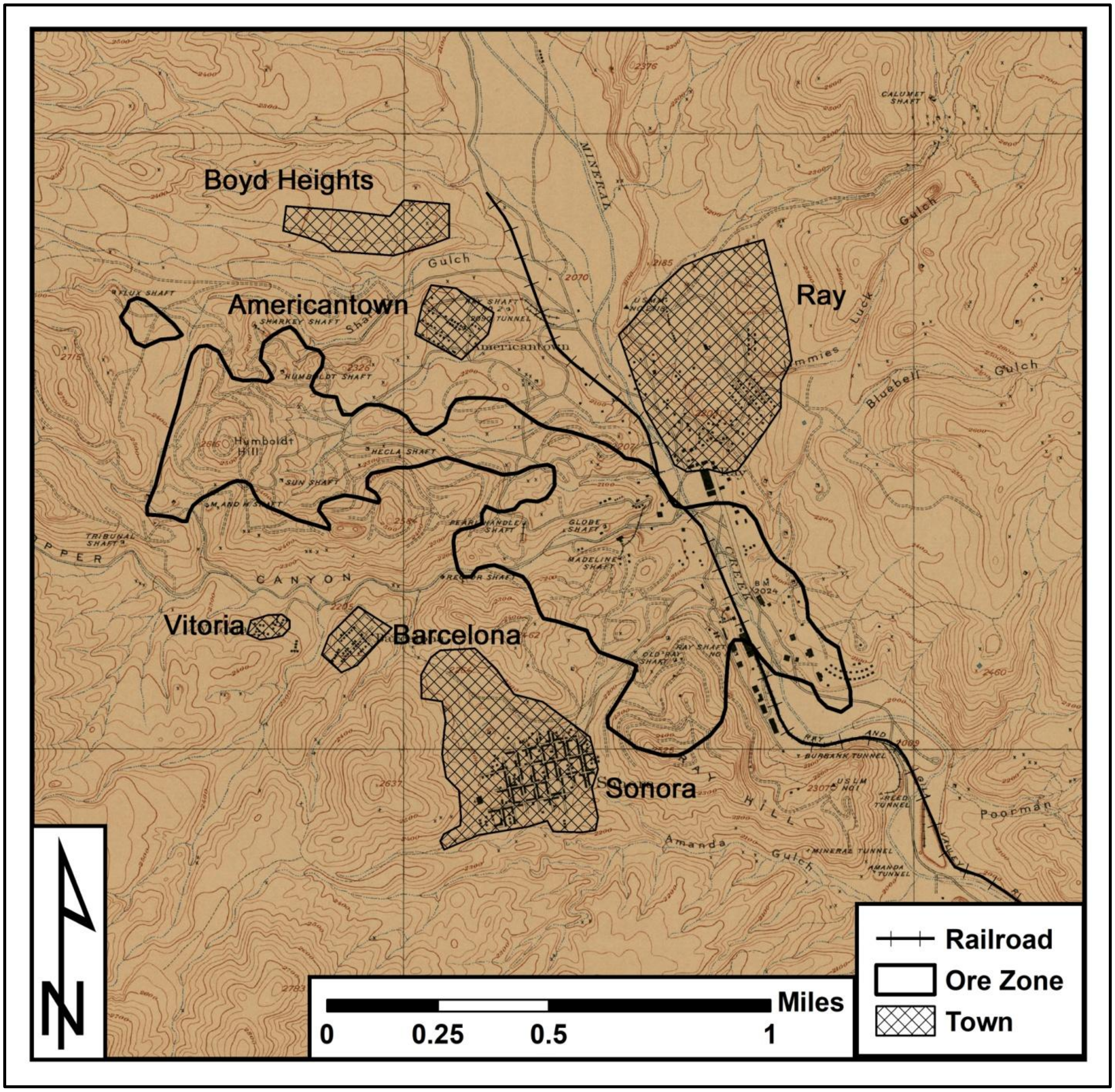


Figure 37. Topographic map showing company-owned town sites developed along Mineral Creek, circa 1910-1920 (Ransome, 1919).

Mine workers recruited from Mexico began arriving in the mining district around 1906. They settled in the community of Sonora, which was located immediately south of the mine area (Figure 38). European miners from Spain created their own enclave of Barcelona northwest of Sonora, while Apache miners resided in Vitoria (Figure 39). Residents of these communities leased the property where they built their homes and businesses (Seefeldt, 2005).

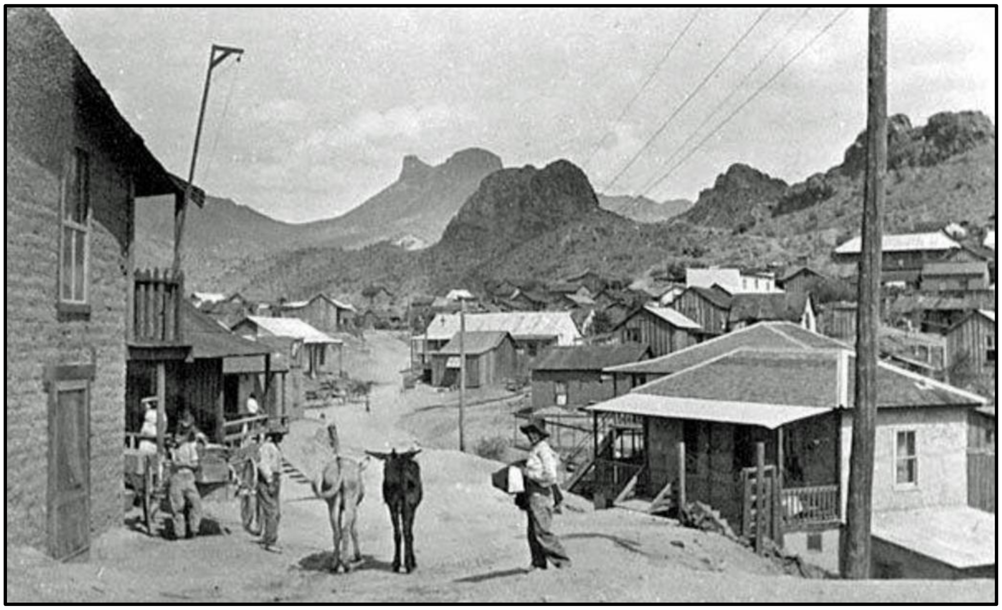


Figure 38. Sonora, Arizona, looking northwest toward Teapot Mountain in distance, circa 1917 (photo from Northern Arizona University, Colorado Plateau Digital Collections).

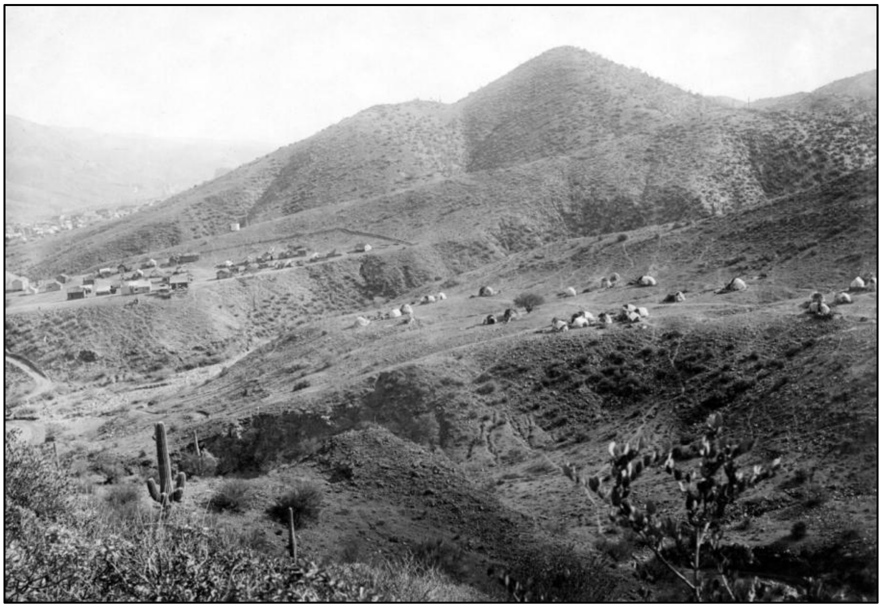


Figure 39. Barcelona (in foreground at far left) and Vitoria (right) mining communities at Mineral Creek, looking SSE toward Sonora Hill, circa 1910 (photo from Ransome, 1919).

Sonora resembled communities of Old Mexico. Spanish was spoken. All of the signs and storefronts of the community were in Spanish. Its culture emphasized strong family ties and tradition with little concern on outward appearances; their homes and stores appeared to be ramshackle, but once inside they were spotlessly clean and orderly. Catholics in the mining district attended church in the nearby town of Sonora (Figure 40). By the 1920s, the population of this thriving community rapidly grew to approximately 6,000.

Figure 40. Catholic Church at Sonora, Arizona, circa 1917 (photo from Northern Arizona University, Colorado Plateau Digital Collections).

English speaking employees resided north of the mine site at Ray, Americantown and Boyd Heights (Ransome, 1919). Its population peaked at approximately 5,000 during World War I (Figure 37).

Ray Consolidated Copper exercised some authority with regard to town’s inhabitants, business conducted, character of the buildings, and sanitary regulations. Unlike Morenci, there were no company-owned stores at Ray. Company-owned buildings in Ray’s single-block business district were leased to merchants. There were grocery, drug, and department stores, two banks, a bakery, butcher shop, movie theatre, restaurant, hotel, post office, two dentists, and jewelry store. It had a hospital, school, and four churches; an Episcopal church (1909-1929), Baptist church, Methodist church, and Mormon church.

Figure 41. Company housing at Boyd Heights (?), circa 1930s, (photo from Arizona State University Library Digital Repository).

Workers' residences (Figure 41) consisted of uniform brick and frame housing rented from the mining company. These homes were furnished with many modern conveniences, including hot and cold water, electric lights and sanitary facilities (Anonymous, 1918).

Ray Consolidated Copper also provided recreational facilities for its employees, including a large club house with a reading room, gymnasium, library, billiard and pool hall, and a ball room, where dances were held weekly (Anonymous, 1918). Baseball games were the community's most important Sunday events. Mariachi bands commonly added flavor to the festivities. Competition was intense with opponents including teams from Hayden, Superior, Miami, Casa Grande, Nogales, and Tucson (Machula, 2012).

6 HAYDEN, ARIZONA (1910-1956)

The mining community of Hayden was established in 1910 to provide the infrastructure required by workers at Ray Consolidated Copper's concentrator and ASARCO's smelting facility (Figure 42). Laid out on three distinct hills, the central hill was the site for the concentrator, business district, school, and Anglo residential housing. To the east was ASARCO's smelter and housing site. On the west side was Barrio San Pedro, where Mexican-Americans resided (Machula, 2012).

Hayden's business district was centered on Hayden Avenue, where there was a grocery store, dry goods store, drug store, café, bank, service station, pool hall, movie theater, butcher shop, bakery, and barber shop (Machula, 2012).

Being a company town, jobs and housing were linked. Anglo workers rented company-owned housing with modern conveniences including electric and sanitary services (Sicotte, 2009). If a worker lost his job, he also lost his home. When a worker retired, he moved. There were never many very old people or many seriously poor in company towns (Machula, 2012).

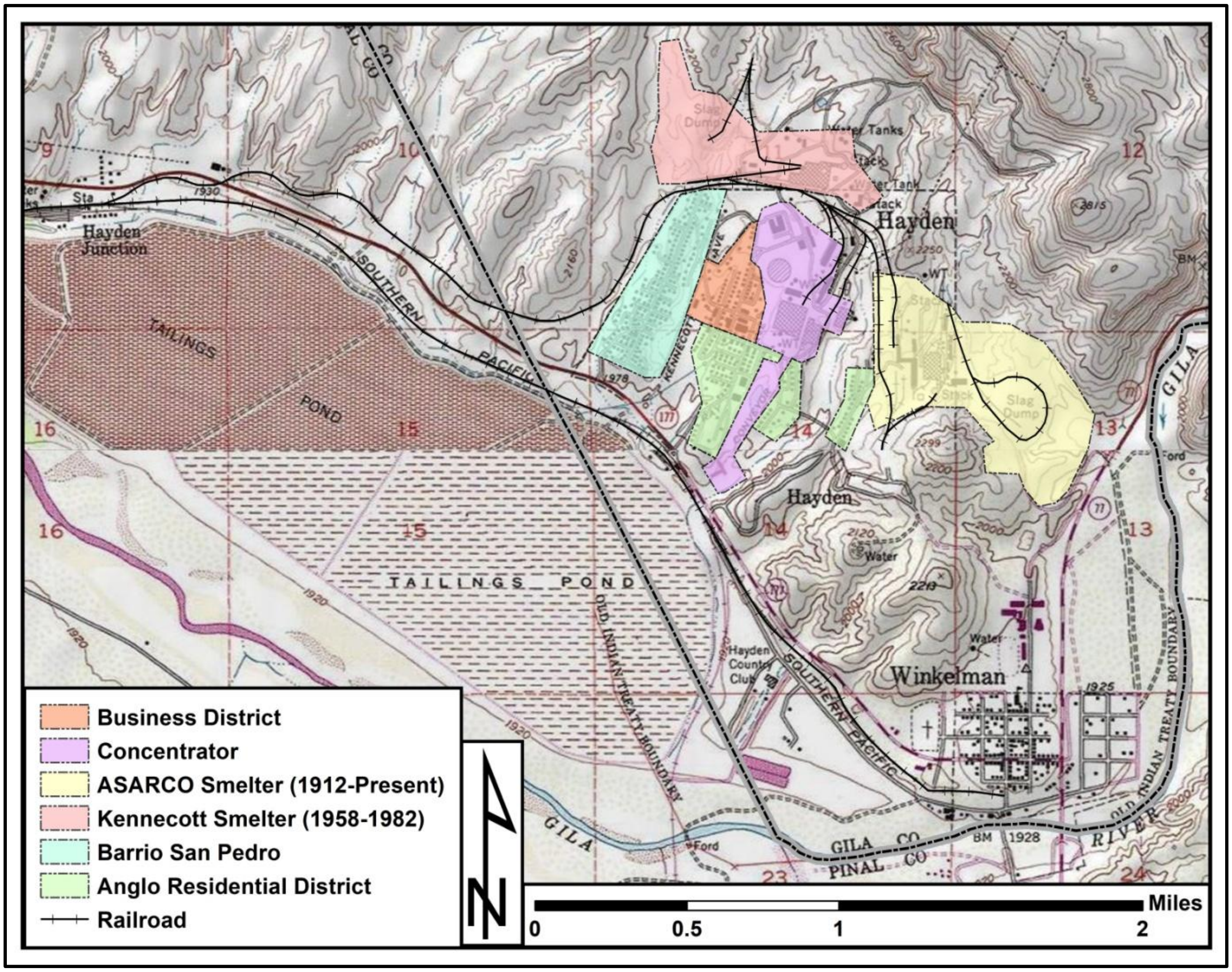


Figure 42. Topographic map showing location of concentrator, smelters and business and residential districts of Hayden Arizona (modified from Sicotte, 2009).

The neighboring Hispanic barrio of San Pedro differed in this respect. Each household acquired a long-term lease on a plot of ground from Ray Consolidated Copper on which they erected their home (Machula, 2012). This community remained without electric service and lacked indoor plumbing until the 1960s (Sicotte, 2009).

7 NEVADA CONSOLIDATED COPPER COMPANY (1926-1933)

The Nevada Consolidated Copper Company acquired the Ray property through its merger with Ray Consolidated Copper Company in June 1926. Under the terms of this transaction, $46.2 million in 5% debenture bonds were issued by Nevada Consolidated Copper in exchange for the Ray assets, with Nevada Consolidated assuming all of Ray's outstanding obligations. These bonds were convertible into Nevada Consolidated stock on the basis of one share for each $15 debenture until July 1, 1927 and were thereafter callable at par on 60 days notice. More than half of the debentures were converted during 1926 and most of the remainder during 1927 (Parsons, 1933).

Groundwater was never a major issue for the early underground mining operations at Ray. Electric-powered triplex pumps were employed to extract approximately 160-gallons per minute from the Ray No. 1 Shaft and 40-gallons per minute from the Ray No. 2 shaft (Thomas, 1929). During 1926, Nevada Consolidated Copper began treating this mine water in launders where 30,000 to 90,000 lbs. of copper were precipitated annually onto scrap iron.

