

# History of the Silver Bell Mining District, Pima County, Arizona

David F. Briggs



Oblique aerial view of the Silver Bell mining district, looking southeast, circa 2000.

May 2017

**CONTRIBUTED REPORT CR-17-A**  
**Arizona Geological Survey**

[azgs.arizona.edu](http://azgs.arizona.edu) | [repository.azgs.az.gov](http://repository.azgs.az.gov)



# Arizona Geological Survey

Phil A. Pearthree, Director

Manuscript approved for publication in May 2017

Printed by the Arizona Geological Survey

All rights reserved

For an electronic copy of this publication: [www.repository.azgs.az.gov](http://www.repository.azgs.az.gov)

For information on the mission, objectives or geologic products of the Arizona Geological Survey visit [azgs.arizona.edu](http://azgs.arizona.edu)

This publication was prepared by a department of the University of Arizona. The University of Arizona, or any department thereof, or any of their employees, makes no warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed in this report. Any use of trade, product, or firm names in this publication is for descriptive purposes only and does not imply endorsement by the University of Arizona

Arizona Geological Survey Contributed Report series provides non-AZGS authors with a forum for publishing documents concerning Arizona geology. While review comments may have been incorporated, this document does not necessarily conform to AZGS technical, editorial, or policy standards. The Arizona Geological Survey issues no warranty, expressed or implied, regarding the suitability of this product for a particular use. Moreover, the Arizona Geological Survey shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this product. The author(s) is solely responsible for the data and ideas expressed herein.

---

Recommended Citation: Briggs, D.F., 2017, History of the Silver Bell Mining District, Pima County, Arizona. Arizona Geological Survey Contributed Report CR-17-A, 26 p.



# History of the Silver Bell Mining District, Pima County, Arizona



Some of the many desert bighorn sheep that live in the Silver Bell mining district. Looking east with the El Tiro waste dumps in the background.

by David F. Briggs, Geologist

## **Introduction**

Recognition and dogged pursuit of economic opportunities throughout southern Arizona during decades spanning the turn of the 20th century provided the stable foundation for later growth and prosperity. The story of the Silver Bell mining district exemplifies the role copper mining played in the area's rich history.

Over the past 150 years, the Silver Bell mining district evolved from a collection of small, intermittent, poorly financed and managed underground mining operations that struggled to make a profit from high-grade ores; to a small but profitable producer, deploying innovative mining practices and advancements in technology to successfully develop the district's large, low-grade copper resource.

## **Early Years (Prior to 1903)**

Primitive mining activities in the Silver Bell mining district pre-date the arrival of Spanish explorers during the 1530s. Shallow trenches and pits in the area were excavated by the Tohono O'odham Indians and/or their predecessors for turquoise, hematite and clay, which were used for pottery, paint and decorative purposes (Briscoe, 1968).

The discovery of small irregularly distributed pockets of high-grade silver mineralization (15 to 17 oz. Ag/ton) at the Old Boot mine attracted prospectors to the southwestern flank of the Silver Bell Mountains around 1865 (Hardwick, 1963). Its remote location - 35 miles northwest of Tucson, Arizona - and lack of potable water impeded development of this mining camp.

Under the leadership of Charles O. Brown of Tucson, copper mining began at the Old Boot mine, also known as the Mammoth mine, in 1873 and the Young America mine in 1874 (Anonymous, 2016). Hand-sorted high-grade ores from these early operations were shipped by wagon to Yuma, Arizona for transshipment via boat to San Francisco smelters (Graybeal, 1991). In an effort to reduce the high costs of transporting ores to distant smelters, a small blast furnace was erected at the site of the Young America mine during the summer of 1874 (Rickard, 1987).

Mining activities at Silver Bell increased following the completion of the Southern Pacific Railroad to Tucson from the west in March 1880. Although access to the railroad at Red Rock significantly reduced the costs of transporting goods and supplies to and from this remote mining camp, the profitability of the mines at Silver Bell remained marginal at best.

The Mammoth, Union, Young America (aka Oxide), and other small prospects were intermittently worked by a number of short-lived partnerships, companies and lessees during the 1890s (Figure 1). Among these early producers were the English-based Silver Bell Mining And Smelting Company Ltd. and Tucson Mining and Smelting Company Ltd. (Anonymous, 2016).

One of the more notable partnerships of the late 19th century involved Louis and William Zeckendorf and Albert Steinfeld, Jewish immigrants from Germany, who ran a prosperous mercantile business based in Tucson that distributed goods throughout Arizona and Sonora, Mexico. In addition to investments held in local farming and ranching businesses, they also held interests in mining ventures throughout southern Arizona, including properties located in the Bisbee, Mineral Creek, Oro Blanco, Helvetia and Silver Bell mining districts. By the early 1900s, the Zeckendorf/Steinfeld partnership acquired a large claim group in the Silver Bell mining district that included the Mammoth and Union mines in the northwest portion of the district (Anonymous, 2016).

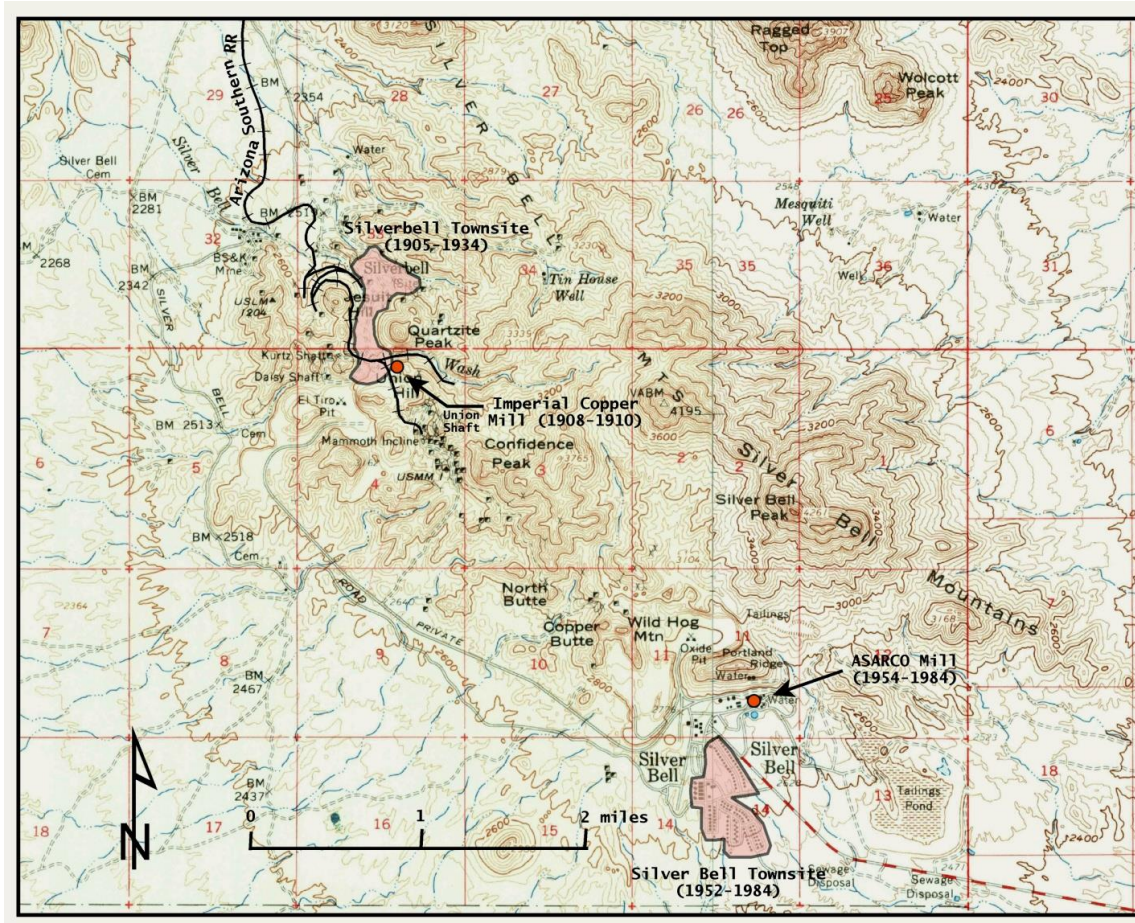
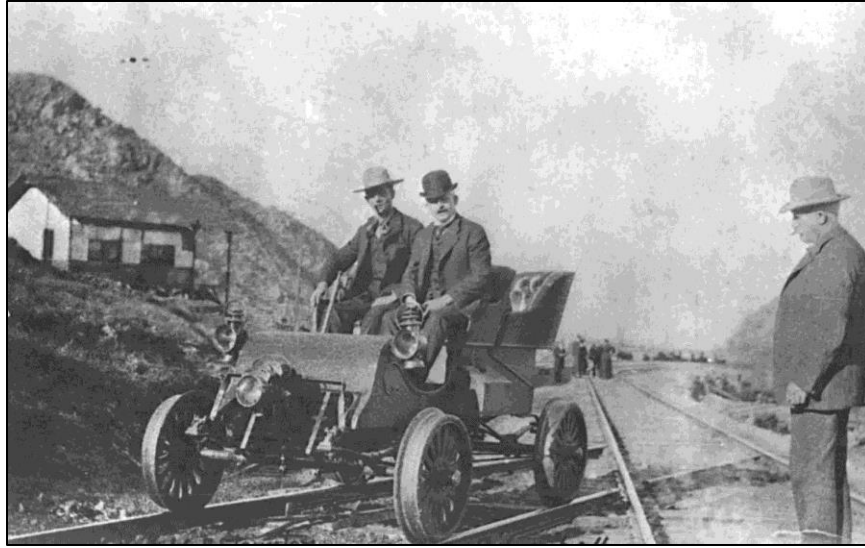


Figure 1. Topographic map of Silver Bell mining district showing townsites, historical mines, mills and railroad.