Nevada Consolidated Copper acquired the assets of the Ray Hercules Mines Company in February 1927, consolidating all of the properties in the Mineral Creek district under a single management.

Operation of the Deister tables, employed to treat coarse sand fraction of the mill feed was discontinued in 1927 (Garms, 1930). The fine crushing rolls were replaced by eight 9-foot by 12-foot rod mills during 1929 (Parsons, 1957).

From the resumption of operations in April 1922, Ray's copper production climbed to 74.7 million pounds in 1925. Ore production reached its peak of 3.6 million tons of ore in 1929. However ore grades declined significantly from 1.52% copper in 1926 to 1.09% copper in 1929, resulting in an 11% decline in total copper production.

Following the crash of the stock market at the onset of the Great Depression in October 1929, copper prices began falling from 17.8 cents per pound in March 1930 to 10.3 cents per pound by December 1930, prompting Nevada Consolidated Copper to cut production to 2.3 million tons during 1930 (Julihn and Meyer, 1934). This combined with continuing declining of ore grades reduced overall copper output from 66.2 million pounds in 1929 to 36.1 million pounds in 1930. Over the next two years, the copper price declined to 4.8 cents per pound (Julihn and Meyer, 1933), forcing further production cuts to 24.4 million pounds of copper in 1931 to 14.3 million pounds in 1932. Nevada Consolidated Copper finally halted all operations at Ray in March 1933 and only retained staff and employees necessary to care for the property during the shut-down (Gerry and Miller, 1935).

Table 7. Nevada Consolidated Copper Company production data for 1926-1933 (U. S. Bureau of Mines data)

Period	Milled & Direct Smelting Ore Short Tons	Cu %	Cu in Concentrate & Direct Smelting Ore lbs.	Precipitate Cu lbs.	Total Cu lbs.	Au Troy Oz.	Ag Troy Oz.
1926-1933	15,814,314	1.19	316,025,479	444,474	316,469,953	5,117	318,235

Between June 1926 and the temporary suspension of operations at Ray in March 1933, the Nevada Consolidated Copper Company produced about 15.8 million tons of ore, assaying 1.19% copper. Approximately 316.5 million pounds of copper were recovered during this period (Table 7).

8 KENNECOTT COPPER CORPORATION (1933-1986)

Kennecott Copper Corporation acquired the Ray property through its merger with Nevada Consolidated Copper Company, making it a wholly-owned subsidiary in June 1933 (Kennecott Copper Corporation, 1934), which managed its copper properties in Nevada (Robinson), Arizona (Ray), and New Mexico (Chino). Reconditioning of the underground mine workings and of the Hayden concentrator and other equipment began during the fall of 1936.

Production resumed on January 2, 1937 (Kennecott Copper Corporation, 1937). After nearly four years of inactivity, broken ore remaining within the block cave operation had been oxidized to a point that it became difficult to mill. It was decided to leach the remaining material in-situ. Drainage drifts were driven and concrete dams installed to prevent the solutions from flowing into working areas. Water was initially applied to the caved surface on January 20, 1937, using rotary head sprinklers. As it percolated down through the caved zone, it dissolved the copper. The pregnant solutions were collected in underground sumps and pumped to the surface, where it was plated onto scrap iron at a precipitation plant (Figure 43). The cement copper product was shipped to the Hayden smelter for further processing. Ten million pounds of copper were recovered during its first eighteen months of operation (Ahlness and Pojar, 1983).

After nearly four years of inactivity, it was also necessary to develop new blocks of ore. This combined with a brief decline in the price of copper that temporarily suspended all mining and milling operations from June 15, 1938 until August 15, 1938 and limited water supplies resulting from a prolonged drought, limited production to less than half capacity through the end of 1939 (Kennecott Copper Corporation, 1938-1940). By

1940, Ray's copper production increased to 63.5 million pounds, its largest annual output since 1929.

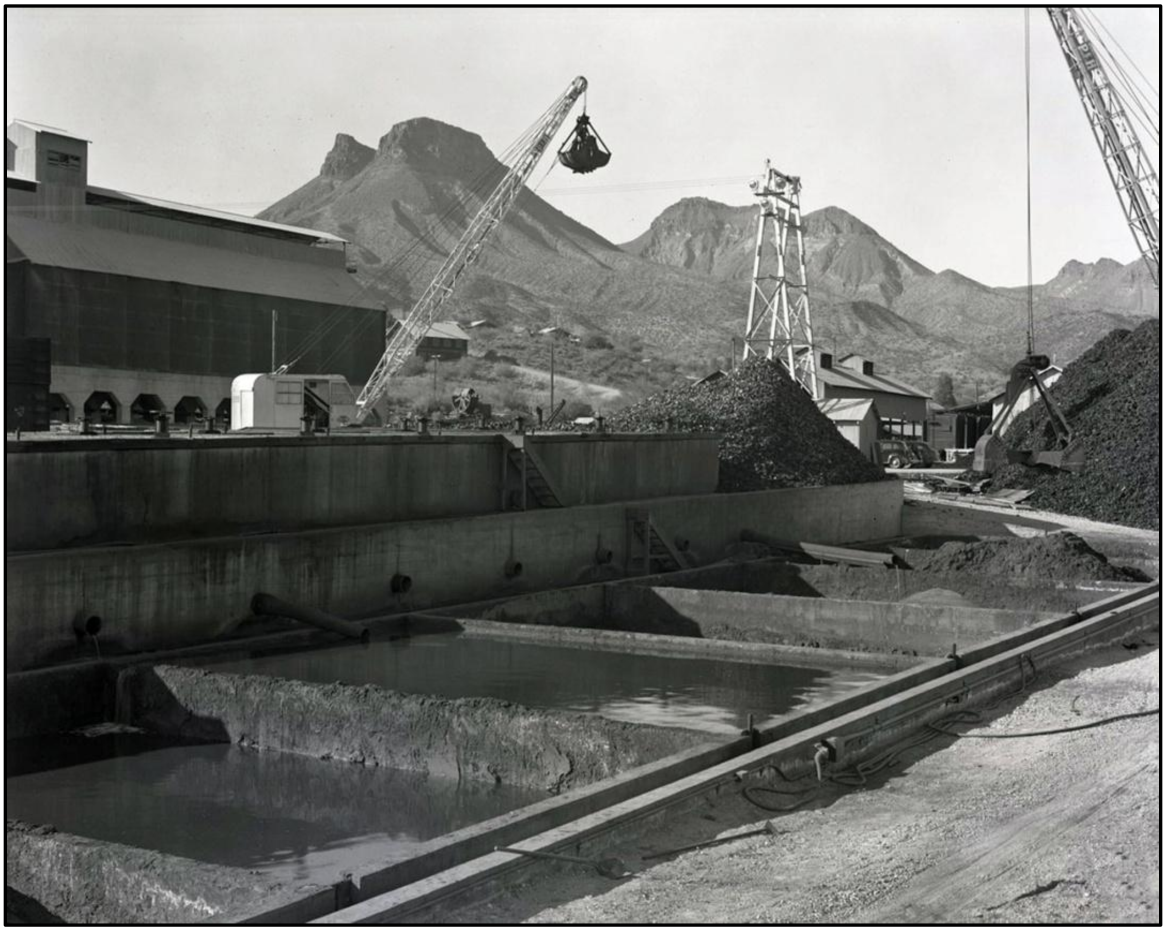


Figure 43. Copper precipitation plant at Ray with Teapot Mountain in the distance, circa late 1930s (photo from Arizona State University Library Digital Repository).

In response to the increased demand for copper at the outset of World War II, Kennecott Copper Corporation began operating its domestic mines, including Ray on a 24-hour basis, seven days per week in October 1940 (Kennecott Copper Corporation, 1942).

In August 1941, the Office of Price Administration fixed the price of copper at 11.8-cents per pound. A premium of 5-cents per pound for copper produced in excess of quotas established by the War Production Board became effective in February 1942 (Kennecott Copper Corporation, 1943). During 1942, ore and copper production at Ray peaked at nearly 3 million tons and 100.7 million pounds, respectively.

In an attempt to simplify its corporate structure, the Kennecott Copper Corporation dissolved the Nevada Consolidated Copper Company to form the Ray Mines Division, Chino Mines Division, and Nevada Mines Division (Kennecott Copper Corporation, 1943).

As a result of labor shortages during World War II, Kennecott's Ray operation began experiencing shortages of skilled underground miners during 1943. Becoming more acute during 1944 and 1945, this severely limited underground mine development, which was unable to keep pace with ore extraction (Kennecott Copper Corporation, 1945). This resulted in a steep decline in ore production from 2.4 million tons in 1943 and 1.4 million tons in 1945; declining ore grades from 1.59% copper in 1943 to 1.28% copper in 1945; and reduced copper output, which fell from 74.8 million pounds in 1943 to 38.9 million pounds in 1945.

By the end of 1945, underground mining operations at Ray had produced 68.3 million tons of ore. The future prospects of expanding production from the underground operation were poor due to declining ore grades and much needed development required to extract the remaining underground reserves. Annual underground ore production during 1946-1949, remained steady at approximately 1.3 to 1.5 million tons.

8.1 Transition to Open Pit Operation (1948-1955)

In an effort to resolve this dilemma, an extensive diamond drilling program began at Ray during 1945. By 1947 feasibility studies demonstrated it was feasible to extract the remaining ore reserves by open pit methods, using modern shovel and truck haulage equipment (Williams, 1956).

A number of factors favored the development of an open pit operation at Ray. Selective mining with power shovels allowed the separation of ore from waste to a much greater degree than underground block caving operations, where the ores were seriously diluted and/or remained unmined. Low-grade material from surface operations could be easily segregated and stockpiled until it could be profitably treated. They were also more flexible, in that rate of copper output could be easily attained by selecting ore of lower grade or by reducing tonnages mined. Care and maintenance costs for shuttered underground mining operations were considerably highly than surface mines. Open pit operations required fewer skilled and semi-skilled workers, compared to underground operations where competent miners were always scarce. Open pit mining operations were also inherently safer than underground operations (Parsons, 1957).

In late 1947, contracts were signed with Isbell Construction Company of Reno, Nevada to strip overburden from the ore body for mining by open pit methods. The initial phase of open pit development was construction of a diversion channel to redirect flood waters from Copper Canyon around the western edge of the proposed Pearl Handle pit

(Williams, 1956). The contract miner began pre-production stripping of the barren leached cap at the Pearl Handle pit during the summer of 1948. By late 1949 approximately 2,500-tons of ore per day were being mined from the open pit (Kennecott Copper Corporation, 1950). Approximately 53% of the ore mined during 1950 was derived from the open pit (Kennecott Copper Corporation, 1951).

The capacity of the Hayden concentrator was raised from 12,000- to 15,000-tons per day in 1951 to handle the increased production from the open pit. At the end of March 1952, the Isbell Construction contract ended after the removal more than 50.5 million tons of material, including 6 million tons ore. Kennecott Copper assumed complete control of the mining operations from the contract miner on April 1, 1952 (Williams, 1956).

Major mining equipment included seven 6- to 7-cubic yard electric shovels, twenty-one 34-ton haul trucks, and four 50-ton haul trucks. The ores were mined on 50-foot benches and initially reduced to a manageable size by a primary jaw crusher located adjacent to the open pit, prior to being loaded on rail cars for transport to the Hayden concentrator (Williams, 1956).

Underground mining operations were phased out over the next two years, ceasing entirely on January 28, 1955. With the cessation of underground mining activity, in-situ leaching operations were expanded to recover low-cost precipitate copper from caved areas of the former underground operation (Kennecott Copper Corporation, 1956). Recovery of copper by leaching sulfide waste dumps adjacent to the Pearl Handle pit began around 1963 (Larson, 1964).

8.2 Open Pit Operations (1955-1986)

The transition from underground to surface mining operations resulted in minor changes in the mineralogical content of the ores that were shipped to the Hayden concentrator. Historical block caving operations at Ray mined the enrichment blanket, which was primarily composed of chalcocite with minor (~10%) amounts of oxide minerals (chrysocolla, cuprite, malachite, tenorite, and native copper) that could not be recovered at the existing mill facility. Derived from broken ground above the former block cave operation, the initial open pit ores contained a greater percentage of copper oxides (Parsons, 1957). While Kennecott's Western Mining Division's Research Center was unable to develop an economical method of increasing recovery by flotation of silicate and carbonate minerals, its use of the leach-precipitation-flotation process significantly improved copper recoveries at Ray (Last, et al., 1957).

During 1956, the flow sheet of Hayden concentrator was modified at a cost of $5 million to employ leach-precipitation-flotation (L-P-F) process. This process included: 1) recovery of pyrite by flotation of the mill tails, 2) production of sulfur dioxide gas from the pyrite in a fluidized-bed reactor that was used to produce sulfuric acid, 3) use of a Bruckner furnace to produce sponge iron residue from the reactor, 4) dissolving oxide copper by separately leaching both sand and slime fractions from the main mill circuit, 5) precipitation of metallic copper from the pregnant leach solution, and 6) recovery of precipitated copper and sulfide copper by flotation (Parsons, 1957).

Designed to reduce the loss of non-sulfide copper from open pit ores at Ray, overall copper recovery was improved by an additional 2 pounds per ton of ore (Last, et al., 1957). The leach-precipitation-flotation process was employed at the Hayden concentrator until about 1968 (?).

During the boom years following World War II, Kennecott Copper's strategic focus shifted from expanding mine output to vertical integration of their domestic copper business, thereby producing a higher value product. While Kennecott Copper's mining operations in Nevada and New Mexico had their own dedicated smelting facilities at McGill since 1908 and Hurley since 1938, respectively, their mining operations at Bingham Canyon and Ray depended on ASARCO to smelt their concentrates.

Kennecott Copper opened its Garfield copper refinery in July 1950, commissioned its Ray smelter in June 1958, purchased ASARCO's Garfield (Utah) smelter in January 1959, and began operating its new $30 million refinery in Baltimore, Maryland in September 1959. This completed the integration of Kennecott's domestic copper production facilities from mining through refining.

Mining, milling and smelting operations at Ray were disrupted by a labor strike from August 10, 1959 until the end of December, 1959 (Kennecott Copper Corporation, 1960). Full production did not resume until March 1960 (Kennecott Copper Corporation, 1961).

A four-year $35 million expansion program was completed during the summer of 1960. It included enlarging the open pit, which necessitated relocation of certain surface facilities, purchase of additional mining equipment, and the expansion of the Hayden concentrator from 15,000- to 22,500-tons/day (Kennecott Copper Corporation, 1961). In-situ leaching operations were discontinued in 1961.

By the mid-1963, stripping operations along the eastern margin of the Pearl Handle pit moved east of the Mineral Creek drainage, destroying much of Ray's business district (Larson, 1964). High-grade silicate ores (>0.8% copper) encountered in this area were stockpiled, while metallurgical testing was conducted to develop a leaching process to treat this resource.

During 1966, the existing jaw crusher was replaced by a 54-inch gyratory crusher located just south of the planned pit boundaries (Larson and Henkes, 1967). A molybdenum recovery circuit was commissioned at the Hayden concentrator in December 1966.

All operations at Ray were halted from July 15, 1967 until late March 1968 as a result of a nation-wide strike by a coalition of 12 smaller unions led by the United Steelworkers of America and International Union of Mine, Mill and Smelter Workers, which halted production at most domestic copper mines, smelters and refineries. In addition to questions concerning wages, pensions and working conditions, negotiations focused on the critical questions concerning the establishment of a bargaining position. The unions insisted on company-wide bargaining and company-wide contracts that were adamantly rejected by management (Rowland and Greenspoon, 1968).

After eight months of unsuccessful negotiations, domestic copper inventories were nearly exhausted. These shortages were further aggravated when longshoremen boycotted foreign copper shipments. On March 4, 1968, President Lyndon Johnson appointed a three-man committee to intervene in the bargaining process; warning both parties the Federal Government would use the Taft-Hartley Act to end the strike, if a voluntary settlement was not reached (Guthals, 1970).

After 18 days of round-the-clock negotiations, settlement was reached only on the economic issues, after union officials reluctantly withdrew their demand for future coordinated bargaining. Later sessions between each company and the unions settled non-economic matters, such as seniority rules, safety regulations and job classifications (Guthals, 1970). Involving approximately 10,000 workers at its peak, this strike was one of the longest in the history of U.S. labor-management relations (Larson and Henkes, 1970).

Kennecott Copper announced plans to leach the oxide silicate ore in a 10,000-ton per day vat leach plant in late 1966 (Figure 44). Construction of this $35 million facility began in March 1967 and was commissioned in early 1969 (Knight and Brown, 1970).

This facility was expanded from 10,000-tons-per-day to 14,000-tons-per-day in 1976 (Miller, 1976). Use of the vat leach system of treating oxide silicate ores was discontinued in May 1982, after recovering about 627 million pounds of cathode copper from approximately 47 million tons of ore, assaying 1.15% copper.

Oxide silicate ores were initially reduced to minus 0.5-inches by a jaw crusher with the coarser material leached by a sulfuric acid solution in large vats for period of 10 days, while the finer slimes fraction was similarly treated in agitation leach tanks. The resulting copper sulfate solutions from both circuits were combined and copper recovered by electrolysis (Larson and Henkes, 1968).

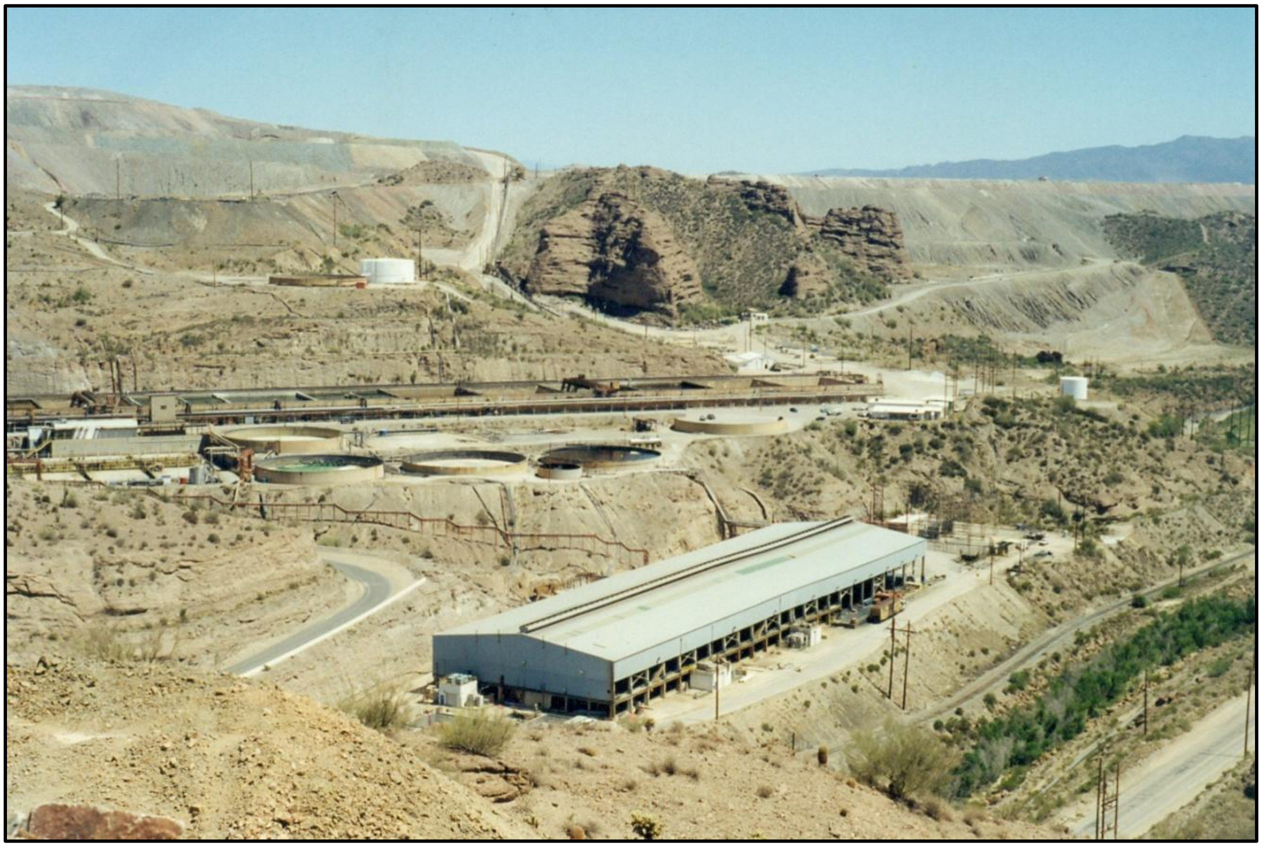


Figure 44. Electrowinning plant (center foreground) and former vat leach facility (center) at Ray, looking east; circa June 1999 (photo by David Briggs).

Fluor Utah Engineers and Constructors, Inc. was awarded a contract in October 1970 to construct a 165-foot-high concrete arch dam and a 3.4-mile-long, 16-foot-diameter horseshoe-shaped, concrete-lined diversion tunnel (Cole, 1972). Located along a narrow portion of Mineral Creek, approximately 1,300-feet downstream from its junction with Devils Canyon, the concrete arch dam served as a flood control structure that was designed to ensure flows downstream did not overwhelm the capacity of the diversion tunnel (Figure 45). The conventional drill-and-blast diversion tunnel channeled water around the active mining area. This project was completed in late 1973 (Greenspoon and Schroeder, 1976).

A $19 million expansion of the solvent extraction plant was completed during 1980. This upgraded the quality of pregnant leach solutions from the 14,000-tons-per-day silicate leach plant, which produced an electrolytic grade copper ready for direct shipment to fabricators.

During the 1970s, production at Ray was maintained at a steady rate except for 1975, when production was suspended for three months while the reverberatory furnace at its smelter was refurbished. The rapid decline in the price of copper during the early 1980s resulted in the decision to temporarily suspend all mining, milling and smelting operations from May 1982 until September 1983 (Hicks, 1985). Never a particularly successful method of treating oxide ores, their vat leach plant that was closed in 1982 and replaced by oxide dump leaching facility in 1985. The SX-EW plant was reactivated in December 1985, treating leach solutions from this facility (Burgin, 1987).

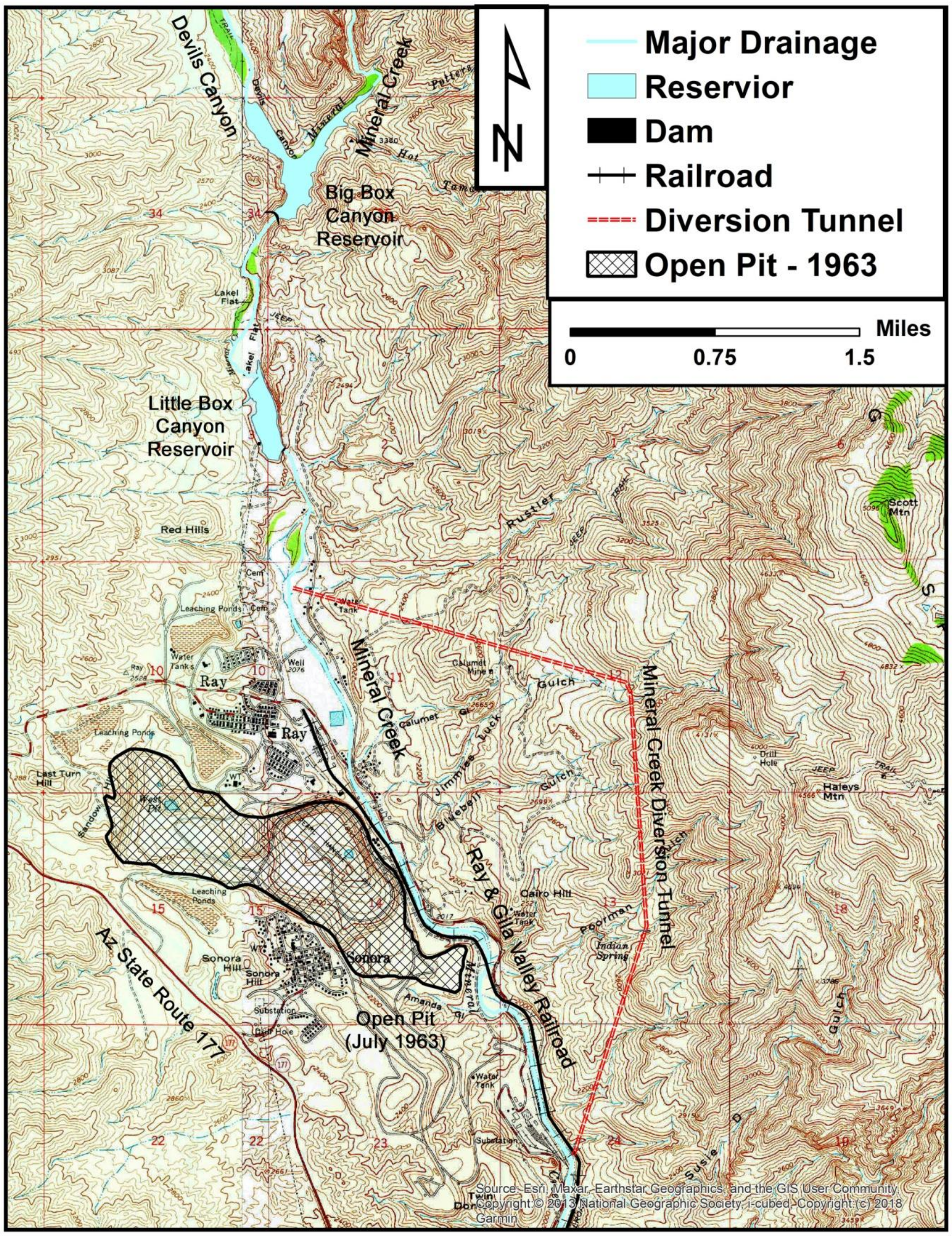


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Figure 45. Topographic map showing the open pit (as of July 1963), railroad, communities of Ray and Sonora, Big and Little Box reservoirs, and Mineral Creek diversion tunnel (1973-2000).

Table 8. Kennecott Copper Corporation production data for 1933-1986 (U. S. Bureau of Mines, Arizona Department of Mines and Mineral Resources, and Kennecott Copper Corporation annual reports).

Ore Type	Ore Treated Short Tons	Cu %	Cu lbs.	Mo lbs.	Au Troy Oz.	Ag Troy Oz.
Milled & Direct Smelting Ore	272,581,683	1.02	4,165199,164	8,016,997	40,140	7,586,142
Vat Leach/SX-EW	46,899,223	1.15	626,956,837	0	0	0
In-Situ-Waste Dump Leach/Precipitate Cu	-	-	890,838,115	0	0	0
Dump Leach/SX-EW	6,980,800	1.20	36,485,922	0	0	0
Total Ore Treated	326,441,706	1.00	5,719,480,038	8,016,997	40,140	7,586,142

Despite efforts to reduce operating costs that were achieved after mining and milling operations resumed in September 1983, the depressed copper market and continued losses at Ray eventually resulted in a decision by Kennecott Copper's parent company, Standard Oil Company of Ohio to dispose of this asset. Between 1933 and its disposal of the Ray operation in November 1986, Kennecott Copper Corporation recovered approximately 5.7 billion pounds of copper from about 326 million tons of ore (Table 8).

8.3 Demise of Ray, Sonora, Barcelona and Victoria (1947-1965)

Kennecott's decision to transition from underground to open pit mining in 1947 tolled the death knell to the small mining communities of Ray, Sonora, Barcelona, and Vitoria. Over the next ten years, the open pit and adjacent waste dumps crept closer to these communities (Figure 46).

Figure 46. Oblique aerial view of Ray mining district, looking south, circa 1957. Pearl Handle pit (left center) with Ray, Americantown and Boyd Heights (lower left) and Sonora (upper right center) (photo from Look and Williams, 1957).

Unlike many western mining camps that were abandoned, when boom turned to bust, the industry that created Sonora and Ray slowly devoured these communities. By 1957, the first residences in Sonora had been condemned and removed to make way for the expansion of the open pit. Arizona State Route 177 was relocated around the western edge of the mining area. Remaining residents and business owners residing in the mining district received eviction notices in 1962, requiring them to leave by December 31, 1965 (Seefeld, 2005).

8.4 Kearny (1958-present)

Based on economic, social, operational and technological reasons, Kennecott Copper decided to get out of the business of running company towns in 1955 (Kennecott Copper Corporation, 1956). This activity diverted energy and resources away from mining operations. Prohibitively expensive to operate, it made it more difficult to compete on the world market. Some company officials felt continued paternalism was morally wrong and labor relations suffered as a result of continued company ownership of these communities. Furthermore, advances in infrastructure (i.e. roads) and automobile affordability made it possible for workers to commute to work from greater distances (Seefeld, 2005).

Figure 47. Oblique aerial photo of Kearny, Arizona, looking north (photo from Google Earth).

In 1955, Kennecott Copper began disposing of its town assets at Ray and Hayden through John W. Galbreath Development Corporation, a real estate broker, who specialized in converting company towns to private ownership. The town of Hayden was incorporated in 1956. Workers, who rented their home at the mine site were given an opportunity to purchase the residence with the understanding they may have to move in the relatively near future as Kennecott still owned the land on which the house stood (Seefeld, 2005).

Besides converting company towns to private ownership, John W. Galbreath Development Corporation also developed new communities for workers of recently shuttered company-owned towns. In 1958, they purchased approximately 1,600 acres of land from Kennecott Copper on which the town of Kearny (Figure 47) was established to house residents that were displaced by the expansion of the open pit at Ray. Located approximately 12 miles southeast of the mine site, this nearly self-sufficient planned community included 214 homes, a motel, apartment buildings, a shopping center, swimming pool, elementary school, and high school. Cemeteries from the Ray area were also relocated to a new site east of Kearny (Arnold, 2024). Construction began in November 1958. The town of Kearny was incorporated in 1959 and its formal dedication was held in May 1962 (Seefeld, 2005).

The two-, three- and four-bedroom ranch-style homes in Kearny ranged in price from $10,800 to $14,250. Although Kennecott Copper compensated residents for the loss of their homes, many were unable to afford to purchase a new home in Kearny (Kennecott Copper Corporation, 1959b). Some, who had purchased their residences at Ray, were able to secure financing to move their houses to Superior or Riverside. This situation was especially difficult for the residents of Sonora, whose homes could not be moved. After stripping out what could be salvaged, they were forced to abandon their dwellings. Those who chose not to move to Kearny relocated to Hayden, Superior or other nearby communities. Others commuted to work from as far away as Mesa and Apache Junction (Seefeld, 2005).

9 KENNECOTT COPPER’S RAY SMELTER (1958-1982)

Prior to 1958, concentrates from Kennecott Copper’s Ray operation were treated at American Smelting and Refining’s Hayden smelter on a toll basis. As a part of Kennecott Copper’s effort to vertically integrate all phases of copper production from mining to refining, they began construction on their own smelting facility at Hayden in July 1956. It was commissioned in June 1958 (Figure 48).

Major components of Kennecott's Ray smelter initially included a natural gas-fired 30-foot-wide by 100-foot-long reverberatory furnace (Figure 35) with two waste heat boilers, three Peirce-Smith converters, an anode furnace and anode casting wheel. Following dust removal by electrostatic precipitators, all gases were discharged through a 600-foot stack (Weisenberg et. al., 1976). This facility produced a nearly pure blister copper product (99.6% copper) that was shipped to an off-site refinery (Figure 49).

In March 1969 a fluro-solids roaster was added to the smelting facility. It converted the copper concentrates to a calcine product prior to smelting, removing approximately 50% of its total sulfur content. Roaster gases (sulfur dioxide) were subsequently cleaned and sent to a 750-ton-per-day acid plant, which produced a sulfuric acid by-product that was used by leaching operations at the mine. By treating calcine instead of raw copper concentrates these modifications increased the plant's smelting capacity and reduced air pollution (Weisenberg et. al., 1976).