### Building a Business Empire (1901-1910)

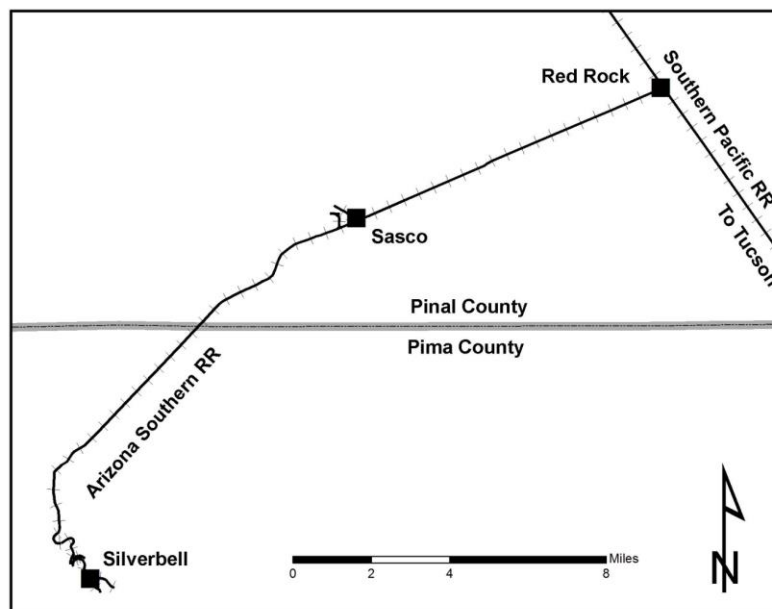
The Development Company of America played an important role in the early development of the copper resources of the Silver Bell mining district. This holding company was incorporated by Frank M. Murphy in November 1901. Like other successful mining entrepreneurs of the time, he recognized successful mining ventures required reliable transportation and affordable processing facilities. The Development Company of America held controlling interests in its investments, enabling it to manage and finance a network of mines, processing plants and railroads (Berg, 1999). Notable Arizona holdings of the Development Company of America included Congress Consolidated Mines Company Ltd., Poland Mining Company, Imperial Copper Company, Southern Arizona Smelting Company, and Tombstone Consolidated Mines Company Ltd. (Stevens, 1911).

The Imperial Copper Company was incorporated by the Development Company of Arizona on May 15, 1903 under the laws of Arizona with initial capitalization of \$5 million at \$10/share (Stevens, 1906). Murphy's longtime business partner and experienced investor, Elipthlet B. Gage was appointed president of Imperial Copper and experienced mining engineer, William F. Staunton served as its general manager (Figure 2). Imperial Copper purchased the Silver Bell holdings of the Zeckendorff/Steinfeld partnership on May 20, 1903 for \$115,000 in cash and a note for \$400,000 that was paid in quarterly installments over a twelve month period at six percent interest (Berg, 1999 and Lyons, 2000).



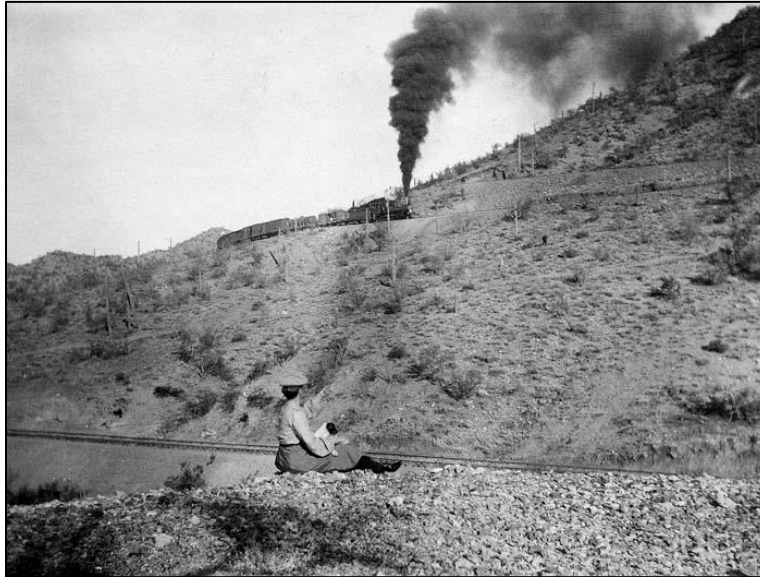
**Figure 2. William Staunton (left) and Elipthlet Gage (far right) with rail car at Silverbell. The individual sitting next to Staunton appears to be Frank Murphy (Photo provided by the University of Arizona, Special Collections).**

At the time of Imperial Copper's acquisition, infrastructure at Silver Bell included a small 50-ton capacity smelter at the mine site. Processed copper from this facility was hauled by wagon to a railhead on the Southern Pacific Railroad at Red Rock at a cost of approximately 9 cents per pound. With copper selling for 12 to 14 cents per pound, William Staunton estimated net profits from existing reserves would be between \$528,000 and \$880,000. Staunton argued operating costs could be reduced to 6 cents per pound by erecting a 300-ton capacity smelter and building a rail line to Red Rock. Not only could this increase estimated net profits to \$1,408,000, but this facility could handle lower grade ores allowing them to increase their reserve base, and generate additional income by custom smelting ores from other mines. These additional projects were financed through the issuance of \$2 million of mortgage bonds to the Bankers Trust Company of New York at an interest rate of 6% (Berg, 1999).



**Figure 3. Early Infrastructure at the Silver Bell mining district.**

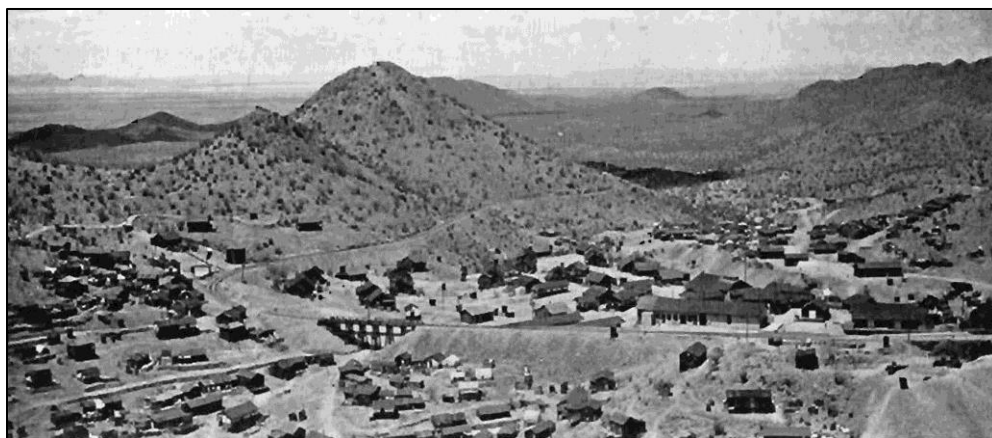
With financing in place, the initial step in realizing their goal was incorporating the Arizona Southern Railroad Company in January 1904 (Irvin, 1987). Connecting the mine site with the Southern Pacific Railroad at Red Rock, this 20.6-mile standard gauge rail line was completed in September 1904 (Figure 3). The final four miles of the rail line employed a series of three switchbacks carved into the slopes of Jesuit Hill that negotiated the 400-foot change in elevation required to reach the Silverbell town site and mines (Figure 4).



**Figure 4. Steam locomotive climbs Jesuit Hill on its way to the town of Silverbell, circa 1909 (Photo provided by the Sharlot Hall Museum).**

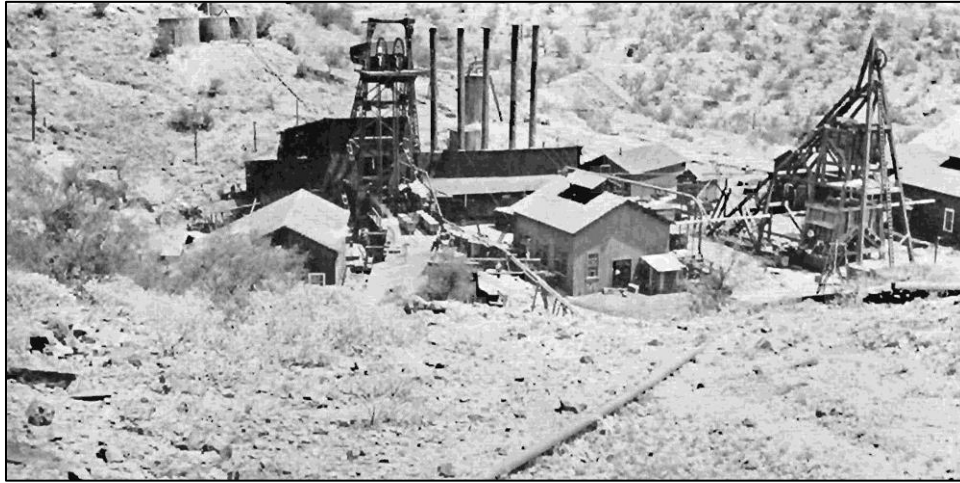
Imperial Copper commenced production in September 1904 with the shipment of high-grade ores to the Copper Queen smelter in Douglas, Arizona (Stevens, 1905).

Shortly after its formation, Imperial Copper also established the town of Silverbell at the site of the 1880s mining camp (Figure 1). Consisting of shacks, tents and lean-tos, this community rapidly grew to 1,000 by 1905 (Figure 5). It included a post office, mine offices, railroad, a Wells Fargo station, company store, hotel, general merchandise store, a school, several saloons, billiard parlor, two bakeries, a dairy, two firehouses, theater and an auto stage (i.e. motorized stagecoach or bus) (Anonymous, 2016).