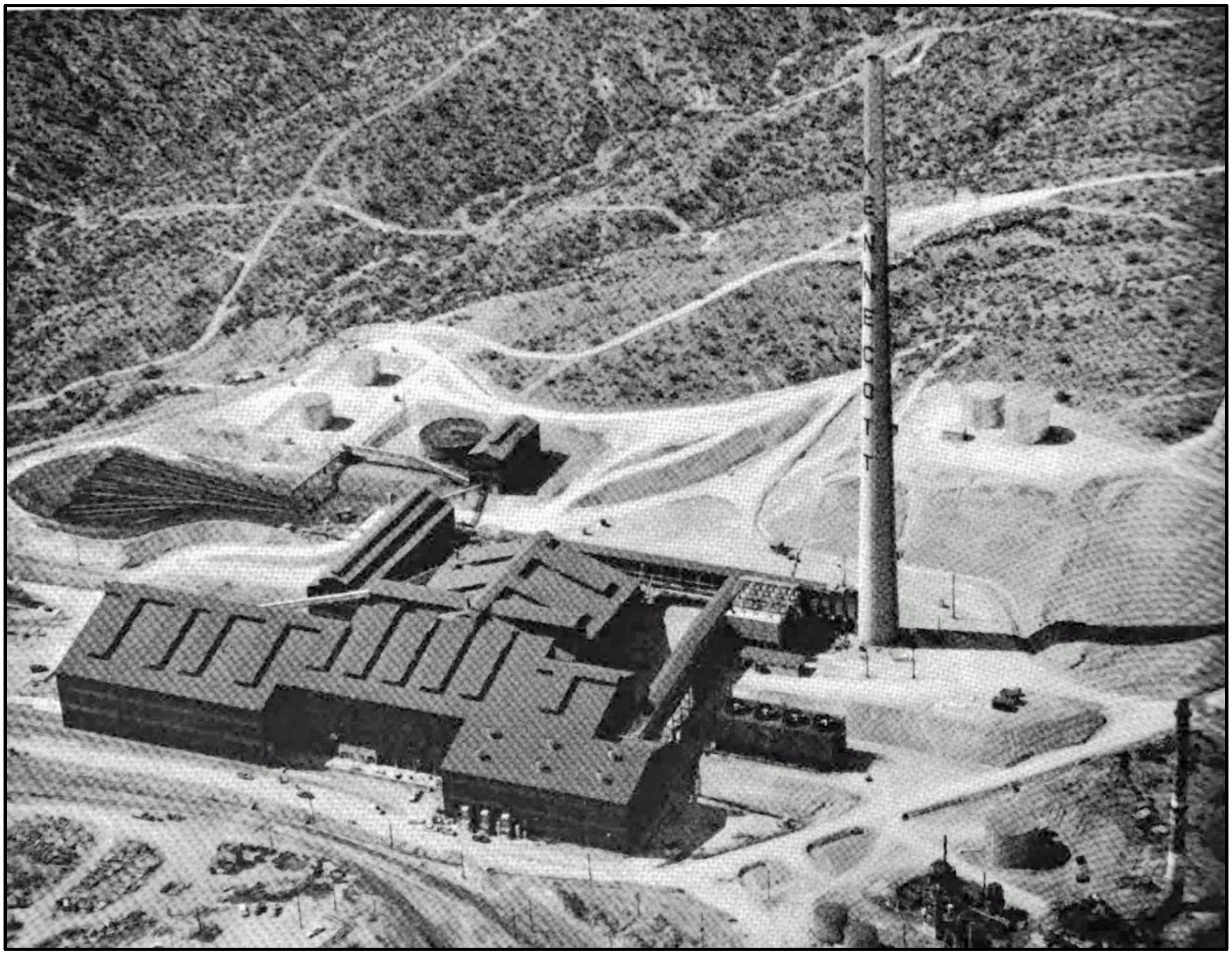

Figure 48. Kennecott Copper's Ray smelter at Hayden, Arizona (photo from Kennecott Copper Corporation, 1959a).

Kennecott’s Ray smelter became Arizona’s first smelter to discontinue recycling its converter slag to its reverberatory furnace in 1971 (U.S. Environmental Protection Agency, 1976). The converter slag was hauled in huge slag pots to earthen cooling pits, where it was permitted cool and harden before it was recycled to the Hayden concentrator for the flotation separation of copper. This practice enabled Kennecott to increase the smelting capacity of its smelter and avoid air quality problems that resulted when the high sulfur converter slag was reprocessed in the reverberatory furnace (Moore, 1973).

Upgrades to the air quality control system completed during 1973 included modifications that allowed the more efficient collection of converter gases for acid plant use. Closed water-cooled hoods were installed on converters, connecting ducts and a water spray gas cooling tower was added to each converter. The sulfuric acid plant was expanded from a 400-ton-per-day single-contact system to a 900-ton-per-day double-contact system (Moore, 1974).

Figure 49. First copper anode cast at Kennecott Copper’s Ray Smelter is on display at the University of Arizona Mineral Museum. Ninety thousand pounds of copper ore was processed to produce each 700 pound anode, which assays 99.6% copper (Daderot, CC0, via Wikimedia Commons).

Air pollution problems were compounded by the presence of two smelters operated by different owners at the same site. A regional computerized air quality monitoring system was commissioned and operated in partnership with ASARCO to maintain sulfur dioxide concentrations at acceptable standards (Everett, 1977).

Mining and milling operations at Ray was temporarily suspended for 12 weeks during summer of 1975, while the reverberatory furnace at its smelter was rebuilt. High smelting and sulfuric acid production rates were achieved following this shutdown (Arundale, 1978).

A decline in the price of copper during the early 1980s resulted in a decision to suspend operations at Kennecott Copper's Ray smelter on May 2, 1982 (Hicks, 1984). When mining and milling operations at Ray resumed in September 1983, their concentrates were treated under a tolling agreement at American Smelting and Refining's Hayden smelter (Dayton 1988). Never resuming production, the Ray smelter remained mothballed after ASARCO purchased Kennecott's Ray operations in November 1986 (Beard, 1987) and was eventually demolished in 2004. Today, only its 600-foot smelter stack remains at the site.

10 HAYDEN SMELTER MODERNIZATION (1970-1984)

In response to the Clean Act of 1970, ASARCO began efforts to bring their Hayden smelter in compliance with new regulations. A $17.1 million 650-ton/day acid plant was added to the facility in late 1971 to treat converter gases (Moore, 1973) and a 1,000-foot, double-shelled stack (Figure 50) replaced the two older short stacks in 1974 (Everett, 1977).

With the exception of minor modifications, facilities at the Hayden smelter remained unchanged since it began operations in 1912. Since the late 1950s, it was a custom and toll copper smelter, which treated an assortment of concentrates, reverts and speisses of variable compositions from numerous sources that required its material handling equipment and smelting process to be flexible (Everett, 1977).

By the early 1980s, the major components of the Hayden smelting operation included twelve multiple hearth roasters, two reverberatory furnaces, five converters, two gas-fired anode furnaces and a pair of automatic anode casting wheels. Calcines from the roasters were fed into the reverberatory furnaces to produce a matte product (40-45% Cu) that was upgraded to blister copper in the converters, fire refined, and cast into anodes that were electrorefined at ASARCO's copper refinery in Amarillo, Texas (Dayton,1988).

Figure 50. Hayden smelter, looking northeast (photo by David Briggs, November 2013).

In a consent decree issued by the U.S. District Court of Arizona in June 1981, ASARCO agreed to limit emissions of sulfur dioxide and particulates at its Hayden smelter. This was accomplished by a $132.6 million modernization project that involved erecting a new smelter within the confines of the older plant; while portions of it continued to operate as it was dismantled and replaced by components of the new facility (Dayton 1988).

The new facility consisted of two Fuller fluid-bed dryers, an Inco oxygen flash smelting system (Figure 51) capable of treating 2,000 tons of copper concentrate per day, 650-ton-per-day Air Products oxygen plant, a Monsanto Enviro-Chem 2,800-ton-per-day double-contact acid plant, a gas handling system, and water treatment plant (Dayton, 1988). Commissioned in November 1983, this facility was the first smelter in Arizona to meet Federal and State air pollution standards (Burgin, 1986). ASARCO also benefited from the sale of the sulfuric acid, a by-product produced at its Hayden facility (Burgin, 1985).

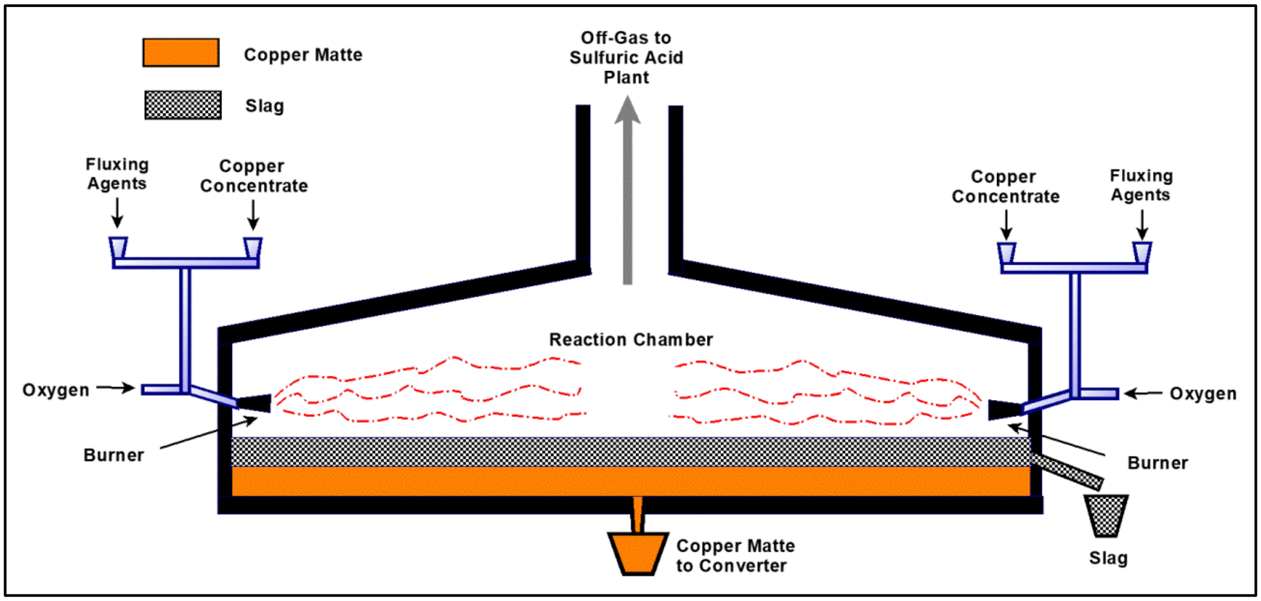

Figure 51. Schematic diagram of an Inco Flash Furnace (modified from U.S. Environmental Protection Agency, 1974).

The finely ground copper concentrates treated by this facility were initially dried by one of two fluid-bed dryers prior to being mixed with fluxing agents and oxygen before being horizontally injected into reaction chamber, where it was ignited by burners. This resulted in an exothermic chemical reaction that produced copper matte, iron oxides and sulfur dioxide. The sulfur dioxide gas reported to a sulfuric acid plant, while the copper matte and iron oxide fell into a bath at the bottom of the furnace, where the iron oxide reacted with the fluxing agents (i.e., silica and limestone) to produce slag. The denser copper matte sank to the bottom of the chamber, while the lighter slag floated on the surface of the molten material, where it was skimmed off and disposed of. The copper matte product, containing 50 to 60% Cu, was further upgraded to a blister copper product (98.5% Cu) in one of the five existing converters, before reporting to two natural gas-fired anode refining furnaces that produced an anode product containing more than 99.5% Cu, and two 20-foot diameter anode casting wheels (Dayton, 1988).

11 DECLINE OF KENNECOTT COPPER CORPORATION (1945-1981)

Following World War II, Kennecott Copper Corporation attempted to invest profits from its existing copper business into diversifying its earnings base through minerals exploration and new business opportunities. Its management employed a conservative approach, spreading its risks through modest investments in a number of business ventures (Morris, 1993).

After two frustrating decades of few successes, management pursued a more risky strategy. In 1966, Kennecott Copper set its sights on Peabody Coal Company, America's largest coal producer. Despite the Federal Trade Commission's warning it would oppose the merger on antitrust grounds; they proceeded with the purchase in March 1968 for cash and other considerations totaling $622 million. After a prolonged legal battle, Kennecott Copper was forced to sell Peabody Coal in June 1977 for $970 million, generating an after-tax gain of only $7 million, a meager return considering the size of its investment in Peabody and inflation of roughly 74% over the nine year period (Morris, 1993).

This did not deter their efforts to diversify. In November 1977, the Kennecott Copper board of directors authorized a tender offer for Carbonundum at $66 per share, which was substantially above the market price that ranged from $31 to $41 per share during the first 10 months of 1977. Kennecott Copper subsequently purchased the Carbonundum Company for $571 million in January 1978. This resulted in a protracted battle with the Curtis-Wright Corporation, who held nearly 10% of Kennecott's capital stock that was not completely resolved until January 1981 (Morris, 1993).

Over the years these distractions diverted both capital and management's attention from more lucrative business opportunities. More importantly, its core business suffered as deteriorating infrastructure at their copper operations slowly eroded their ability to compete on the world market. Concentrators at their operating mines were originally commissioned prior to 1912. Although they had been refurbished and upgraded over the years, the only new facility was the Bonneville crushing and grinding plant (commissioned in 1966) in Utah, which supplied ground ore from the Bingham Canyon mine to the Magna and Arthur plants. Although their operating smelters at Hayden (commissioned in 1958) and Hurley (commissioned in 1938) were younger than their concentrators, only their Garfield smelter (purchased from ASARCO in 1959) had been extensively modernized to comply with stringent environment regulations issued during the 1970s. And even there, the modernization was incomplete and some of the original components of the older facility, originally commissioned by ASARCO in 1906, were still in use (Morris, 1993).

Kennecott's earnings were then devastatingly diminished by the July 1971 expropriation of their profitable, giant El Teniente copper operation by the Chilean Government and costly environmental regulations imposed on their domestic operations during the 1970s (Morris, 1993). Anaconda similarly failed after losing its Chuquicamata and El Salvador operations and was subsequently acquired by the Atlantic Richfield Company (ARCO) in January 1977.

11.1 Big Oil's Failure at Metals Mining (1981-1989)

Having failed to balance its dependence on copper through diversification and squandering its capital in the attempt, Kennecott Copper was unprepared to cope with the downturn of copper prices during early 1980s. It became vulnerable to a takeover and its assets were eventually acquired by Standard Oil Company of Ohio (Sohio) in June 1981 for $1.77 billion. Kennecott's corporate structure was dismantled into its various components; Carbonndum, Quebec Iron and Titanium, Chase Brass and Kennecott Minerals Company, which continued to oversee its traditional mining, smelting and refining business (Morris, 1993).

After reaching a high of $1.33 per pound in February 1980, price of copper began a prolonged steady decline. In early 1982 an analysis showed Kennecott Minerals' losses could be reduced by the shutdown of Ray, if its break-even price was $0.69 cents per pound for a year or more. By March 1982, the copper price had fallen below Ray's break-even price and future prospects for its near-term improvement seemed highly unlikely (Morris, 1993).

All mining, milling and smelting operations were suspended at Ray in May 1982. The workforce was initially reduced from 1,850 in early 1982 to 640 in May 1982. Only its leaching operations remained in operation. The remaining workforce was retained to complete major repair and maintenance projects until mid August 1982, when 440 additional workers were laid off. Only 200 workers remained for care and maintenance.

When Ray resumed production at the mine and Hayden concentrator in September 1983, operating costs were reduced by favorable terms to treat their concentrates at ASARCO's Hayden smelter, modified operating mode, above average ore grades, lower than average stripping ratios, and an overall reduction of manpower requirements. The vat leaching facility, molybdenum flotation circuit and its smelter remained closed (Morris, 1993).

Silicate ores were stockpiled until December 1985, when Ray's new dump leach facility was commissioned. These silicate ores were placed on impermeable leach pads and leached with a weak sulfuric acid solution. Solvent extraction-electrowinning (SX-EW) technology was used to recover a low-cost, easily marketable copper cathode product. Kennecott's cost reduction program at Ray reduced its real cost of copper production by more than 50% (Morris, 1993).

Despite efforts to reduce costs at its domestic copper operations, Kennecott's parent company, Sohio disillusioned by continued weak copper prices and uninterrupted losses at Bingham Canyon, Chino and Ray had been considering alternatives to reduce its exposure to the non-ferrous minerals business for several years (Morris, 1993).

By December 1984, three options were under consideration: 1) exit the copper business; 2) modernize Bingham Canyon and sell Ray and Chino; and 3) modernize Bingham Canyon and retain Ray and Chino. Their choice was based solely on the outlook for future copper prices. If the long-term copper price was less than $0.70 per pound, the first option was expected to yield the highest return for Sohio. A copper price from $0.70 to $0.80 per pound made the second option most attractive, and a price greater than $0.80 per pound favored the third option (Morris, 1993).