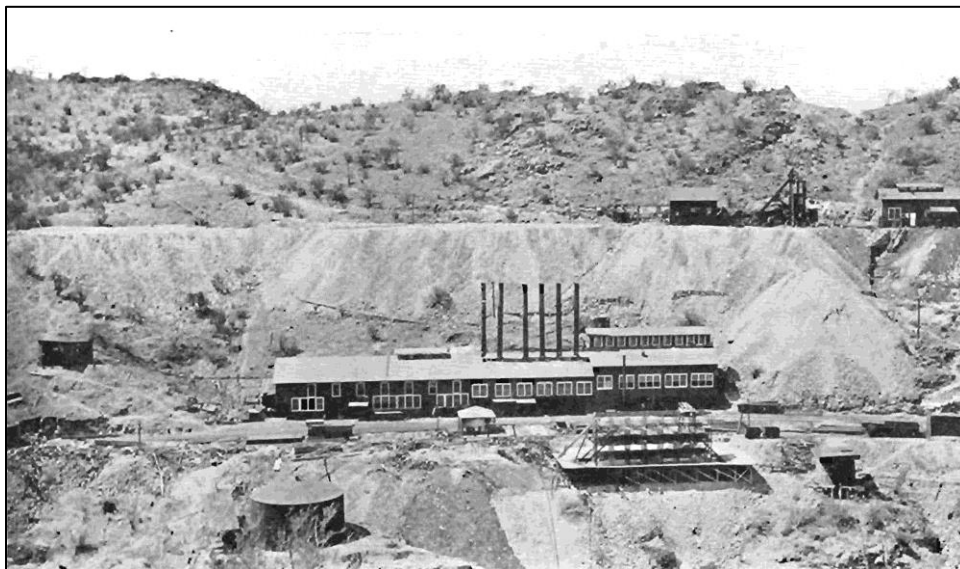
**Figure 5. Town of Silverbell, looking north toward Jesuit Hill, circa 1910 (Stewart, 1912).**

This Silver Bell Mountains and environs suffered from a lack of readily available potable water due the high mineral content of the local groundwater water. Throughout its brief history, drinking water was imported, first by mule and wagon and later by rail. The town's water supply was stored in tanks located adjacent to the company store and piped to two taps that were turned on for two hours each morning and night and sold to the town's residents (Anonymous, 2016).



**Figure 6. Headframes accessing a 700-foot vertical and 900-foot inclined shafts at Mammoth Mine, circa 1910 (Stewart, 1912).**

The Mammoth, Union and Billy mines were important producers for the Imperial Copper Company (Figures 6 and 7). Other important early claim groups included the El Tiro property (Daisy, Kurtz and Burtis shafts), located immediately west of Imperial Copper holdings in the northwest portion of the district and the Young America mine in the southeastern portion of the district. The El Tiro property was controlled by the Cleveland-Arizona Mining Company, which was succeeded by the El Tiro Copper Company in May 1907. The Young America mine was controlled by the Oxide Copper Company (Stevens, 1911).

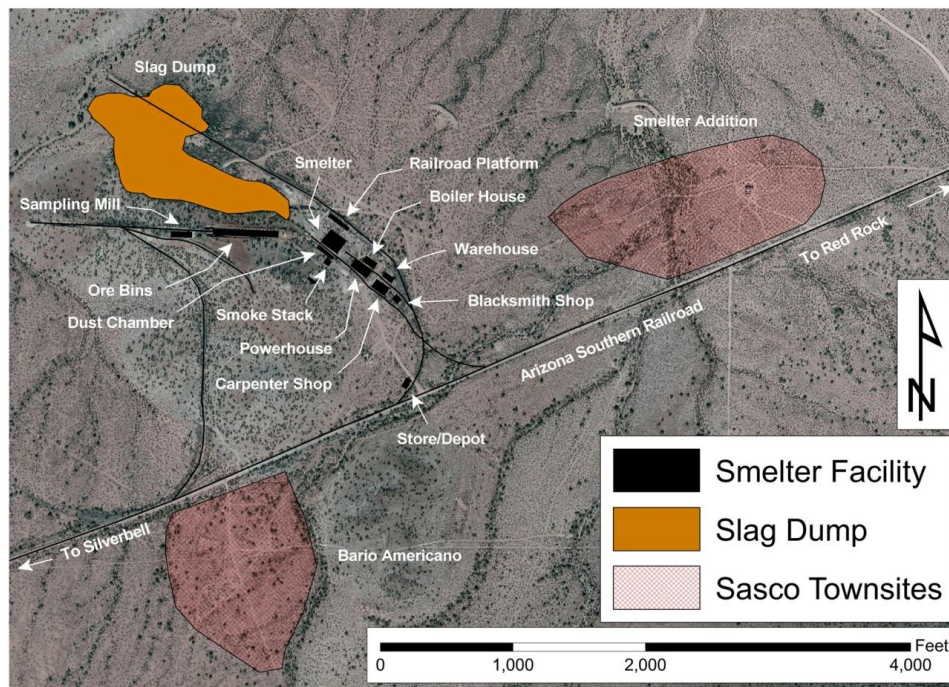


**Figure 7. 450-foot Union shaft (upper mine dump) and power houses, circa 1910 (Stewart, 1912).**

## Development of the SASCO Smelter (1905-1910)

While establishing a rail connection between the mine and main line of the Southern Pacific Railroad at Red Rock was completed during the fall of 1904, financing and planning for the new smelting facility required more time and effort. Envisioned to employ a single 300 to 350-ton blast furnace with provisions for adding a second furnace later, all aspects of its construction and operation were performed by the Development Company of America or its subsidiaries (Berg, 1999).

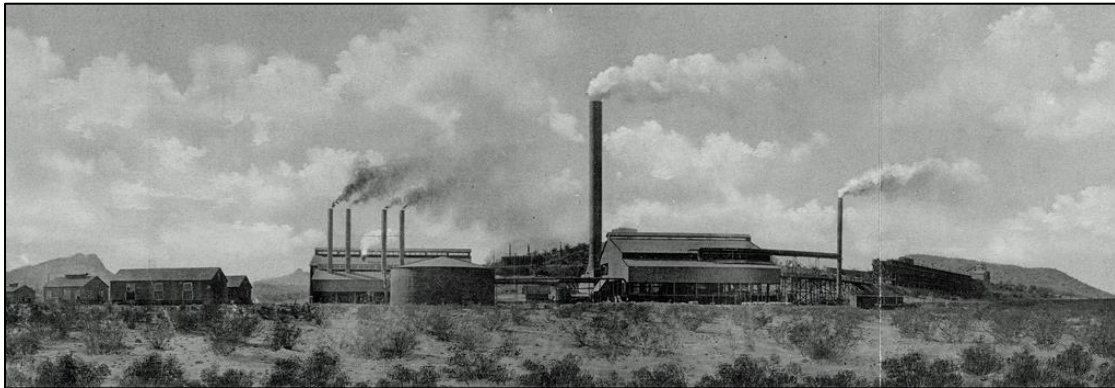
One of the most crucial aspects of this project was finding an ideal location to build the smelter, which required a level building site, reliable water supply, and easy access to the railroad. The existing mine site was poorly suited due to the rough terrain and the insufficient water. William Staunton ultimately chose a site below a low hill near Cerro Prieto, located adjacent to the Arizona Southern Railroad right-of-way, approximately seven miles southwest of Red Rock and twelve miles northeast of the town of Silverbell. This small hill was the perfect location for the smelter's water tanks and ore bins, while nearby volcanic outcrops provided stone for construction (Figure 8). A reliable source of water was available via an 8-inch, 2-mile long pipeline from wells along the Santa Cruz River. Located on federal lands, the Development Company of America petitioned the U.S. government to have the area surveyed and eventually acquired the property rights through purchases and land scrip (i.e. certificates granting private ownership) (Berg, 1999).



**Figure 8. Layout of SASCO smelter and townsites of Sasco (modified from Berg, 1999).**

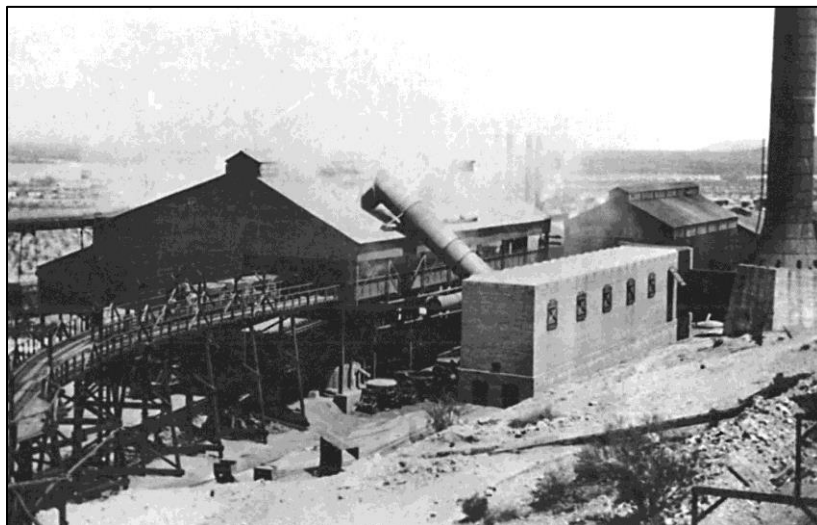
On August 10, 1906, the Development Company of America incorporated the Southern Arizona Smelting Company (SASCO) with an initial capitalization of \$1.5 million at \$100/share (Stevens, 1911). Approximately 53% of stock was held by the Imperial Copper Company. Eliphlet B. Gage was appointed president of Southern Arizona Smelting, while William F. Staunton served as its General Manager (Berg, 1999). Another of Frank Murphy's associates, Mead Goodloe, who worked as assayer at the Congress mine, was made smelter superintendent (Berg, 1999).

SASCO commenced construction of the smelter during the summer of 1907. This effort was hampered by economic uncertainties resulting from the Panic of 1907 (October 1907), which made it difficult to obtain workers and materials. Despite these challenges, the first blast furnace was commissioned on February 5, 1908 and the second furnace came on-line during November 1908 (Anonymous, 1910). It was one of the Arizona's last large smelters to employ blast furnaces for the primary smelting of ores (Figure 9). At the time of its construction, most smelters were converting their facilities to more modern reverberatory furnace technologies that were better suited for processing milled concentrates.



**Figure 9. Panorama of power plant and smelting facilities at Sasco, circa 1910 (Photo provided by the Marana Heritage Conservancy).**

The smelting process relies on the simple principle that most valuable metals like copper, gold and silver are heavier than the more common minerals (i.e. quartz and feldspar) contained within the ores. Once the ores are melted, the heavier more valuable minerals tend to sink to the bottom of the furnace, while the lighter gangue minerals that make up the slag tend to float. By skimming off the lighter slag, the more valuable ore minerals are concentrated to produce a high-grade product known as matte.



**Figure 10. Close up of the smelter and dust chamber as viewed from the ore bins. Note the slag pot being filled at the settler at the rear of building, circa 1908 (Photo provided by the University of Arizona, Special Collections).**

This facility included two 300-ton, water-jacketed, blast furnaces capable of producing a 42% copper matte product, which was upgraded by one of two converters to produce a blister copper product, averaging 99.3%

copper with minor amounts of gold and silver (Stevens, 1911). The metal values contained within fines suspended within the gases generated by the smelting process were allowed to settle out in a dust chamber prior to the discharge of the gases through a 175-foot smoke stack (Figure 10).

Although this facility mainly treated ores from Imperial Copper's Silver Bell operation, ores from the El Tiro and Oxide Copper properties were also treated on custom basis.

Early development of the town of Sasco was situated across the railroad tracks, south of the smelter. This community initially consisted of a collection of wood and canvas cabins scattered around a row of company-owned buildings, which included a boarding house and mess hall that provided living quarters for the single workers. Well-to-do families built more comfortable and permanent homes. As this original community matured, it became known "Barrio Americano", which was largely the home of the smelter supervisors and engineers (Berg, 1999).

By mid-1908, the influx of workers to the area made it necessary to survey a second series of townsite lots, known as the "Smelter Addition." Located on the north side of the railroad tracks, northeast of the smelter, this site became the center of Sasco's working class community, composed of individuals dominantly of Mexican heritage, but also included recent immigrants from Germany, Denmark, England, Canada, Sweden and the Philippines (Berg, 1999).

Typical of other western mining operations at the turn of the 20th century, employment opportunities for Mexican and Mexican-American workers were limited low-level jobs, while higher paying positions were held by Anglos. Daily wages for a 10 to 12 hour shift ranged from \$1.75 for unskilled laborers to \$4.50 to \$5.00 for engineers and foremen (Berg, 1999).

By the spring of 1909, the town of Sasco had grown to 600 residents, including 175 men on the company payroll. It included a several stores, saloons, hotel and restaurants as well as a 500-kw power generating plant that provided electricity to the smelter and the towns of Sasco and Silverbell (Berg, 1999).

### **Poor Decisions Doom Imperial Copper's Operations**

With the depletion of the higher grade, direct smelting ores, Imperial Copper commissioned a 300-ton/day gravity concentrator at Silverbell in September 1908 at a cost of approximately \$165,000. This facility employed a combination of jigs, tables and vanners to produce a concentrate product that was suitable for smelting (Stevens, 1911).

Throughout its short life, the Development Company of America and its subsidiaries financed the development of their operations through corporate bonds and loans. Interest on this debt compounded by the failure of some of their operations to produce expected profits left them at risk to the misfortune that befell their Tombstone operation on June 1, 1909.

In June 1901, properties of the Grand Central Company, Tombstone Mill and Mining Company and Contention Company were consolidated under the management of Tombstone Consolidated Mines Company Ltd. (Butler et. al., 1938). Development Company of America was persuaded to finance needed dewatering efforts in exchange for a substantial portion of its stock. Although expensive, these efforts successfully lowering the water to the 1,000-foot level after six years, allowing operations to resume production. However, on June 1, 1909, a shipment of contaminated fuel extinguished the fires in the boilers, shutting down the steam-driven dewatering pumps. The mine workings were flooded within hours. Although efforts were made to stem the flow of water and reclaim the flooded workings, the cost of this attempt combined with thousands of dollars of destroyed equipment and lost production ultimately lead to the closure of Tombstone Consolidated Mines' operations on January 18, 1911.

Frank Murphy's decision not to cut Tombstone Consolidated's losses resulted in far reaching implications for Development Company of America's other operations. A dispute over this decision resulted in William Staunton's resignation from posts he held with the Imperial Copper Company and other Development Company of America subsidiaries in May 1910 (Berg, 1999). With the working capital needed to continue operations at Silver Bell diverted to Tombstone, Imperial Copper was unable to develop sufficient high-grade ore to continue profitable operations at the SASCO smelter. All mining and smelting operations at Silver Bell were suspended on August 10, 1910.

Many of the private businesses left after the mines closed, only a grocery store and saloon surviving. Unable to obtain a \$500,000 loan from the Southern Pacific Railroad, the Imperial Copper Company declared bankruptcy in July 1911 (Graybeal, 1991). Its assets and those of the Arizona Southern Railroad Company and the Southern Arizona Smelting Company were placed under the management of M. P. Freeman, who served as receiver and trustee. Over the next six years, efforts to reorganize these businesses failed as Frank Murphy and lawyers representing the various creditors fought over the distribution of companies' assets (Berg, 1999).

### **ASARCO to the Rescue (1914-1930)**

In response to the increase in the demand for copper accompanying the onset of hostilities in Europe in July of 1914, a number of companies re-examined the mineral potential of the Silver Bell mining district. One of these firms was the American Smelting and Refining Company (ASARCO), who initially evaluated Imperial Copper's property in early 1915. Based on recommendations of H. A. Guess, a mining engineer, ASARCO representatives began negotiations with Frank Murphy and the lawyers representing major creditors (Graybeal, 1991). The foreclosure was approved by the courts in early 1916 and Imperial Copper's holdings were transferred to Leo Goldschmidt, who had been appointed receiver in March 1915. In March 1916, Goldschmidt transferred the stock and deeds to the mine, smelter and railroad to ASARCO, pending consummation transaction. Based on the final agreement, ASARCO agreed to settle the companies' remaining debts and organize the properties under a new corporation, in which Frank Murphy would own 35% interest. ASARCO would in turn lease these holdings from the new organization and remit 50% of its profits to a fund that would be used to pay off the debts owed to creditors (Berg, 1999).

This agreement didn't set well with a number of small creditors, who felt Frank Murphy was manipulating the bankruptcy proceedings for his own benefit and that of a few major investors. Legal sparring continued until Murphy's death on June 23, 1917 brought most of this litigation to an end (Berg, 1999).

Encouraged by the high copper prices of the World War I era, ASARCO refurbished the rail line connecting Silverbell with Red Rock and resumed operations at Silver Bell and the Sasco smelter in May 1916 (Weed 1918). Limited copper production was also renewed at the El Tiro and Young America mines. The population of Silverbell and Sasco temporarily rebounded to 1,200 and 1,000, respectively (Berg 1999 and Anonymous, 2016).

The end of World War I in November 1918 brought a decline in the price of copper. El Tiro Copper Company was sold at public auction in January 1919 under a mortgage foreclosure sale to G. D. Bouton, who served as trustee for the bond holders. It was subsequently leased to the El Tiro Leasing Company, which was incorporated in April 1919 to resume operations at the site (Weed, 1922).

With the decline in production from Silver Bell's mines following the end of World War I, ASARCO permanently closed the Sasco smelter in early 1919. Silverbell and Sasco's subsequent decline was further hastened by the Spanish Flu pandemic that struck during the winter of 1918-1919, resulting in the deaths of many of the area's residents (Berg, 1999).

Following the closure of the Sasco smelter, ASARCO continued limited shipments of ore to its Hayden smelter prior to suspending all mining operations at Silver Bell in late 1920 (Heikes, 1922). All production ceased with the closure of El Tiro Leasing Company's underground operations in April 1921 (Heikes, 1924).

The Silver Bell mining district remained idle until October 1922, when the El Tiro Leasing Company resumed production from the Kurtz shaft (Heikes, 1925). Operations at the El Tiro Leasing Company's mines accounted for most of the district's production until June 1928, when ASARCO acquired control of the El Tiro property (Anonymous, 1957). Following the crash of the stock market in October 1929, falling copper prices once again forced Asarco to suspend its Silver Bell operations in January 1930. With its decision not to exercise its option on the El Tiro property in February 1930, ASARCO returned the property to its owners (Gerry and Miller, 1933).

**Table 1. Underground Mine Production at Silver Bell Mining District (1885-1930) (Keith, 2016).**

| Mine                  | Period    | Ore<br>Short Tons | Cu<br>Lbs  | Pb<br>Lbs | Zn<br>Lbs | Au<br>Oz | Ag<br>Oz  |
|-----------------------|-----------|-------------------|------------|-----------|-----------|----------|-----------|
| Atlas                 | 1915-1928 | 1,783             | 181,896    | 0         | 253,705   | 2        | 2,325     |
| Copper Blossum        | 1929-1930 | 748               | 41,420     | 5,012     | 0         | 90       | 739       |
| El Tiro               | 1905-1930 | 201,668           | 21,290,417 | 712,420   | 0         | 15       | 33,595    |
| Imperial-Mammoth      | 1887-1930 | 1,061,448         | 74,195,421 | 166,554   | 150,835   | 139      | 1,028,424 |
| Young America         | 1885-1918 | 4,146             | 892,542    | 0         | 0         | 450      | 5,420     |
| Other Small Producers | 1916-1929 | 297               | 17,577     | 15,479    | 0         | 4        | 1,738     |
|                       |           |                   |            |           |           |          |           |
| Total UG Production   | 1885-1930 | 1,270,090         | 96,619,273 | 899,465   | 404,540   | 700      | 1,072,241 |

Total production from underground operations at Silver Bell prior to closure in early 1930 was approximately 1.27 million tons of ore, which yielded about 96.6 million pounds of copper (Table 1). Most of this early production consisted of high-grade copper ores that were shipped to the Sasco smelter or other facilities.

When the mines closed in early 1930, the population of Silverbell, which averaged around 500 during the 1920s, fell to fewer than 50 by 1931 (Anonymous, 2016). Limited rail service to Silverbell continued until December 1933, when it was suspended and the rail line abandoned and dismantled (Irvin, 1987). The Sasco smelter was also demolished at that time (Anonymous, 2016).

### **Recognition and Development of Porphyry Ores (1909-1954)**

Prior to 1903, most of the production from the Silver Bell mining district involved high-grade pods of massive sulfide or their oxidized products (5 to 10 % copper) hosted by altered limestone (i.e. skarn). However, ores from the El Tiro area during the early 1900s were oxidized products of supergene enriched ores, localized along a brecciated zone that marked the contact between an intrusive lithology known as alaskite and dacite porphyry volcanics (Graybeal, 1991).

Early recognition of disseminated chalcocite hosted by alaskite in the underground workings of the El Tiro property, and its similarity to other major porphyry districts as early as 1909 led to numerous intermittent exploration efforts to evaluate the potential of mining disseminated ores in the Silver Bell mining district over the next four decades (Miller and Briscoe 1994).

One of the earliest efforts to develop porphyry ores at Silver Bell was conducted by the Imperial Copper Company, which leased of 240 acres of adjoining mining claims owned by the El Tiro Copper Company in 1909. Over the next couple of years, 87 churn drill holes were completed northwest of the Mammoth mine, outlining a large sub-economic body (1,000 by 2,500 feet) of disseminated chalcocite mineralization (averaged 2.3% copper) lying beneath approximately 100 feet of barren leached cap (Parsons, 1957 and Graybeal, 1991).