Having little experience in the copper business, Standard Oil Company of Ohio's executives had no basis to choose any of the alternatives. Frank Joklik, President of Kennecott Minerals Company, stated it was short sighted to think copper prices will remain in $0.60 to $0.70 per pound range, arguing; "this implies 60% of the Free World's copper production will continue to be produced at a loss. Over the long term, prices of mineral commodities tend to reflect the costs of production, including profits. As capacity deteriorates and demand slowly grows, costs of production, including profits will become more fully reflected in the price of copper" (Morris, 1993).

Despite Joklik's efforts to retain Kennecott Minerals' three remaining domestic copper producers (i.e., Bingham Canyon, Ray and Chino), Sohio sold the Ray property to ASARCO in November 1986 and its 66.7% interest in the Chino property to Phelps Dodge in December 1986. Within six months, Joklik's forecast of higher copper prices materialized and remained at levels that enabled the new owners to quickly recoup their investments. Kennecott Minerals was subsequently acquired by British Petroleum through its merger with Sohio in July 1987 and sold to the RTZ Corporation in July 1989. Unlike Sohio and BP Petroleum, RTZ was a mining company, whose management understood the mining business (Morris, 1993).

12 AMERICAN SMELTING AND REFINING COMPANY (ASARCO) (1986-1999)

Like Frank Joklik, the management of ASARCO, Inc. was also optimistic about the domestic copper industry's future. Having reached a high of nearly $1.33 per pound in February 1980 (Butterman, 1981), the price of copper had experienced a prolonged period decline that reached a low of 62 cents per pound in October 1984 (Jolly and Edelstein, 1985). During the early 1980s, seven mining companies exited the copper business resulting in the suspension of operations at more than a dozen U.S. mining operations (O'Neil, 1989). This resulted in lucrative business opportunities for those bold enough to make wise investments.

The first of ASARCO's opportunities occurred at the Mission mine, located south of Tucson, Arizona. Commissioned by ASARCO in July 1961, this project was located adjacent to the Pima mine, which began production in December 1956 (Williams, 2018). Copper ores from these projects were initially mined from two separate pits, which over time coalesced to become a single large excavation by the 1970s. ASARCO and Anamax formed the Eisenhower Mining Company in August 1976, to mine the adjacent Palo Verde property that was partially surrounded by ASARCO's holdings at Mission and San Xavier South (on the Tohono O'odam Indian reservation). Benefiting both companies, this partnership enabled the extraction of ore their adjoining properties that would have been prohibitively expensive to mine otherwise (Williams, 2018).

Following the decline of the price of copper during early 1980s, operations were halted at the Pima mine in October 1982. Shipments of Anamax's share of sulfide ores from the Palo Verde property to its Twin Buttes concentrator were suspended at the end of July 1983 (Williams, 2018).

ASARCO, Inc. purchased the Pima property in September 1985 for $12.5 million. Anamax's interest in the Eisenhower Mining Company was acquired for $1 million in April 1987. The Mineral Hill property, located adjacent to the southwest boundary of the Pima pit, was purchased from Anamax Mining Company in October 1987 for $207,000, giving ASARCO complete control of the Mission mining complex (Williams, 2018).

In a second more significant acquisition, ASARCO, Inc. purchased the Ray project from Standard Oil of Ohio in November 1986 for $72 million in cash plus an earn-out (i.e., additional payments) related to the price of copper over a 10-year period that was capped at $65 million (ASARCO, Inc. 1989). At the time, its major components included the Ray open pit mine, a well-equipped mining fleet, dump leach and SX-EW facility, 26,000-short ton/day Hayden concentrator and the mothballed Ray smelter (Dayton, 1988).

ASARCO management's decision to acquire the Ray project proved correct. The price of copper began to sharply rise from $0.71 per pound in May 1987 to $1.325 per pound in January 1988 (Jolly and Edelstein, 1990). Asarco's initial cash outlay of $72 million was recouped by the end of March 1988 (Dayton, 1988).

These investments enabled ASARCO, Inc. to double its domestic copper production from 99,400 short tons in 1984 to 205,000 tons in 1987. Similarly, its U.S. copper reserves more than tripled from 2.1 million short tons in 1984 to 7.5 million short tons in 1987 (ASARCO, Inc. 1985; and ASARCO, Inc., 1988). Furthermore, this reduced ASARCO's reliance on outside sources of concentrates at its recently rebuilt Hayden smelter from 75% to 33% of its capacity (Dayton, 1988).

Shortly after acquiring the Ray project, ASARCO implemented a modest $1.1 million program designed to reduce operation costs through simple modifications of its leaching practices in January 1987. It ceased production of cement copper precipitate redirecting the leach solutions from the sulfide waste dumps through the solvent extraction plant to more fully utilize electrowinning tankhouse capacity. This simple adjustment allowed this facility to produce a marketable product (i.e., copper cathode), eliminating costs related to smelting and refining the copper precipitate (Dayton, 1988).

Management soon realized operations at Ray could efficiently function with a smaller workforce than had been employed by Kennecott during the early 1980s. Kennecott employed approximately 2,200 at the mine, Hayden concentrator and Ray smelter in 1981 (Dayton, 1988). ASARCO's employment at the mine, Hayden concentrator and smelter in 1988 was 757 (Arizona Department of Mine and Mineral Resources, 1988).

Improvements were made to the Hayden concentrator (Figure 52) during 1989 to maintain production capacity to offset anticipated effects as mining operations encountered harder ores with increasing depth (O'Neal, 1989). This $12 million capital investment included a sixth tertiary crusher, a seventh grinding line, consisting of a single primary 14-foot by 18-foot rod mill and two secondary 12.5-foot by 16-foot ball mills, and a single row of twelve 500-cubic foot rougher flotation cells (Anonymous, 1994). An electric slag cleaning furnace was commissioned at the Hayden smelter in August 1989 at a cost of $22 million project, which was designed to reduce amount of copper contained within slag (Greeley and Kissinger, 1991).

Figure 52. Hayden Concentrator, November 2013, looking north (photo by David Briggs).

In November 1989 ASARCO selected Bechtel Corporation as the prime engineering contractor at its Ray mine and mill expansion project, which commenced construction in May 1990. Major components of this undertaking included a semi-mobile 60,000-short ton/day in-pit gyratory crusher, a 4,200-foot overland conveyor, a 30,000-short ton/day concentrator, and a new tailings impoundment in Elder Gulch, located about 2.5 miles southeast of the Ray concentrator (McGhee, 1993). The mining fleet was enlarged by adding twenty-two 240-ton haul trucks and two 41-cubic yard shovels. Upgrades were completed in February 1992 at a total cost of $240 million (Anonymous, 1999).

The on-site concentrator at Ray has a two-stage grinding circuit employing a single primary semi-autogenous (SAG) mill operated in closed circuit with two secondary ball mills followed by flotation cells to produce a copper concentrate product that is shipped to the Hayden smelter (Figure 53). Coarsely crushed ore shipped via rail to the Hayden concentrator undergoes two additional stages of crushing prior to entering the grinding circuit consisting of four three-stage and three two-stage grinding lines, composed of primary rod mills and secondary and/or tertiary ball mills before undergoing flotation (Anonymous, 1994).

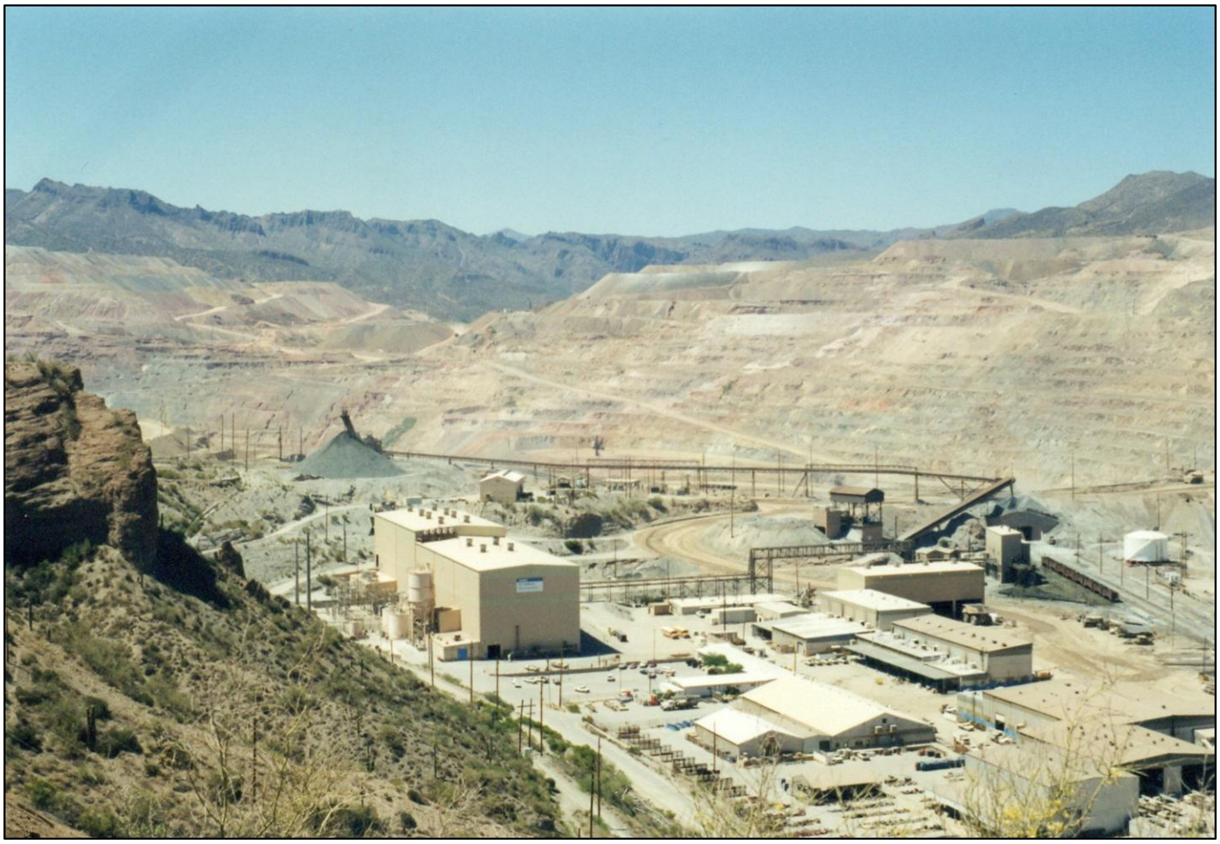

Figure 53. Ray Concentrator and rail loading facility, circa June 1999, looking north (photo by David Briggs).

Weather related problems disrupted the commissioning of the new concentrator and mining operations at Ray during 1992. More than twice the normal annual precipitation of 17.5-inches fell; rain-fall totaled 36-inches for the year. This included 8-inches during the month of December (ASARCO, Inc., 1993). Fourteen-inches of rain fell during January 1993, which resulted in flooding that severed the rail line to Hayden for three weeks and disrupted mining operations that resulted in lost production and added costs totaling $22 million. While the worst effects of this heavy precipitation were overcome by the spring of 1993, full production was not fully restored until late 1993, due substantial amounts of water retained in the open pit (ASARCO, Inc., 1994).

However, in early 1994, mining operations encountered a number of unanticipated difficulties, including lower grade ores that were difficult to treat and wet sticky zones that resulted in materials handling problems. Limited availability of ore to blend with this more difficult to treat material resulted in the decision to suspend milling operations at the older Hayden concentrator in July 1994, while mining operations accelerated waste removal to restore operating flexibility and production capacity lost as a result the unusually heavy precipitation during 1992 and early 1993 (ASARCO, Inc., 1995). Milling operations resumed at the Hayden concentrator in late May 1995, after completing a $5 million modernization program (ASARCO, Inc. 1996).

Figure 54. Blasthole drilling and shovel operations at Ray open pit, circa November 2001 (photo by David Briggs).

In 1993, major mining equipment included eighteen Wabco 170-ton haul trucks, six Wabco 120-ton haul trucks, twenty-five 240-ton Dresser haul trucks, three P&H 2800XP 41-cubic yard shovels, one P&H 2800 32-cubic yard shovel, two P&H 2100 BL 15-cubic yard shovels, one P&H 2100 BLE 21-cubic yard shovel, two Marion 191-M 15-cubic yard shovels, two Leourneau L1000 17-cubic yard front end loaders, one Letourneau L1100 21-cubic yard front end loader, one Cat 994 21-cubic yard front end loader, four Bucyrus-Erie 60R electric drills, two Bucyrus-Erie 60R diesel electric drills, and a single rubber-tire Ingersol Rand T5 drill (Anonymous, 1994).

Mining occurs on 50-foot benches with the material being initially drilled by blasthole drills and sampled to define oxide ore, sulfide ore, and waste. The material is extracted by large shovels and/or front-end loaders and loaded into haul trucks (Figure 54). Waste material is transported to the sulfide or silicate waste dumps, while silicate ores report to a three-stage silicate ore crushing circuit where it is reduced to a 1/2-inch product before being transported by 120-ton haul trucks to dedicated leach pads and stacked in 8-foot lifts. Sulfide ores are hauled to a semi-mobile in-pit, 60-inch by 89-inch gyratory crusher (Figure 55) located on a lower level of the open pit and reduced to a minus 8-inch product that is transported out of the pit by a 4,200-foot overland conveyor system to an ore transfer station, where it is conveyed to a coarse ore stockpile located adjacent to the Ray concentrator or to the railroad load-out stockpile prior to being transported to the Hayden concentrator (Anonymous, 1994).

Figure 55. Open pit mining operations at Ray, showing semi-mobile primary gyratory crusher (lower right), circa November 2001 (Photo by David Briggs).

Leach solutions from the oxide and sulfide leach dumps at Ray are passed through a solvent extraction-electrowinning (SX-EW) plant, which produce a marketable cathode copper product (Anonymous, 1994). The ferric cure leach process was adopted by the oxide dump leaching operation in 1997, resulting in a shorter leach cycle that yielded high copper recoveries. Expansion of the electrowinning tankhouse during early 1999 increased its annual capacity from 45,000 to 51,000 tons of copper cathode (ASARCO, Inc., 1999a).

Over the years, leaching operations conducted on sulfide and silicate dumps located along Mineral Creek have resulted in surface water quality issues along this drainage. By 1991, ASARCO began discussions with the Environmental Protection Agency (EPA) and the Arizona Department of Environmental Quality (ADEQ) on how to best resolve these problems. Over the next several years, efforts were made to control discharges along Mineral Creek by a variety of pump-back systems, liners, cut-off walls, and stormwater collection systems (Yanagisawa, 2001).

In 1998 the conversion of the Hayden smelter's flash furnace dry gas cleaning circuit to a wet gas cleaning system helped to reduce operating costs (Russell, et al., 2019; and ASARCO, Inc., 1999a).

Investments at Ray since ASARCO's acquisition of the property in November 1986 enabled the operation to increase its copper output from approximately 200 million pounds in 1986 to 331 million pounds in 1992. With minor improvements to the operation over the next seven years, copper production averaged nearly 320 million pounds, annually.

Table 9. ASARCO production data for 1986-1999 (compiled from data released in ASARCO, Inc. annual reports and the Arizona Department of Mines and Mineral Resources).

Ore Type	Ore Treated Short Tons	Cu %	Cu lbs.	Mo lbs.	Au Troy Oz.	Ag Troy Oz.
Milled & Direct Smelting Ore	209,774,808	0.78	2,704,075,985	0	NA	7,541,900
Waste Dump Leach (Precipitate Cu)	0	-	6,519,000	0	0	0
Dump Leach (SX-EW)	53,692,364	1.03	994,208,600	0	0	0
Total Ore Treated	263,467,172	0.83	3,704,803,585	0	NA	7,541,900

Between November 1986 and November 1999, the Mineral Creek mining district recovered approximately 3.7 billion pounds of copper from milling and dump leaching operations (see Table 9).

12.1 ASARCO's Achilles Heel

In response to public concerns to clean up contaminated sites, the U.S. Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (i.e., CERCLA) in December 1980. Provisions contained within this important environmental legislation included the following four categories of responsible parties, who could be held financially liable for the costs of dealing with environmental problems associated with contaminated sites (Congressional Research Service, 2012):

1. any entity who currently owns or operates a facility from which a hazardous substance was released;
2. any entity who at the time of disposal of a hazardous substance owned or operated the facility at which such disposal occurred;
3. any entity who arranged for the disposal or treatment of a hazardous substance and any person who arranged for the transport of a hazardous substance for disposal or treatment; and
4. any entity who accepts or accepted a hazardous substance for transport to a disposal or treatment facility, incineration vessel or site selected by such person.