Another notable exploration effort at Silver Bell was the Oxide Copper Company's 76-hole churn drilling program at its Young America mine in the southeast portion district during 1910 (Parsons 1957). This exploration program also encountered a large body of sub-economic disseminated chalcocite mineralization hosted by igneous lithologies (Richard and Courtright, 1966).

Although neither of these early exploration efforts delineated mineralization that could be profitably mined at the time, the presence of large bodies of sub-economic disseminated mineralization hosted by the igneous rocks was an important factor in ASARCO's decision to acquire a property position in the Silver Bell mining district (Graybeal, 1991). Even though the results from a drilling program designed to confirm the data of Imperial Copper's previous drilling campaign were disappointing, ASARCO ultimately purchased the property in 1916.

ASARCO also examined the mineral potential of Oxide Copper's holdings during 1916, but decided against acquiring the property because of its small size, marginal grade, and \$1 million purchase price. Metallurgical testing suggested only 78% of copper could be recovered from this material, producing a concentrate product containing 14% copper (Graybeal, 1991).

The open pit potential of the El Tiro property was briefly examined by the Calumet and Arizona Mining Company from August 1923 until February 1924 (Shoemaker and Somers, 1924). Asarco acquired an option on the El Tiro property in June 1928 and held the property until February 1930, at which time it was returned to its owner.

ASARCO also re-examined the Oxide property during the late 1920s, spending \$25,000 on a mapping, underground sampling, and drilling program, which outlined a reserve of approximately 10 million tons, averaging 1.46% Cu within an 85-foot thick enrichment blanket (Graybeal, 1991). However, the Oxide property returned to its owner due to the spotty distribution of the mineralization that was estimated to contain about 1% copper, which was sub-marginal at the time. Higher grades recorded by the churn drilling programs were judged to be unreliable, presumably due to contamination from the uncased drill holes (Graybeal, 1991).

ASARCO ceased making property tax payments on its Imperial Copper holdings in 1938, forcing Pima County to place a lien on the property in 1939. However, Pima County's initial attempts to recover taxes owed through the sale of property failed. A review of data from the Silver Bell mining district during mid-April 1940 convinced ASARCO's management that in light of recent advancements in mining and metallurgy, a thorough re-evaluation of area's disseminated mineral potential was warranted (Graybeal, 1991).

In early May 1940, the Oxide Copper property was offered to ASARCO for a third time. Asarco purchased the Oxide Copper property for \$40,000 on June 5, 1940, acquired the El Tiro Copper property for \$10,000 on June 14, 1940, paid all outstanding taxes on the Imperial Copper properties, and staked all open ground in the district (Graybeal, 1991).



**Figure 11. Churn drilling on Copper Girl Hill at Silver Bell (circa late 1940s). This form of early drilling employed a blunt-edge chisel bit attached to a string of drill pipe, which was raised by a cable or rope and allowed to drop, pulverizing the rock with successive blows (Photo provided by Arizona Geological Survey).**

Although ASARCO's initial re-evaluation of the Silver Bell mining district was performed under the direction of Harrison Schmitt during 1941, detailed studies were deferred until after World War II. J. Harold Courtright was assigned the task of designing and supervising a churn drilling program at the Oxide area in November 1947 (Figure 11). By July 1948, this examination and another study by Kenyon Richard had delineated a measured reserve in the Oxide and El Tiro areas of 32 million short tons, averaging 0.89% copper (Graybeal, 1991).

The ores in the Oxide and El Tiro areas occur in tabular-shaped ore bodies of chalcocite that were produced by the supergene enrichment of the primary sulfide mineralization (pyrite and chalcopyrite) (Richard and Courtright, 1954). Supergene enrichment occurs as mineralized rocks containing pyrite, chalcopyrite and bornite are oxidized. During this process, any iron contained in these minerals is transformed into red, reddish brown orange, or yellow colored iron oxides preserved in the leached cap, while the sulfur is combined with groundwater to produce a weak sulfuric acid solution. Any copper contained within the rock is dissolved by these acidic solutions, which percolate downward to the water table, where they encounter reducing conditions that allow the copper to precipitate out as chalcocite (a copper-bearing sulfide). Over time this action forms a thick, copper rich zone, known as an enrichment blanket, which is what occurs at Silver Bell.

The saucer-shaped Oxide ore body measured 1,500 by 2,100 feet, ranged from 100 to 200 feet in thickness and underlies 100 feet of barren leach cap. It was the larger of the two ore bodies, containing approximately 19.8 million tons of ore. Located approximately 2 miles northwest of the Oxide ore body, the El Tiro deposit is an irregular-shaped elipsoidal body. It measured 1,300 by 2,200 feet, ranged from 100 to 300 feet in thickness and underlies 100 to 300 feet of barren leach cap. It was reported to contain 12.2 million tons of ore (Hardwick, 1963).

With the start of the Korean War in June 1950, concerns grew over shortages of copper, a strategic metal. In November 1951, ASARCO entered an agreement with the Defense Material Procurement Agency under which ASARCO agreed to finance the development of its Silver Bell property in exchange for a guarantee by the Federal Government to purchase 177 million pounds of the first 197 million pounds of copper production for 24.5 cents

per pound, in the event it could not be sold at that price or more on the open market. Over the 3.5 year life of the agreement, the sale of copper to the Federal Government was not necessary (Hardwick, 1963).

In an effort to avoid delays, ASARCO hired Isbel Construction Company to commence pre-production stripping and mine development activities. Contracts were also negotiated and signed with the Utah Construction Company to build a townsite and Stearns Rodger Manufacturing Company to erect a 7,500 ton/day concentrator.

One of the first things that needed to be done at this remote site was to provide supporting infrastructure for the workers (Figure 12). A new paved road was built from Plata, a rail siding near Rillito on the Southern Pacific Railroad, across Arva Valley to Silver Bell. This new company-owned community was located at an elevation of 2,650 feet in a low lying pass between the Silver Bell and Waterman Mountains (Figure 1). The first buildings erected at this site were apartments and bunkhouses for the construction workers. Approximately 65 two-bedroom (880 square foot) and 35 three-bedroom (1,062 square foot) prefabricated homes were manufactured on an assembly line in Tucson and transported by truck to Silver Bell between April 1952 and September 1952. There were also two trailer courts, which could each accommodate 90 trailers. Water was supplied by six wells located in Arva Valley, approximately 9 miles east of the townsite. In addition to housing, supporting infrastructure also included a general store, mess hall and baseball field (Anonymous, 2016).



**Figure 12. Early view of ASARCO's Silver Bell townsite, circa 1950s (Photo provided by the Arizona Geological Survey).**

Initial stripping of approximately 100 feet of barren leach cap in the Oxide pit area commenced in December 1951. This was performed by two 6-cubic yard electric shovels, one 3-cubic yard diesel shovel, seven 37-ton haul trucks and seven 22-ton haul trucks. Support equipment included six churn drills, one rotary drill, three Cat D-8 dozers, one DW-10 grader and other service vehicles (Sense, 1956). Over the next six months, monthly stripping rates at the Oxide pit increased to 500,000 tons. By March 1954, approximately 13 million tons of waste had been removed and enough ore exposed to allow sustainable production from the Oxide ore body (Hardwick, 1963).

A suitable location for the 7,500 ton/day concentrator was chosen along the southern slope of Portland Ridge near the Oxide pit, the larger of the two recognized ore bodies. Construction of this treatment facility began in

February 1952 and was substantially completed in late February 1954. The first ore was processed in March 1954 and operations achieved commercial production in May 1954. Projected mine life at start-up was 12 to 13 years.

The Silver Bell project was brought in under budget with total capital expenditures amounting to slightly less than \$17 million (ASARCO, 1955). It was also a milestone for ASARCO, being its first large scale open pit mine. It also represented a major step toward greater integration of mining operations into what had largely been a smelting and refining business (Graybeal, 1991).

### **Boom Years (1954-1984)**

During the two decades following the end of World War II, an increasing demand for copper resulted in expansions at many existing U. S. mining operations and the development of new mines. Expansions included the development of open pit operations at former underground producers such as Bagdad, Inspiration, Ray, Bisbee, and Butte during the late 1940s and 1950s. New copper projects were commissioned at Yerington in 1953, Silver Bell and Copper Cities during 1954, Pima and San Manuel during 1955, Esperanza in 1959, Mission in 1961, and Mineral Park in 1964.

Stripping of waste in the El Tiro area began in March 1953 and its first ore was mined in March 1955. By mid-1956, approximately one-third of the Silver Bell's production was derived from the El Tiro pit (Anonymous, 2016). The 4.1 mile haul road connecting the El Tiro pit and mill site was paved to reduce tire wear (Krupp, 1958). Mining of ore from the El Tiro pit also occurred during the afternoon shift (4:00 PM to 12 midnight), because of cooler temperatures and better truck performance on the long haul to the crusher. ASARCO personnel took over the duties performed by the contract miner, Isbel Construction on April 1, 1957 (Krupp, 1958).



**Figure 13. Abandoned crusher and concentrator along the south slope of Portland Ridge with the modern solvent extraction facility in the foreground (Photo taken in July 2004).**

The sulfide ores at Silver Bell were treated at a 7,500 ton/day concentrator, which employed a three-stage crushing circuit that initially reduced ore to 1/2-inch size (Figure 13). This was followed by a grinding circuit, consisting of four single-stage ball mills that ground the ore to the consistency of a fine beach sand before it reported to a conventional flotation circuit, which produced a copper concentrate product that averaged approximately 30% copper. The copper concentrates were dewatered and dried prior to shipment by truck to the Plata siding, where it was loaded into rail cars for transport to ASARCO's smelters at Hayden, Arizona or El Paso, Texas (Hardwick 1963).

A molybdenite recovery circuit was added to the concentrator in May 1956. It initially employed the "Morenci process" which used sodium ferrocyanide, sodium cyanide and sulfuric acid to recover approximately 60% of the molybdenum contained within the ores (Hardwick, 1963). The moly recovery circuit was modified in April 1962 to one that employed dextrin depression, heat treatment and reflation to produce a moly concentrate product containing 88%  $\text{MoS}_2$  (Salter and Chase, 1964).