A party could be held liable regardless of whether its conduct was deemed negligent at the time of disposal and could be held responsible for the full site cleanup costs without regard to its degree of involvement in the contamination. Furthermore, it was also liable for cleanup of hazardous substances that were released prior to the passage of CERCLA on December 11, 1980 (Congressional Research Service, 2012).

Like many businesses, the impact of CERCLA on the mining industry was profound. Older established mining companies like ASARCO had been involved with many mining, smelting and refining operations throughout the United States, including many that pre-dated its founding in April 1899. Despite the fact that it was involved in some of these sites for only a short period of time, being the sole surviving party during a site's ownership history now made it legally responsible for all of its remediation and restoration costs. As of December 31, 1998, ASARCO spent more than $800 million remediating and restoring its former industrial sites. Generated from its continuing businesses and the sale of its investments, these funds were not available for more productive investments, resulting in the gradual deterioration of ASARCO's income producing assets (Asarco, Inc., 1999a).

ASARCO's financial situation worsened when the price of copper began falling in mid-1997 (Edelstein, 2001). Over the next 27 months, Asarco experienced net losses totaling approximately $141 million (ASARCO, Inc., 1999a; and ASARCO, Inc., 1999b).

12.2 Restructuring of the U.S. Copper Industry

In response to a rising surplus of copper on the world market and rising inventories, the price of copper continued to fall until March 1999, reaching $0.66 per pound its lowest level since February 1987. In constant dollar terms (i.e., adjusted for inflation) it was the lowest level since the depths of the Great Depression during the 1930s (Edelstein, 2001).

As annual U.S. copper production declined from a high of nearly 4.3 billion pounds in 1997, a number of domestic producers sought ways to reduce operating costs and improve their competitive position in an evolving world market. Some copper producers like BHP Copper suspended operations at Pinto Valley in February 1998 and San Manuel in June 1999. Subsequent attempts to sell these assets failed. Others sought to enhance their situation through acquisitions and mergers.

On July 15, 1999, ASARCO, Inc. and Cyprus Amax Minerals Company announced that they had reached an agreement to merge their organizations to form Asarco Cyprus, Inc. (ASARCO, Inc., 1999b). This was followed by Phelps Dodge's unsolicited offer to acquire assets of both ASARCO, Inc. and Cyprus Amax Minerals Company on August 11, 1999, which was initially rejected on August 20, 1999. As negotiations continued over the next month, Grupo Mexico, S.A. de C.V. made an unsolicited cash offer to acquire all outstanding shares of ASARCO, Inc. on September 27, 1999 (Cyprus Amax Minerals Company, 1999).

In response to this development, both ASARCO, Inc. and the Cyprus Amax Minerals Company decided to unilaterally explore alternatives to their proposed merger on September 27, 1999. On September 30, 1999, the Board of Directors of Cyprus Amax Minerals Company approved the Phelps Dodge/Cyprus Amax merger agreement, terminating its previous agreement with ASARCO, Inc. (Cyprus Amax Minerals Company, 1999).   The effective date of the Phelps Dodge/Cyprus Amax Minerals merger was October 16, 1999 (Phelps Dodge Corporation, 2000).

On October 6, 1999, ASARCO's Board of Directors accepted Phelps Dodge's offer to acquire ASARCO, Inc., but subsequently terminated this agreement after Grupo Mexico increased their tender offer for its outstanding shares, deciding to merge with Grupo Mexico on October 25, 1999 (ASARCO, Inc., 1999b). ASARCO, Inc. became a wholly-owned subsidiary of Grupo Mexico S.A. de C.V. on November 17, 1999 (ASARCO, Inc., 1999d).

13 EARLY HISTORY OF GRUPO MEXICO (1881-1999)

The corporate history of companies that would become Grupo Mexico S.A. de C.V. began as a collection of mining operations in Mexico controlled by the Guggenheim family (Figure 56), who initially invested in mining opportunities in Leadville, Colorado around 1881. Soon realizing that more profits could be realized by those smelting and refining the ores, they commissioned Philadelphia Smelting and Refining Company’s lead smelter in Pueblo, Colorado in December 1888. In an effort to obtain feed for this facility, several mine owners in Mexico were persuaded to ship their rich lead-silver ores to their Pueblo smelter (Marcosson, 1949).

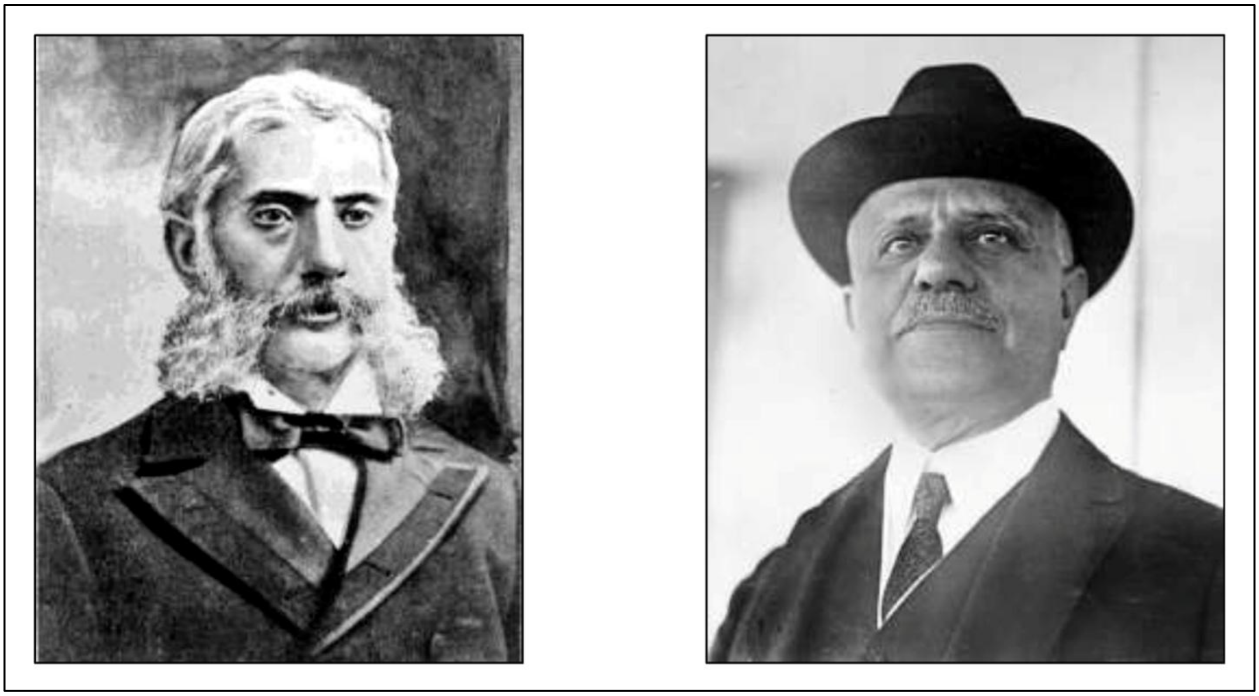

Figure 56. Meyer Guggenheim (1828-1905), left, the patriarch of Guggenheim family, who initially invested in several Colorado mining properties in 1881. Daniel Guggenheim (1856-1930), right, served as the Chairman of ASARCO from April 1901 until 1919 (photos from Library of Congress).

The passage of the Sherman Silver Purchase Act in July 1890 was an attempt to combat falling silver prices. While this initially benefited their smelting business, it also stimulated production from domestic sources, resulting in a collapse in the price of silver (Marcosson, 1949). While Guggenheim’s Mexican suppliers could compete with U. S. silver operations, the passage of the McKinley Tariff Act in October 1890 was in part an attempt by domestic competitors to reduce the flow of rich imported silver ores to their Colorado smelter. In response to this legislation, the Guggenheims established smelters at Monterrey, Mexico (1892), Aquascalientes, Mexico (1895), and initially leased, then purchased, Mexican mining operations to supply ore and concentrates to these facilities (Wasserman, 2015). By 1901, their smelters were processing 40% of the lead and 20% of the silver mined in Mexico, much of which was sold on the world market (Anonymous, 2023).

Incorporated under the laws of New Jersey in April 1899, the American Smelting and Refining Company (ASARCO) was organized as a holding company by Leonard Lewisohn and Henry H. Rodgers (Figure 57). Initially composed of lead-silver smelting and refining operations mainly located in Colorado, Utah, Montana and Texas, ASARCO's initial effort to acquire Guggenheim's U. S. and Mexican operations in September 1900 was rebuffed. However, after further negotiations, the Guggenheim family (Figure 56) exchanged their U. S. and Mexico holdings for a controlling interest in the American Smelting and Refining Company in April 1901 (Marcosson, 1949).

Figure 57. Leonard Lewisohn (1847-1902), left and Henry H. Rodgers (1840-1909), right (photos from King, 1899).

Over the next six decades, the American Smelting and Refining Company would become a major force in the smelting and refining business. They commissioned the Garfield copper smelter (1906) in Utah, purchased the Baltimore copper refinery (1909) and added a copper smelter to the El Paso lead facility (1910), Hayden copper smelter (1912) in Arizona, zinc refinery in Amarillo, Texas (1922) and electrolytic zinc plant in Corpus Christi, Texas (1942). Lucrative foreign investments included Northern Peru Mining and Smelting Company (1923), Mount Isa Mines Ltd. (1930) in Australia and

Southern Peru Copper Company (1952), which commenced mining operations at Toquepala in 1960 and Cuajone in 1976 (ASARCO, Inc., 1999c).

While American Smelting and Refining Company's business always included mining, the smelting and refining operations were its principal money-makers. However, this corporate strategy changed following World War II. The Silver Bell mine in southern Arizona became the company's first large scale open pit mining operation in 1954. It was followed by Toquepala in 1960, Mission in 1961, Sacaton in 1974 and Cuajone in 1976 (ASARCO, Inc., 1999c).

Prior to the nationalization of the mining industry in Mexico in February 1961, many of the mines were owned and operated by foreign interests, including operations controlled by the American Smelting and Refining Company and the Anaconda Company. Taking approximately a decade to complete, the process of Mexicanization of the nation's mining industry gradually transferred control of their mineral resources to Mexican business interests (Perdue, 2019).

In June 1965 ASARCO's Mexican operations were consolidated to form Asarco Mexicana, S.A., which was owned by ASARCO (49%) and group of Mexican investors (51%) (Ulatowski, 1985).

Following the discovery of the La Caridad deposit during the summer of 1967 by Consejo de Recursos Naturales no Renovables, an agency of the Mexican government, Asarco Mexicana was awarded an exploration contract to evaluate this discovery in September 1968 (Coolbaugh, 1971; and Saegart, et al., 1974). Mexicana de Cobre S.A. de C.V., a 49% owned affiliate of Asarco Mexicana, was organized to explore and develop this new discovery, which achieved commercial production in June 1979 (Anonymous, 1987).

In 1974, Asarco Mexicana S.A. was reorganized as Industrial Minera Mexico, S.A. and sold an additional 15% interest to Mexican investors, reducing ASARCO's stake to 34% (Ulatowski, 1985). Industrial Minera Mexico S.A. became a part of Grupo Industrial Minera Mexico S.A. de C.V., a holding company entirely owned by Mexican equity in 1978. Its subsidiary Mexico Desarrollo Industrial Minero S.A. de C.V (Medisma) remained 34% owned by the American Smelting and Refining Company, which had changed its name to ASARCO, Inc. in 1975 (Asarco, Inc., 1999c).

The Cananea copper mine, controlled by Cia Minera de Cananea S.A. de C.V., a wholly-owned subsidiary of the Anaconda Company, became the final large mining enterprise to be nationalized in November 1971 (Perdue, 2019). At that time, 51% of the company was sold to Mexican investors (Skillings, 1972). Anaconda's remaining 49% equity interest in Cia Minera de Cananea S.A. de C.V. was purchased by the Mexican government in 1982. By the late 1980s, Cia Mineral de Cananea was experiencing economic difficulties and declared bankruptcy in August 1989. In October 1990 the Mexican government sold its interest in Cananea to Mexicana de Cobre (76.1%), ACEC Union Miniere S.A. (21.2%) and a worker's union (2.7%) (Golder Associates USA, Inc., 2022). Grupo Industrial Minera Mexico in turn controlled a 94.8% interest in Mexicana de Cobre.

In August 1994, Grupo Mexico, S.A. de C.V. was formed as a holding company that replaced Grupo Industrial Minera Mexico S.A. (Grupo Mexico S.A. de C.V., 1995). After purchasing most of ASARCO's remaining equity interest in Mexico Desarrollo Industrial Minero in 1997, Grupo Mexico brought its relation full circle in November 1999, when it acquired ASARCO, Inc., including the Ray operation, in a transaction valued at US $2.523 billion, including the assumption of US $1.16 billion in debt (Grupo Mexico S.A. de C.V., 2000).

14 GRUPO MEXICO (1999-2005)

Prior to Grupo Mexico's acquisition of the Ray project in November 1999, ASARCO had been working with the EPA and the ADEQ to resolve surface water quality issues along Mineral Creek. Although these efforts had improved the water quality, regulatory standards remained unmet. After significant discussions concerning the best method to meet and maintain required water quality standards, ASARCO, Inc., EPA and ADEQ entered a consent decree in May 1998. Under the terms of this agreement, it was decided to isolate Mineral Creek from the mine operations (Yanagisawa, 2001). In addition to improving water quality, this project would also permit an expansion of its leach dumps.

The cornerstone of this $30 million project was the 13,000-foot extension of the existing Mineral Creek diversion tunnel northward with its new inlet portal located just south of the Big Box Canyon Dam (Grupo Mexico C.A. de C.V., 2003). A 7,100-foot section of the existing tunnel from its inlet portal to the junction with the new tunnel was subsequently abandoned. A diversion dam that has an impermeable core, which extended to bedrock, was built immediately downstream from the diversion tunnel's new inlet portal, located 2,400 feet south of the Big Box Canyon Dam (Figure 58) (Yanagisawa, 2001).

On September 7, 1999, Frontier-Kemper Constructions, Inc. of Evansville, Indiana was awarded the contract to excavate and concrete line the new extension of the Mineral Creek diversion tunnel, which has a design grade of 1.5%. Excavated by a hard rock tunnel boring machine, the tunnel had an excavated diameter of approximately 18.3-feet. With a 13-inch concrete lining, the inside diameter measured about 16.7-feet

(Yanagisawa, 2001). Finished under budget, the new extension of the Mineral Creek tunnel was completed in December 2002, approximately ten months behind schedule (Speers and Jurich, 2003).

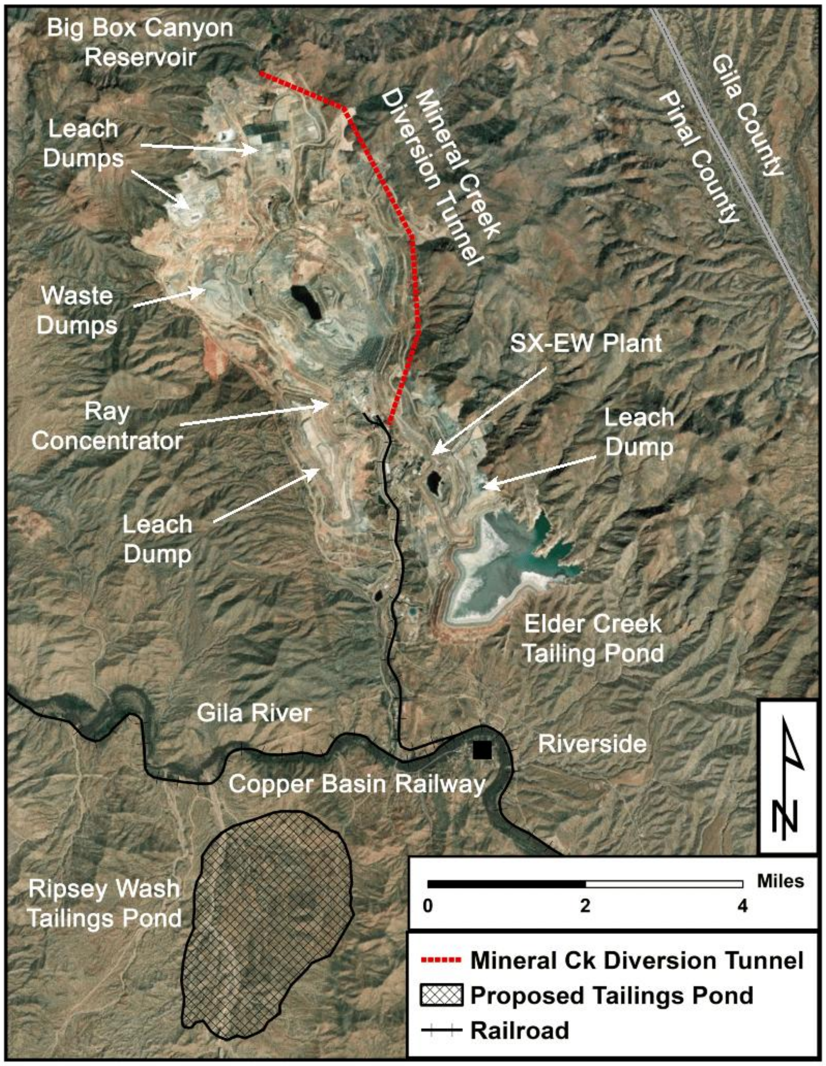

Figure 58. Aerial photo showing current and proposed facilities at the Ray copper mine (imagery from ESRI).

Efforts to divert Mineral Creek around the mining operation also included lining Mineral Creek with concrete, extending from the diversion tunnel outlet to a point south of most of the mining activity, approximately 9,000 feet downstream (Figure 59). It also included the erection of a cut-off wall and pump-back system at the south end of the lined channel as well as controls along the sides of the channel to prevent storm water contamination. Copper stained gravels were also removed from the portion of Mineral Creek, located from the end of the lined channel south to the bridge on Arizona State Route 177 (Thomas, 2007).

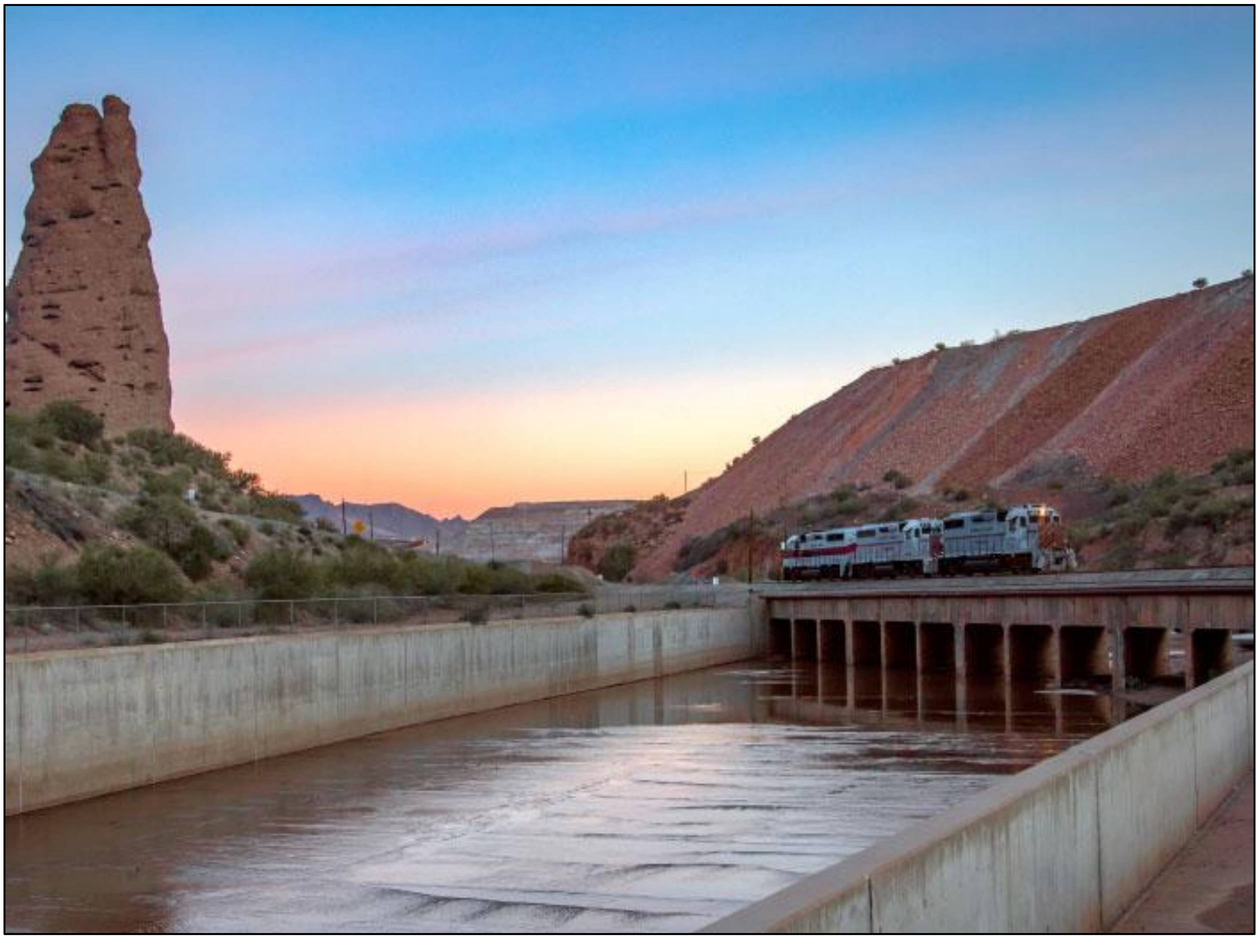

Figure 59. Concrete lining along Mineral Creek immediately downstream from the diversion tunnel outlet and Copper Basin Railway Bridge, looking north toward open pit (photo from ASARCO website).

In its rush to acquire ASARCO, Inc., Grupo Mexico failed to conduct meaningful due diligence prior to making its tender offer. While it was aware of ASARCO's potential environmental and asbestos liabilities, it was assumed they were of no major concern. It was only after the acquisition of ASARCO in November 1999 that Grupo Mexico realized it faced serious problems, which continued to multiply during the years following the merger (Anonymous, 2008).

Copper prices ranging from $0.67 to $0.90 per pound during the early 2000s only compounded these problems. While copper production from 2000 to 2004 at ASARCO's Silver Bell operation remained steady and profitable, it declined by more than 70% at its Mission complex.

In spite of the low copper prices, total copper production at Ray rose from 304 million pounds in 2000 to a record high of 382 million pounds during 2002, when higher grade areas in the pit were mined to generate more income (Niemuth, 2004). However, this was achieved at a cost of deferring maintenance expenditures, waste removal and capital purchases, which were reflected in a sharp decline in Ray’s copper production to 282 and 241 million pounds during 2003 and 2004, respectively (Niemuth, 2005).

By the fall of 2003, the price of copper began to rise, permitting Asarco to resume removal of waste rock at Ray in April 2004. Eighty percent of its stripping goals were achieved by the end of March 2005. Copper production was further impacted by flooding resulting from heavy precipitation during the winter of 2004/2005 and a 50-day suspension of operations at the Hayden smelter for maintenance in early 2005. Matters became more serious in July 2005, when Ray’s union workforce went out on a strike that lasted until November 2005, further reducing Ray’s annual copper production to 225 million pounds during 2005 (Niemuth, 2006).

14.1 Asarco Bankruptcy (2005-2009)

In the years prior to its bankruptcy in August 2005, Grupo Mexico’s subsidiary, ASARCO, Inc. struggled to remain solvent due its past and on-going environmental liabilities. Not only did they have to deal with low copper prices of the early 2000s, but when copper prices began to rise in October 2003, their financial situation had deteriorated to a point that it only delayed the inevitable.

During this period the company cannibalized assets, sold or abandoned other assets, reduced its workforce, high-graded its mining operations, cashed in badly needed insurance policies and cut operating costs. In delaying or refusing to pay creditors, many vendors demanded payment at the time of delivery, resulting in the curtailment of operations at Ray, Mission and Hayden due to a lack of supplies or fuel (Anonymous, 2008). This only hindered ASARCO’s ability to maintain efficient operations, ultimately resulting in lower copper production and higher operating costs.

In an attempt to reduce the debt incurred by this transaction, Grupo Mexico sold several of ASARCO’s non-core assets. Cookson Group plc purchased ASARCO’s Enthone-OMI, a chemical business, for $503 million in December 1999. In May 2000, the American Limestone Company, a construction aggregate, ready-mix concrete and limestone business, was sold to CSR Ltd. for $232 million (Anonymous, 2008).

By the fourth quarter of 2001, ASARCO’s financial problems could no longer be ignored. In September 2001, it technically defaulted on a $450 million debt, prompting ASARCO to consider bankruptcy and restructuring. In October 2001, its debt greatly exceeded sales volume and profit. However, bankruptcy was avoided when Americas Mining Corporation loaned ASARCO $41.75 million in late 2001 to keep it afloat. Between

1999 and 2002 ASARCO (excluding Southern Peru Copper Corporation) incurred net losses exceeding $680 million (Anonymous, 2008).

ASARCO's financial difficulties began to jeopardize its joint venture interest in the Continental copper mine at Butte, Montana during the fall of 2002. It had held a 49.9% joint venture interest in this property since June 1989. Under the terms of its joint venture agreement with Montana Resources, Inc. (50.1%), each partner was liable for "cash calls" to meet the partnership's expenses. In the event a partner was unable to make its share of expenses within 30 days of a "cash call", its interest in the joint venture would be reduced by 1.0% for each $100,000 of capital it failed to contribute (Anonymous, 2013).

Expenditures required by mining ventures are normally funded from its operating revenues. However, production at Butte had been temporarily suspended in July 2000, making it necessary for each of the joint venture partners to contribute its share of the on-going care and maintenance costs. Over a fourteen month period beginning in October 2002, ASARCO failed to make four cash calls totaling more than $5 million that resulted in the reduction of its 49.9% interest to 25.3%, to 3.9%, to 1.2% and finally 0% in December 2003 (Anonymous, 2017).

As early as December 2001, Grupo Mexico began internal discussions about selling ASARCO's equity interest in Southern Peru Copper Corporation as a way to resolve its outstanding liabilities. As the scope of these negotiations was expanded to include lenders and others during 2002, some of ASARCO's creditors voiced concerns about this proposal. Worried about ASARCO's ability to meet its environmental responsibilities if its equity interest in Southern Peru Copper was sold, the U.S. Department of Justice filed a law suit in federal court in August 2002 to prohibit its sale. This resulted in the issuance of a temporary injunction until ASARCO was able to assure its commitments would be kept (Anonymous, 2013).

After further negotiations, Grupo Mexico agreed to temporarily resolve their differences with the U.S. Department of Justice in February 2003. Under the terms of this Consent Decree, Grupo Mexico was permitted to sell ASARCO's 54.2% equity interest in Southern Peru Copper Corporation to Americas Mining Corporation (i.e., a wholly-owned subsidiary of Grupo Mexico) for $765 million, which included a $100 million environmental trust fund to pay Asarco's outstanding environmental liabilities (Grupo Mexico S.A. de C.V., 2003). In return the U.S. government agreed to a three-year moratorium on any attempt to seek legal enforcement of environmental liabilities (Anonymous, 2008).

In June 2004, Grupo Mexico sold the Helvetia-Rosemont property to Triangle Ventures LLC for $4.8 million (Briggs, 2020). Purchased in August 1988, ASARCO had considered mining copper reserves identified at Helvetia-Rosemont after completing operations at its nearby Mission Complex.

By early 2005, ASARCO was once again facing bankruptcy due to increasing cash flow problems and asbestos related and environmental liabilities. In April 2005, Capco Pipe Company and Lac D'Amiante du Quebec Ltee, which were directly involved in asbestos litigation, filed for bankruptcy. ASARCO, Inc. followed these subsidiaries into Chapter 11 bankruptcy in August 2005 (Anonymous, 2008).

A court appointed administrator assumed control of ASARCO after it filed for bankruptcy and began the long road of restoring profitability to its operations. The first order of business was to end the strike that began in July 2005. The impasse was resolved in November 2005, when both sides agreed to extend the previous labor contracts until the end of 2006 (Ducote, 2006). Two days before the labor contracts were set to expire, a new contract was negotiated that not only improved wage and benefits for the workforce, but also required any future owner to honor the union contract once bankruptcy proceedings had been completed (Niemuth, 2007).

Conditions improved for ASARCO during 2006 allowing its U.S. domestic copper production from its mines to rise from 311 million pounds in 2005 to 375 million pounds in 2006. Most of this increase occurred at the Mission Complex, where production increased 150% over the previous year, with Ray and Silver Bell production remaining steady or rising slightly (Niemuth, 2007).

With copper prices averaging $ 3.1475/lb. during 2006, court filings showed ASARCO's net income was $571 million and had accumulated $497 million in cash assets by yearend. With court approval, ASARCO spent some of its cash assets on new operating equipment, ordering nine 400-ton Liebherr T282B haul trucks for Ray that were delivered in late 2006 or early 2007. The Mission Complex also benefited from this purchase by receiving some of the older haul trucks that were relocated from Ray (Neimuth, 2007).

During this period, ASARCO also purchased the Copper Basin Railway for $11.5 million in September 2006 (Niemuth, 2007). Connecting the Ray project with the concentrator and smelter complex at Hayden, this 54-mile-long short line runs from Winkelman to Magma Junction, where it joins a mainline of the Southern Pacific Railroad (now a part of the Union Pacific Railroad) (Figure 60). It also includes short spurs to the Ray mine and Hayden smelter (ASARCO, Inc., 2023).

A complicated bankruptcy process was made more difficult in February 2007. At that time ASARCO filed a separate law suit against Grupo Mexico, claiming if it had not been fraudulently stripped of its equity interest in the Southern Peru Copper Corporation, it would have never gone bankrupt.

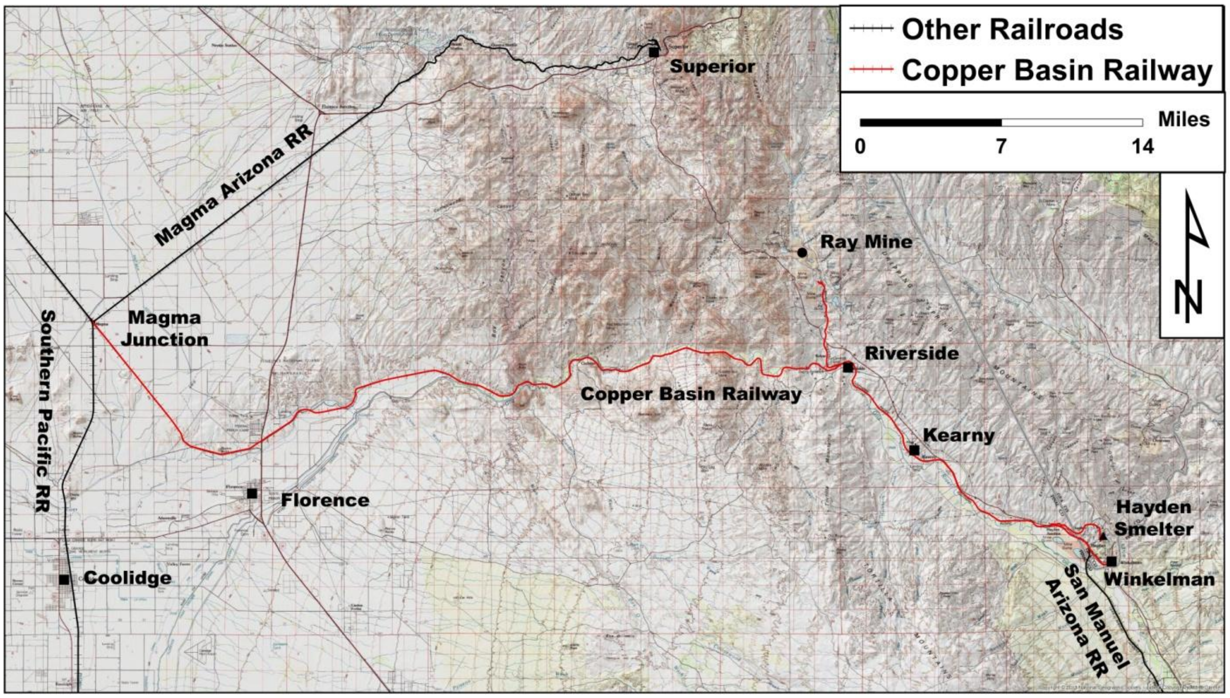

Figure 60. Copper Basin Railway, other railroads, towns, Ray mine and Hayden smelter (modified from ASARCO, Inc., 2023).