Exploration drilling during 1962 confirmed the presence of sufficient ore to justify expanding mining operations to include high-grade chalcopyrite-bearing skarns, located in a contact zone northeast of El Tiro pit. The increased hardness of these newly delineated ores resulted in an expansion of the concentrator's capacity to 9,000 tons/day with the addition of a fifth ball mill and additional flotation cells in February 1963. The mill capacity was further expanded to 11,000 tons/day with the addition of a sixth ball mill in May 1966 (Darrah, 1967).

Dump leaching of oxide ores from the Oxide and El Tiro deposits began in January 1960 and July 1961, respectively. Ores containing two pounds or more copper per ton from each of the deposits were stacked on specially prepared dumps located adjacent to each of the pits, where the drainage pattern and ground surface was favorable to solution recovery. Although these dumps contained some sulfides, making the addition of sulfuric acid unnecessary, a small amount of acid was added to the solution applied to dumps to increase the efficiency of the recovery process (Power, 1966).



**Figure 14. Aerial photo of the Oxide Pit and leach pads, looking northeast, circa 1960s (Photo provided by the Arizona Geological Survey).**

Small ponds, measuring 50 feet on a side prepared on the surface of the dumps, were flooded with a weak sulfuric acid solutions, which percolated down through the dump (Figure 14). The resulting copper-bearing solutions, containing 1.5 to 2.5 grams of copper per gallon, were collected from each of the leach areas and piped to a central precipitation plant located adjacent to the Oxide leach dumps, where the copper was precipitated onto scrap iron (detinned cans) in launders, washed, dried and shipped to smelter for further treatment (Hardwick, 1963). Initially designed to recover 10 tons of copper daily, this facility was expanded to 15 tons/day in 1965.

By 1970, the company-owned town of Silver Bell had grown to about 1,000 residents. There were 176 homes, 24 apartments, 30 trailer spaces, 2 bunkhouses, a mess hall, general store, barber shop, U. S. post office (85270), and recreational facilities that included a swimming pool and ball park. School children attended public schools in Marana (Anonymous, 2016).

Silver Bell milling operations suspended recovery of molybdenum concentrates from early 1972 until September 1978. During 1978, ASARCO conducted a feasibility study to construct a 15-ton/day solvent extraction-electrowinning (SX/EW) plant to replace the existing precipitation plant. This study was modified during 1979 to include a 20-ton/day SX/EW plant that was capable of processing solutions from on-stream leaching of mill tailings and high-grade in-pit leaching.

With the collapse of the copper price from \$1.33 in February 1980 to \$0.79 per pound in December 1981, mining and milling operations at Silver Bell were suspended on December 23, 1981 (Burgin, 1983). However, precipitate operations continued to recover copper from the leach dumps. Of the 175 company-owned homes in the town of Silver Bell, 100 were sold and moved to other locations, 46 were still occupied and the remainder boarded up by the end of 1982 (Burgin, 1984). An attempt to resume mining and milling operations was made in October 1983, but operations were permanently halted on August 15, 1984. Only 15 to 18 workers were retained to continue recovering copper from the dump leaching operations and maintain the facilities (Burgin, 1986).

### **Lean Years (1984-1997)**

With the cessation of mining operations at Silver Bell in August 1984, its sulfide concentrator was placed on care and maintenance status and eventually closed. Housing and other infrastructure at the Silver Bell company townsite was also demolished, making it necessary for the mine's personnel to find living accommodations elsewhere (Anonymous, 2016).

Although annual copper production declined to 7 to 13 million pounds during this thirteen year period, efforts to resume full-scale mining operations at Silver Bell continued. This work included evaluation of an area known as North Silver Bell, located on land controlled by ASARCO and BS&K Mining. BS&K Mining had operated the Atlas mine, a small underground zinc producer, adjacent to this site from 1947 until October 1964.

Located approximately one mile north of the El Tiro pit, the economic potential for copper mineralization of the North Silver Bell area had been intermittently evaluated by ASARCO and others since 1955. By the early 1980s, this work had delineated a combined oxide/sulfide resource of 41.2 million tons, averaging 0.55% copper (Niemuth, 2001).

After several years of surface exploration, ASARCO commenced an infill drilling program at North Silver Bell in 1988 and purchased the adjacent BS&K property from the American Pacific Mining Company in 1990. By 1994, ore reserves at Silver Bell stood at 101.3 million tons, averaging 0.47% copper, including approximately 80 million tons of ore at North Silver, averaging 0.4% copper (ASARCO, 1994 and Miller and Briscoe, 1994).

With increasing copper prices and reduced production costs that accompanied improved technology and innovative mining practices during the late 1980s, ASARCO management approved resumption of mining operations at Silver Bell, pending receipt of applicable permits. The proposed project included the replacement of the existing precipitate facility with a modern 50-ton/day SX-EW plant, which could produce a marketable product at the mine site, eliminating need for additional smelting and refining. The conversion of the milling operation to a conventional dump operation permitted a lower cutoff grade to be used at the North Silver Bell deposit. It also allowed rubble leaching methods to be employed to recover copper from low-grade material ( $<0.4\%$  Cu) along the margins of the El Trio and Oxide pits, which was uneconomic to mine by conventional mining practices (Browne and Miller, 2002).

After approximately four years all of the federal and state permits for the new Silver Bell's SX-EW facility were approved. Mitsui & Company, Inc. purchased a 25% interest in the Silver Bell project from ASARCO for \$15 million, forming the Silver Bell Mining LLC in December 1995. Construction of the SX-EW plant began in January 1996 and mining operations resumed in April 1996, employing used mining equipment from ASARCO's Ray and Mission mines as a cost savings measure. Following a short period of pre-production stripping, the first ores from the North Silver Bell area were stacked on the leach dumps in December 1996. Operations at the copper precipitate plant were terminated in April 1997, in preparation for the commissioning of the new SX-EW facility, which came on line in July 1997 at a cost of \$70 million (Anonymous, 2016).

### **Revival (1997-Present)**

With the commissioning of the SX-EW plant in July 1997, Silver Bell became a leach-only operation, producing copper from low-grade oxide and chalcocite bearing ores. Since that time, both conventional open pit/dump leach and in-place leaching methods have been employed at Silver Bell. ASARCO's cash costs for the operation were reported to be 50 cents per pound of copper recovered (Phillips, et al, 2000).



**Figure 15. Mining operations at West Oxide pit (looking southwest) (Photo taken in April 2016).**

Conventional open pit mining operations at Silver Bell are conducted by two 30-cubic yd. shovels and one 25-cubic yd. front end loader, which load the ore and waste into five 256-ton haul trucks and two 170-ton haul trucks

(Figure 15). Support equipment include two blast hole drills, three Cat D-10 track dozers, three rubber-tired dozers, two graders, and other service vehicles.

Approximately 62,000 tons of material are mined daily, consisting of sub-equal amounts of waste and leach ore. Uncrushed leach ores are transported directly to dedicated leach pads, where it is dumped in 20-foot lifts.

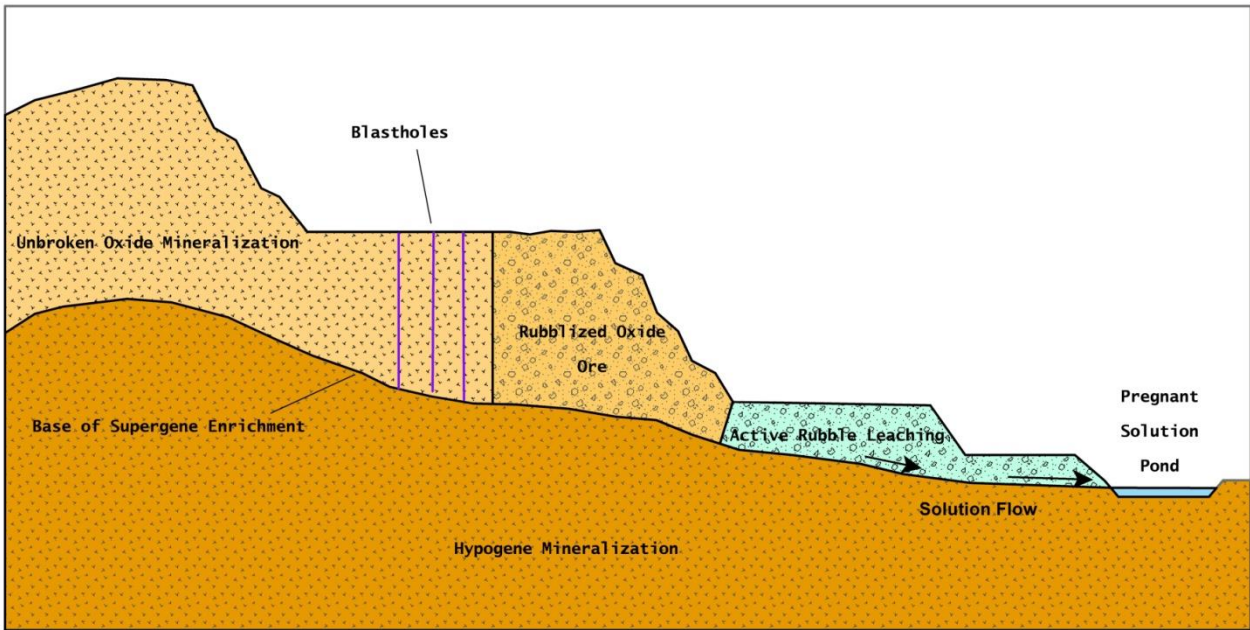


**Figure 16. In-place leaching at the Oxide pit (looking southeast) (Photo taken in April 2016).**

A weak sulfuric acid solution is applied to the leach pads by sprinklers or drip emitters, which are similar to those used by farmers to irrigate their fields. As the weak acidic solution percolates down through the dump it dissolves the soluble copper minerals contained within the ore. The copper-bearing solutions are collected from the bottom of leach pad and directed to a pregnant solution leach pond located adjacent to the leach dump.