With copper prices averaging $3.28/lb. during 2007, production at ASARCO's domestic operations rose to 398 million pounds. Like 2006, most of this increase was recorded at its Mission Complex. ASARCO announced the purchase of a new $46 million in-pit crusher and conveying system for its Ray operation that was expected to be commissioned by early 2009 (Niemuth, 2008).

In March 2008, the Bankruptcy Court of the Southern District of Texas approved a process by which ASARCO would sell its operating assets. With copper prices at a record high (i.e., $3.87 to $4.00/lb.), this resulted in a bidding war between Vedanta Resources PLC (an Indian Corporation) and Grupo Mexico. At the end of May 2008, Vedanta Resources PLC was declared the winner and executed a purchase and sales agreement. However, in response to a collapse of the copper price in October 2008 (i.e., $2.24/lb.), Vedanta Resources informed the Bankruptcy Court for the Southern District of Texas that it could no longer honor its agreement.

This set off a second round of bidding as copper prices tumbled to a low of $1.78/lb. in March 2009. As the price of copper recovered during the summer of 2009, Grupo Mexico ultimately prevailed in its effort to reacquire ASARCO (U.S. Environmental Protection Agency, 2023).

Court approval of an agreement to settle all claims brought during the Chapter 11 process was reached in November 2009, concluding the largest environmental bankruptcy in U.S. history (U.S. Department of Justice, 2009). As a part of the settlement, the Environmental Protection Agency along with other federal and state agencies pursued and received \$1.79 billion to fund environmental cleanup and restoration efforts at more than 90 sites located in 19 states (U.S. Environmental Protection Agency, 2023).

Grupo Mexico reacquired ASARCO’s operating U.S. assets in December 2009. In doing so, it contributed \$705 million in cash and secured financing for \$1.5 billion to recapitalize ASARCO. In addition, ASARCO contributed \$1.357 billion to make a total payment to creditors of \$3.562 billion (Grupo Mexico S.A. de C.V., 2010).

14.2 Grupo Mexico (2009-present)

From 2005 until 2014, annual copper production from Ray has remained relatively steady, ranging from 206 to 235 million pounds. However, by 2019 it had significantly declined to approximately 105 to 111 million pounds, where it remains today.

By the early 2013, the Elder Gulch tailings facility at Ray had been in operation for about 20 years. With only the capacity to store about more 10 years of production from the Ray concentrator, ASARCO submitted a proposal (Section 404) to the U. S. Army Corps of Engineers in March 2013 to construct a new tailings facility (750-million ton storage capacity) in Ripsey Wash (U. S. Army Corps of Engineers, 2016). Following its acquisition of the land from the State of Arizona in 2015-2016, ASARCO received approval from the U. S. Corps of Engineers to construct the Ripsey Walsh tailings facility in December 2018 (Figure 58) (U.S. Army Corps of Engineers, 2018).

ASARCO’s Hayden smelter was among the cleanest smelters constructed and/or modernized by the 1980s; capturing about 95% of its SO_2 emissions, compared with industry-wide SO_2 emissions capture average of 80% to 90% (Arizona Geological Survey, 2017). However, in June 2010, the U. S. Environmental Protection Agency established a new 1-hour standard for SO_2 emissions of 75 ppb replacing the prior standard of 140 ppb 24-hour standard (Russell, et al., 2019).

Realizing they needed a major retrofit to meet this new regulatory standard, ASARCO enlisted support from Gas Cleaning Technologies to study their options. Ventilation upgrades were made on the two natural gas-fired anode refining furnaces during 2012. After approximately four years of research, engineering design and negotiations with state and federal authorities, a consent decree was reached with the U.S.

Environmental Protection Agency in November 2015 (U. S. Environment Protection Agency, 2015).

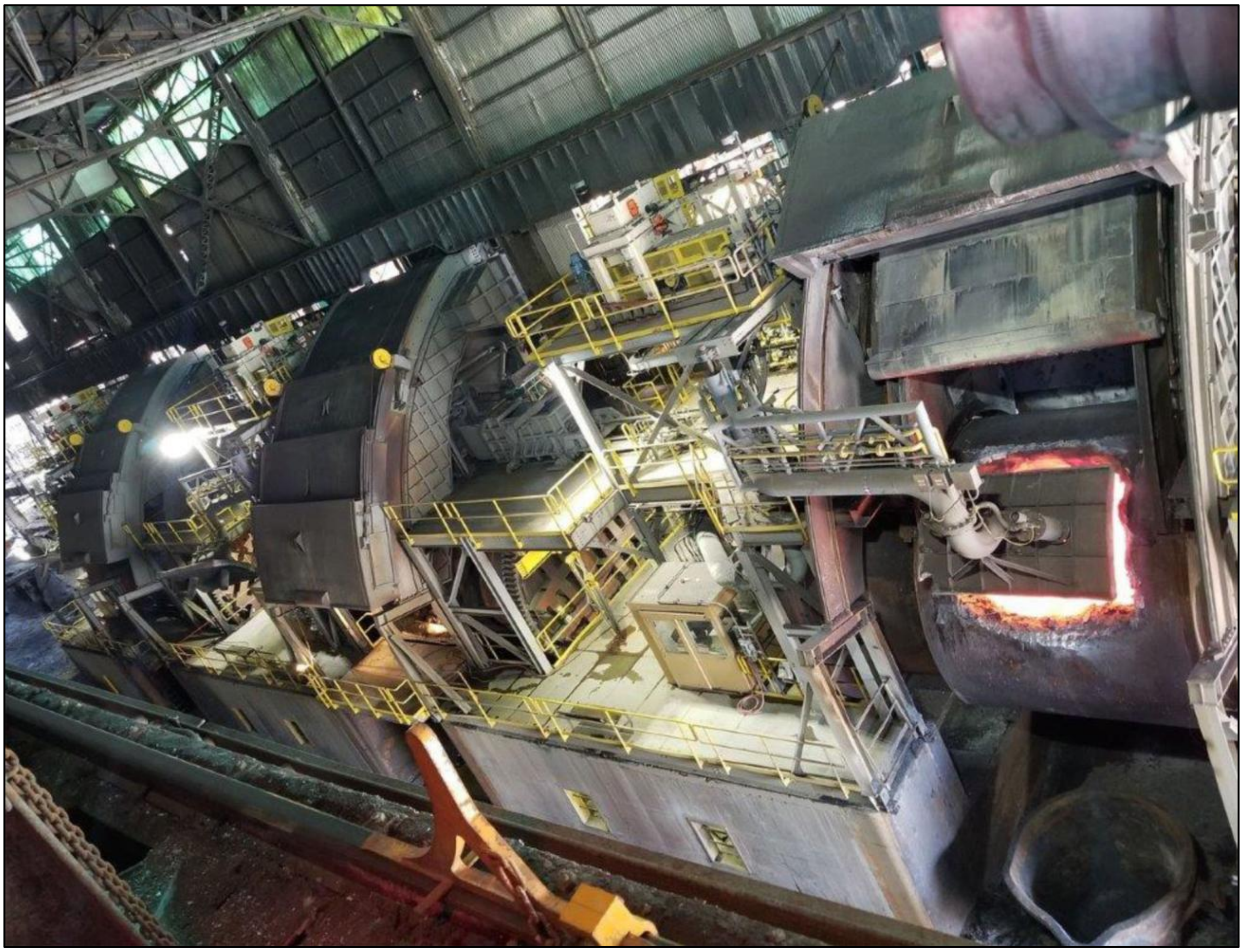

Figure 61. New converter aisle at Hayden Smelter (photo from Russell et al., 2019).

Under the terms of this agreement, the smelter's existing five 13-foot diameter converters were replaced by three 15-foot diameter converters (Figure 61), new ventilation systems installed to capture fugitive gas emissions and the existing sulfuric acid plant modernized (Anonymous, 2017). This project was completed in November 2018 at an estimated cost of $229 million (Lake, 2018; and Russell et al., 2019). Following this retrofit, the Hayden smelting facility captured more than 99% of its SO_2 emissions, making it one of the world's cleanest copper smelters (Russell, et al., 2019).

ASARCO's domestic mining, smelting and refining operations were subsequently negatively impacted by a company-wide strike that began on October 13, 2019. At Ray, cut backs resulted in the temporary suspension of operations at the Hayden concentrator and smelter, while operations at Ray continued on a reduced basis, using workers who decided to remain on the job and new hires.

Since the strikers returned to work on July 6, 2020, both the Hayden concentrator (except for limited reprocessing of smelter slag) and smelter have remained closed, with all mill grade ores from Ray being treated at its on-site concentrator. All copper concentrates from ASARCO's Ray and Mission projects have been shipped to foreign smelters for treatment since October 2019.

Copper production from Ray's milling operations have remained steady since 2017, despite lower concentrator throughputs since 2020 due to the higher head grade of the mill ores (0.51-0.56% Cu) compared to what was treated from 2015 through 2019 (0.33-0.40% Cu). These differences reflect head grades of the primary (hypogene) ores being mined; the diabase is a better host for copper than the Pinal Schist. Since the 2019-2020 strike, treatment of dump leach ores have also significantly declined resulting in a 33% drop in copper recovered at Ray's SX-EW plant.

Table 10. Grupo Mexico production data for 1999-2022 (compiled from data released in Grupo Mexico annual reports and other regulatory filings).

Ore Type	Ore Treated Short Tons	Cu %	Cu lbs.	Mo lbs.	Au Troy Oz.	Ag Troy Oz.
Milled & Direct Smelting Ore	346,497,100	0.55	3,317,306,000	0	0	5,109,428
Dump Leach (SX-EW)	446,275,400	0.33	1,511,421,400	0	0	0
Total Ore Treated	792,772,500	0.43	4,828,727,400	0	0	5,109,428

Between November 1999 and December 2022, the Mineral Creek mining district recovered approximately 4.8 billion pounds of copper from milling and dump leaching operations (see Table 10).

As of December 2023, ASARCO's Hayden smelter remains closed. Future plans for this facility remain on hold, while Grupo Mexico considers its options; to resume smelting operations at Hayden, permanent closure, or to sell the facility.

15 SEARCH FOR THE SOURCE OF EXOTIC CU

The presence of altered and mineralized Pinal Schist along the Gila River east of Cochran and exotic copper mineralization at Copper Butte has been known since the turn of the 20th century. This eventually led to a search for concealed porphyry copper targets beneath post-mineral cover in a basin of Whitetail Conglomerate situated between Copper Butte and exposures of Pinal Schist along the Gila River near Cochran.

One of the first deep exploration drill holes to examine the potential of this area was financed by Martha Purcell, which was drilled approximately 4,500 feet southwest of the

Copper Butte mine in 1951. Collared in Whitetail Conglomerate in the hanging wall of the Spine Canyon Fault, this effort encountered minor pyrite mineralization with weak secondary chalcocite hosted by Pinal Schist at a depth of approximately 2,000 feet (John and Fountain, 1994). In an interesting side note, Martha Purcell was also involved in early exploration efforts that eventually lead to the discovery of the Kalamazoo copper deposit by Quintana Minerals Corporation in 1967 (Lowell, 1968).

Subsequent deep exploration drilling in the area west of Copper Butte during the early 1970s by Bear Creek Mining Company (i.e., an exploration division of Kennecott), Quintana Minerals Corporation, and ASARCO delineated a large zone of moderate quartz-sericite-pyrite alteration with minor amounts of chalcopyrite and chalcocite hosted by Pinal Schist northwest of the Purcell drill hole, which is now known as Ray West (Scott and McDonnell, 1989; and Maher, 2008). While significant, the copper grades encountered failed to meet expectations.

In 1960 Bear Creek Mining Company began a comprehensive exploration program, consisting of detailed geological mapping, geochemical sampling and geophysical surveys over a large claim block southwest of the Copper Butte mine, resulting in the discovery of the exotic copper occurrence at Buckeye East (John and Fountain, 1994).

Exploration drilling by Bear Creek Mining Company at Buckeye West (DDH CB-75 – located 900 feet north and 200 feet west of SE Corner Section 33, T3S, R12E) during September 1973, encountered approximately 120 feet of leached cap and 654 feet of weak chalcocite (assaying between 0.1 to 0.5% Cu) in quartz-sericite-pyrite altered Pinal Schist concealed beneath approximately 550 feet of post-mineral Tertiary cover. At a depth of 1,476 feet, a low-angle fault (i.e. Grayback Fault) was encountered. Unmineralized propylitically altered Tea Cup Granodiorite in the footwall of the Grayback Fault was present to a depth of 1,744 feet. Subsequent exploration efforts by Kennecott and ASARCO confirmed the discovery at Buckeye West, identifying a large, but undefined, zone of weak supergene enrichment hosted by phyllic altered Pinal Schist (Grupo Mexico S.A. de C.V., 2023).

After commencing treatment of oxide ores at the Ray early 1969, Kennecott’s Ray Mines Division exercised the Bear Creek Mining Company option to purchase the Copper Butte property in 1971. This asset along with their adjacent exploration holdings was subsequently transferred to ASARCO, Inc., when it purchased the Ray mine in November 1986 (John and Fountain, 1994).

15.1.1 Lessons Learned

While deep exploration drilling (1,000- to 3,000-foot) was successful in finding exotic copper mineralization at Buckeye East and weakly mineralized quartz-sericite altered

Pinal Schist at Ray West and Buckeye West, it failed to discover the porphyry copper target thought to be concealed by post-mineral cover in this area (John and Fountain, 1994). This puzzled exploration geologists for many years.

Where is the source for the exotic copper and large concentrations of altered clasts contained within the Whitetail Conglomerate? How does one explain the large area of weakly mineralized, phyllic altered Pinal Schist underlying the Whitetail Conglomerate? As early as 1968, John E. Welch, a Kennecott Exploration Services geologist, postulated the sulfide source for the copper was the Ray deposit, located about 5 miles northeast of Copper Butte, but failed to explain large areas of altered Pinal Schist underlying Whitetail Conglomerate at Ray West and Buckeye West, and exposed along the Gila River northeast of Cochran (John and Fountain, 1994). It would take another 40 years of research to explain the spatial distribution of the observed mineral and alteration assemblages (shown in section A-B-C of Figure 10). This task was made more difficult by the post-mineral cover that concealed much of the area southwest of Granite Mountain.

A detailed structural reconstruction of the region by Maher (2008) and later work by Favorito (2020) suggests the mineral and alteration assemblages observed along this northeast trending traverse represent portions of two partially superimposed porphyry copper systems at Mineral Creek. Post-mineral crustal extension along five sets of normal faults have dismembered the Granite Mountain and Teapot Mountain porphyry copper systems that are progressively tilted from approximately 30 degrees to the northeast at Ray to about 90 degrees to the northeast at Pioneer-Alabama.

A traverse from Ray Silver deposit, southwest to Granite Mountain represents a cross-section of the Ray porphyry copper deposit that has been dismembered and tilted to the northeast by post-mineral extensional faulting. The polymetallic deposit at Ray Silver represents the upper portions of the system, while deeper greisen alteration exposed along the western flank of the Granite Mountain is situated at deeper levels.

Allochthonous phyllic alteration assemblages encountered by drill holes at Ray West, Buckeye West, and Pioneer-Superior occupy the hanging wall of the Copper Butte Fault and/or related structures. Post-mineral dismemberment of the Ray West porphyry copper deposit transported upper peripheral slices of the weakly mineralized quartz-sericite halo southwestward to produce the observed distribution of mineral and alteration assemblages west of Granite Mountain. Absence of a preserved ore shell at Ray West, is best explained by post-mineral deformation, uplift, and erosion, which resulted in the development of widespread exotic copper resource hosted by Whitetail Conglomerate.

In some regions many seemingly unrelated mineral occurrences dot a landscape that is the product of a long and complicated geologic history. Back to basics field work combined with a better understanding of these mineral occurrences, tectonic processes and data gathered from well thought out exploration programs suggest deposits at Mineral Creek are related to several large, dismembered porphyry copper systems (i.e., Ray, Ray West and Red Hills).

In regions, such as the Southern Basin and Range Province of Arizona, more than a century of exploration activity has already identified the most obvious ore deposits. Unraveling this region's complex geological history is the key to future exploration successes, where undiscovered mineral resources remain concealed as a result of post-mineral deformation and/or buried beneath younger sedimentary/volcanic cover.

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