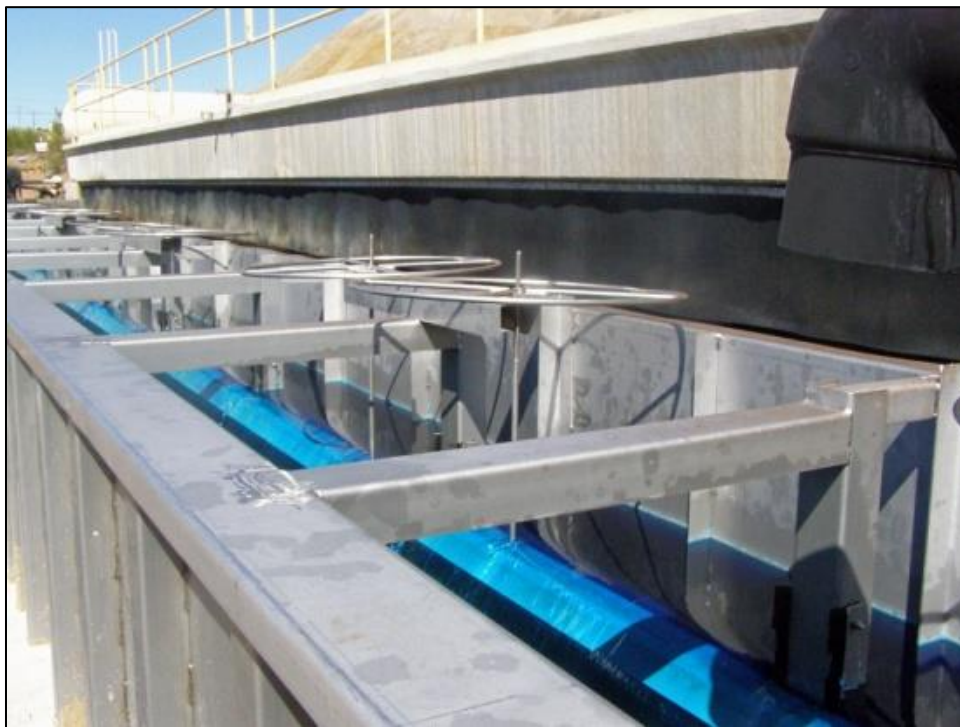
Copper production from conventional open pit/dump leaching methods at Silver Bell is supplemented by in-place leaching methods that recover copper from low-grade surface ores remaining in the walls of the Oxide and El Tiro pits, where the costs of further stripping are prohibitive (Figure 16).

Over a period of time, the walls of these pits were systematically drilled and blasted (Figure 17). The resulting rubble was ripped and terraced by bulldozers prior to applying a weak sulfuric acid solutions, which dissolves the soluble copper minerals contained within the broken zone. The resulting copper-laden solutions flow by gravity to a pregnant solution pond located in the bottom of the open pit (Browne and Miller, 2002).



**Figure 17: Schematic cross section of in-place leaching operations at Silver Bell (modified from Browne and Miller, 2002 and Briggs, 2015).**

The copper-bearing solutions from the dump and in-place leaching operations are pumped to a main pregnant solution pond located adjacent to the solvent extraction facility (Figure 18).



**Figure 18. Upgraded blue copper-bearing solution at solvent extraction facility (Photo taken April 2016).**

These solutions are initially upgraded by the solvent extraction facility to produce a blue, enriched copper-laden solution before being transferred to the electrowinning tank house, where an electric current is used to plate the copper onto stainless steel starter sheets (Figure 19).



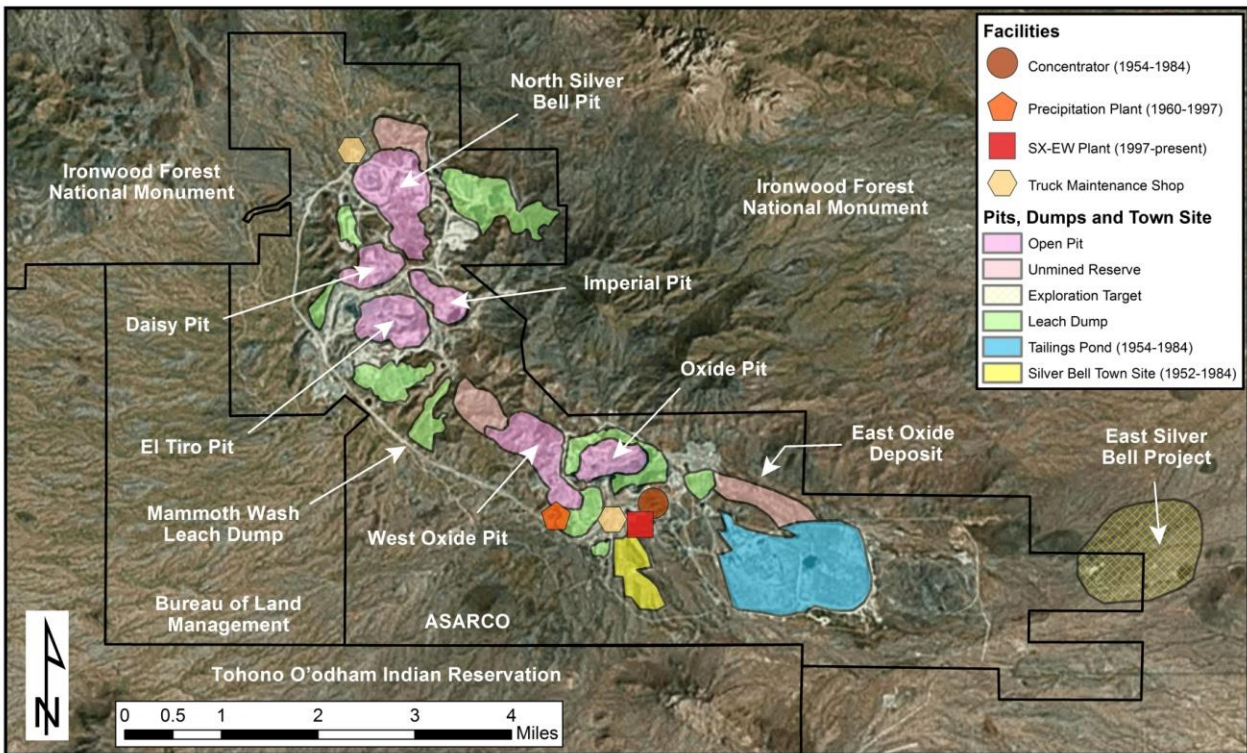
**Figure 19. Electrowinning tank house at Silver Bell (Photo taken July 2004).**

A final copper cathode product (99.99% copper) is stripped from the starter sheets and bundled for shipment to the consumer (Figure 20) (Anonymous, 2016).



**Figure 20. Bundles of copper cathodes ready for shipment to the consumer (photo taken in April 2016).**

Grupo Mexico S. A. B. de C. V. acquired a 75% interest in Silver Bell Mining LLC through its merger with ASARCO, Inc. in November 1999. The production capacity of the SX-EW plant was increased to 55 tons/day in 1998 and further expanded to 65 tons/day during 2003.



**Figure 21. Satellite photo of Silver Bell mining district, showing distribution of facilities, open pits, active and inactive leach dumps, tailings pond, townsite and land ownership.**

In June 2000, President Bill Clinton used the Antiquities Act of 1906 to create the Ironwood Forest National Monument. As a result, ASARCO was required to remove a pipeline, power line, and road from federal lands lying within the boundaries of the monument (Niemuth, 2004). The creation of the Ironwood Forest National Monument severely restricted efforts by ASARCO and others to explore and develop known and/or suspected porphyry copper targets on adjacent public lands along the northwest trending zone of mineralization (Figure 21).

Located 13,000 feet east of the tailings pond, JABA's East Silver Bell project was one of the exploration targets that were impacted by the creation of Ironwood Forest National Monument. Following extensive geophysical (magnetic and induced polarization) and geochemical surveys, exploration drilling during the late 1990s revealed the presence of leached cap accompanied by weak supergene copper enrichment beneath the post-mineral cover. Efforts to exclude this and other favorable exploration targets from the Ironwood Forest National Monument failed, placing the area off limits for future evaluation and development (Liberty Star Uranium and Metals, 2015).

Mining of the West Oxide pit began in late 2010 or early 2011. In September 2014, ASARCO LLC increased its interest in the Silver Bell project to 100% through the purchase of Mitsui Mining's 25% interest in the project for \$115.2 million (Grupo Mexico, 2015).

Construction of the Mammoth Wash dump leach pad and leach solution ponds was completed in January 2017. Located between the West Oxide and El Tiro pits (Figure 21), this facility will provide space to treat approximately 80 million tons of copper ore. Mining rates are currently 66,000 tons/day.

**Table 2. Silver Bell Mining District Production (1885-2015). Ore treated only includes milled and direct smelting ores. It does not include an estimated three to four hundred million tons of dump/in-place leach ores that have been treated at the site since 1960 (Keith, 2016 and Briggs, 2016).**

| Operation        | Period    | Ore Treated<br>Short Tons | Cu<br>lbs     | Mo<br>lbs | Pb<br>lbs | Zn<br>Lbs  | Au<br>Oz | Ag<br>Oz  |
|------------------|-----------|---------------------------|---------------|-----------|-----------|------------|----------|-----------|
| ASARCO Open Pit  | 1954-2015 | 91,985,351                | 2,165,546,191 | 6,569,968 | 2,509,633 | 605        | 736      | 4,817,389 |
| Atlas (BS&K)     | 1915-1964 | 147,548                   | 3,368,541     | 0         | 204,125   | 40,622,215 | 677      | 64,866    |
| El Tiro          | 1905-1930 | 201,668                   | 21,290,417    | 0         | 712,420   | 0          | 15       | 33,595    |
| Imperial-Mammoth | 1887-1930 | 1,061,448                 | 74,195,421    | 0         | 166,554   | 150,835    | 139      | 1,028,424 |
| Young America    | 1885-1918 | 4,146                     | 892,542       | 0         | 0         | 0          | 450      | 5,420     |
| Other Producers  | 1916-1957 | 1,560                     | 77,396        | 0         | 67,840    | 6,050      | 97       | 5,212     |
|                  |           |                           |               |           |           |            |          |           |
| Total            | 1885-2015 | 93,401,721                | 2,265,370,508 | 6,569,968 | 3,660,572 | 40,779,705 | 2,114    | 5,954,906 |

Over past 130 years, the Silver Bell mining district yielded approximately 2.27 billion pounds of copper, 6.6 million pounds of molybdenum, 3.7 million pounds of lead, 40.8 million pounds of zinc, 2,100 ounces of gold and 5.95 million ounces of silver (Table 2).



**Figure 22. Oblique aerial view of the Silver Bell mining district, looking southeast, circa late 2000s (Photo provided by Arizona Dept. of Mines and Mineral Resources).**

At the time ASARCO commenced open pit operations at Silver Bell in 1954, it was estimated to have sufficient reserves to continue production for 12 to 13 years. Innovative mining practices, improvements in technology and favorable metals prices have enabled Silver Bell to remain productive for 61 years (Figure 22). Conventional milling, precipitation, and SX-EW recovery methods have accounted for 50%, 11.6%, and 38.4% of copper recovered, respectively (Keith, 2016 and Briggs, 2016). With a remaining reserves as of December 31, 2015,

reported to be 214.4 million tons, averaging 0.283% Cu, production at ASARCO's Silver Bell mine is expected to continue until 2034 (Grupo Mexico, 2016).

### **Acknowledgements**

The author thanks ASARCO LLC, who hosted the Tucson Section SME 2016 spring field trip to the Silver Bell mine, which provided an opportunity to tour the mine site, ask questions about their operation and photograph the mine and process facilities.

Discussions with former Silver Bell geologist, James Briscoe provided an interesting perspective into the challenges faced by those who explored and developed the Silver Bell's copper resources. Early production data from the district's mines were obtained from unpublished sources provided by Stan Keith.

Michael Conway edited a rough draft of this paper. His comments greatly improved its presentation.

### **References**

- Anonymous, 1910, The Sasco Smelter: Mine and Methods: v. 1, n. 5, January 1910, Salt Lake City, Utah, p. 177-180.
- Anonymous, 1957, Story of Silver Bell, A. S. & R. Co.'s New Arizona Copper Project: Unpublished Report, May 1957, 6 p.
- Anonymous, 2016, The Silver Bell Scoop: Tucson Section SME Field Trip Brochure, April, 23, 2016, 8 p.
- ASARCO, Inc., 1955, 1954 Annual Report.
- ASARCO, Inc., 1994, 1993 Annual Report.
- Berg, E., 1999, The Nature of the Business: Construction, Operation, and Litigation at the Sasco Smelter; in History of the Mining in Arizona: J. Michael Canty, H. Mason Coggin and Michael N. Greeley (eds.), Mining Foundation of the Southwest, Tucson, Arizona, v. 3, Chapter 7, p. 133-154.
- Briggs, D. F., 2015, Recovery of Copper by Solution Mining Methods: Arizona Geological Survey Contributed Report CR-15-A, 10 p.
- Briggs, D. F., 2016, Unpublished data.
- Briscoe, J. A., 1968, Alteration and Mineralization of the Paleozoic Sediments in the El Tiro Pit Area, Silver Bell, Arizona: Presentation to the Mining Geology Division of the Arizona Section of the A.I.M.E., May 1968, Tucson, Arizona, 8 p.
- Browne, Q. J., and Miller, M. A., 2002, Use of Geologic Parameters for the Development of Low-Grade Copper Reserves, Silver Bell Mine, Az.: SME Annual Meeting, February 25-27, 2002, Phoenix, Arizona, Pre-print 02-069, 5 p.
- Butler, B. S., Wilson, E. D., and Rasor, C. A., 1938, Geology and Ore Deposits of the Tombstone District, Arizona: Arizona Bureau of Mines, Geological Series, No. 10, Bulletin No. 143, 114 p.
- Burgin, L. B., 1983, The Mineral Industry of Arizona: U. S. Bureau of Mines Minerals Yearbook, Area Reports: Domestic 1981, v. 2, p. 55-73.
- Burgin, L. B., 1984, The Mineral Industry of Arizona: U. S. Bureau of Mines Minerals Yearbook, Area Reports: Domestic 1982, v. 2, p. 55-76.
- Burgin, L. B., 1986, The Mineral Industry of Arizona: U. S. Bureau of Mines Minerals Yearbook, Area Reports: Domestic 1984, v. 2, p. 65-85.
- Darrah, R. M., 1967, Silver Bell Concentrator: Unpublished Paper presented at Spring Meeting of the Minerals Beneficiation Division, Arizona Section, A.I.M.E., 27 p.

- Gerry, C. N., and Miller, T. H., 1933, Gold, Silver, Copper, Lead, and Zinc in Arizona; in Mineral Resources of the United States 1930: Part 1-Metals, United States Department of Commerce, Bureau of Mines, Government Printing Office, Washington D. C., p. 1085-1142.
- Graybeal, F. T., 1991, History of Exploration at Silver Bell, Arizona; in Case Histories of Mineral Discoveries: Victor H. Hollister (ed.), Society of Mining, Metallurgy and Exploration, Inc., v. 3, chapter 13, p. 45-47.
- Grupo Mexico S. A. B. de C. V., 2015, Consolidated Financial Statements for Years Ended December 31, 2014 and 2013 and Independent Auditor's Report, 80 p.
- Grupo Mexico S. A. B. de C. V., 2016, Annual Report for Fiscal Year Ending 12/31/2015, 132 p.
- Hardwick, W. R., 1963, Open-Pit Copper Mining and Concentrating Methods and Costs, Silver Bell Unit, American Smelting and Refining Co., Pima County, Arizona: U. S. Bureau of Mines Information Circular 8153, 72 p.
- Heikes, V. C., 1922 Gold, Silver, Copper, Lead, and Zinc in Arizona; in Mineral Resources of the United States 1920: Part 1 - Metals, United States Geological Survey, Government Printing Office, Washington, D. C., p. 339-364.
- Heikes, V. C., 1924, Gold, Silver, Copper, Lead, and Zinc in Arizona; in Mineral Resources of the United States 1921: Part 1 - Metals, United States Geological Survey, Government Printing Office, Washington, D. C., p. 311-339.
- Heikes, V. C., 1925, Gold, Silver, Copper, Lead, and Zinc in Arizona; in Mineral Resources of the United States 1922: Part 1 - Metals, United States Geological Survey, Government Printing Office, Washington, D. C., p. 489-518.
- Irvin, G. W., 1987, A Sequential History of Arizona Railroad and Mining Development 1864-1920; in History of Mining in Arizona: J. Michael Canty and Michael N. Greeley (eds.), Chapter 11, p. 253-278.
- Keith, S., 2016, Unpublished Mine Production Data from Silver Bell Mining District.
- Krupp, L. M., 1958, Better Roads for Lower Costs: Mining Engineering, Society of Mining Engineers, v. 10, n. 11, p. 1167-1168.
- Liberty Star Uranium and Metals Corporation, 2015, 10-K Report for Fiscal Year Ending January 31, 2015, 62 p.
- Lyons, B. 2000, Mr. Steinfeld is in Sole Control: The Celebrated Case of Louis Zeckendorf vs Albert Steinfeld and the Silver Bell Copper Company: Journal of Arizona History, v. 41, n. 2, Summer, 2000, p.149-180.
- Miller, M., and Briscoe, J., (eds.), 1994, Silver Bell, North Silver Bell: Arizona Geological Society Bootprints along the Cordillera Porphyry Copper Deposits from Alaska to Chile Conference, Tucson, Arizona, October 1994, Field Trip 15, 18 p.
- Niemuth, N. J., 2001, Arizona Copper Reserves, Arizona Department of Mines and Mineral Resources Open File Report 01-17, 77 p.
- Niemuth, N. J. 2004, Arizona Mining Update - 2002 and 2003: Arizona Department of Mines and Mineral Resources Circular 108, 10 p.
- Parsons, A. B., 1957, Silver Bell; in The Porphyry Coppers in 1956: American Institute of Mining and Metallurgical Engineers and Petroleum Engineers, New York, Chapter 16, p. 234-243.
- Phillips, K. A., Niemuth, N. J., and Bain, D., 2000, Arizona Mining Update for 1999: Arizona Department of Mines and Mineral Resources Circular 87, July 2000, 14 p.
- Power, K. L., 1966 (?), Copper Dump Leaching at Asarco's Silver Bell Unit, Arizona: Unpublished Paper, 27 p.
- Richard, K. E., and Courtright, J. H., 1954, Structure and Mineralization at Silver Bell, Arizona: Mining Engineering and American Institute of Mining, Metallurgical and Petroleum Engineers Transactions, v. 199, n. 11, p. 1095-1099.

- Richard, K. E., and Courtright, J. H., 1966, Structure and Mineralization at Silver Bell, Arizona; in *Geology of the Porphyry Copper Deposits Southwestern North America*: Spencer R. Titley and Carol L. Hicks (eds.), University of Arizona Press, Tucson, Arizona, p. 157-163.
- Rickard, F. R., 1987, History of Smelting in Arizona; in *History of Mining in Arizona*: J. Michael Canty and Michael N. Greeley (eds.), Chapter 9, p. 191-228.
- Salter, R., and Chase, C. K., 1964, Byproduct Molybdenum Recovery at Silver Bell: *Mining Engineering*, Society of Mining Engineers, July 1964, v. 16, n. 7, p. 116-117D.
- Sense, J. J., 1956, Silver Bell Pit Development: Unpublished ASARCO report, 6 p.
- Shoemaker, A. H., and Somers, G. 1924, The Geology of the El Tiro Mine, Silverbell, Arizona: MS Thesis, Department of Geology and Mineralogy, University of Arizona, 40 p.
- Stevens, H. J., 1905, The Copper Handbook, A Manual of the Copper Industry of the World: Houghton, Michigan, v. 5, 882 p.
- Stevens, H. J., 1906, The Copper Handbook, A Manual of the Copper Industry of the World: Houghton, Michigan, v. 6, 1116 p.
- Stevens, H. J., 1911, The Copper Handbook, A Manual of the Copper Industry of the World: Houghton, Michigan, v. 10, 1902 p.
- Stewart, C. A., 1912, The Geology and Ore-Deposits of the Silverbell Mining District, Arizona: A.I.M.E. Transactions, v. 43, p. 240-290.
- Weed, W. H., 1918, International Edition The Mines Handbook an Enlargement of the Copper Handbook: Published by W. H. Weed, New York, v. 13, 1896 p.
- Weed, W. H., 1922, International Edition The Mines Handbook succeeding The Copper Handbook: The Mines Handbook Company, Tuckahoe, New York, v. 15, 2248 p.