Chapter Six

History of Mineral Processing in Arizona

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Foreward

The wealth of information regarding the myriad of mineral processing operations in Arizona in past years precludes even a brief coverage of all the activities. Tenney's History of Mining in Arizona describes or at least mentions a large number of mineral processing plants. This paper will attempt to list a few others, plus describe some of the major processes and cite several of the prominent men who contributed to mineral processing in Arizona.

Early History

The earliest written record of a significant milling operation in Arizona was for gold and silver at the Longoreña mine (aka. Longuerino or Longerena) in Fraquita Wash near Arivaca (or Aribac) in 1763. Some antigua evidence remains from these early operations: several large arrastra sites, charcoal ovens and traces of crude mercury retorts.

What little mining and ore processing as was done in the 1700's and 1800's was performed by the Indian converts of the Catholic Church.

After the Jesuit expulsion in 1767, another Spanish government report dated 1774 mentions a rich silver mine at Aribac. The property was again active in 1857 when a 20-stamp mill ran intermittently for a few years prior to the Civil War. The 1880 census listed the Longoreña as an active mine in the Oro Blanco District.

The claim was re-filed as the "Longuerino" in 1945 and is now known as the Ajax but no appreciable mining or milling has been evident in recent years.

Evidence and relics from some of the earliest mining and ore processing in Arizona has been discovered at Tule Springs near Dome Rock in northern Yuma County and La Paz County. The red cinnabar, mercury sulphide, was pulverized and washed out of the ore by Indian tribes long prior to the coming of the Spanish. The dried mineral was stored in special small pots, and sometimes mixed with oil or grease.

Early Spanish and Mexican mineral operations were confined to recovery of gold from desert placers plus crude sorting, crushing and the treatment of high-grade silver ores on a relatively small scale. Remains of previous milling and smelting operations ("Antiguas") have been reported by the first American prospectors (c. 1850) in Oro Blanco, Sierrita, Tucson, Patagonia, the Santa Rita and Santa Catalina mountain areas.

Early miners and prospectors generally panned in or along stream beds searching for placer deposits or surface gold. Swirling a shovelful of sand and gravel in a pan filled with water might result in the settling of the heavier grains of gold to the bottom. This panning technique was also used to assay large pieces of ore. Chunks of rock were crushed in a heavy cast-iron mortar-and-pestle and then panned to recover any valuable materials.

With practice, an experienced miner can estimate roughly the potential value of the rock.

Gold placers are reported to have been worked at Quijotoa in 1774 but significant systematic mining and processing of gold ores in Arizona did not start until after U.S. acquisition in 1848 and 1853 and, even then, the only readily accessible part of the Territory was the area around Tucson and Tubac. By 1854, the Mowry mine was shipping rich lead-silver ore which had been hand sorted and crudely beneficiated by gravity means.

The first copper mine in Arizona was near Ajo in 1854 but the costs of operation at this relatively remote site were too much for base metals to pay for. There was actually little or no mineral processing. The direct-shipping ore was carted to Yuma and shipped to Swansea, Wales.

When the Civil War removed soldiers in 1860-61, the Apaches came in and mining activity was curtailed. However, in 1861 when soldiers and experienced miners arrived from California, placers were opened at Quartzsite, La Paz, Olive City and Ehrenberg and in 1863, in the Bradshaw area.

The first major mineral recovery operation was in 1861 at the gold placers at La Paz, followed by the Lynx and Hassayampa placers in 1863.

In 1863, "Hassayampers", fanning out from the Wickenberg area, discovered "monstrous" gold nuggets along lower Lynx Creek. California style rocker-boxes and Long Toms were introduced but the deposits were relatively shallow and soon exhausted.

Later, in the 1920's and 30's large floating dredges worked this area for a distance of six miles with only mixed success.

By 1864, outcrops of silver were found along with some gold and copper in Yavapai, Mohave and Gila Counties but the Apaches extended their raids to the northwest and mining was more hazardous and consequently very limited. After 1874, when the Apache wars were quieted, many silver properties were discovered and brought into production: the McCracken, Silver King, Tip Top, McMillan and Oro Blanco.

Until the 1880's, mineral processing in Arizona was a continuation of early Spanish-Mexican techniques and the more than three centuries of experience based on the text by the German physician, George Bauer (Georgius Agricola). Milling was simplicity itself. In some instances as practiced even today in Mexico, after selective mining the ore was hand cobbed or sorted on the mine dump. The ore was hammered to coarse sand and placed in inclined wooden troughs resembling small hollow log canoes. Water at the lower end was scooped up repeatedly in a cow horn and thrown onto the crushed ore at the top of the inclined troughs. The soft, light-weight gangue which washes down is thrown out and the heavy concentrate saved and piled to one side to drain. Although metal losses were heavy, this method produced a high-grade, self-fluxing concentrate for a small charcoal-fired shaft furnace (*castellano* or *chimbo*). How much unrefined *chimbo* lead was produced and how much silver was recovered by a subsequent cupellation is thought to be relatively small but this procedure was employed in remote areas with repeated success.

One of the earliest methods of processing the ore used an arrastra, a crude Spanish ore-crusher in a circular vat with drag-stones or shoes worked by one or more horizontal beams.

A round pit was dug in the ground and the floor lined with flat stones. A heavy upright pole was set in the center of the pit and horizontal crossbars were attached to the upright pole. From these spoke-like crossbars huge rocks or "shoes" were fastened by chains or cables so as to drag around the center.

The principle of the operation was to revolve the crossbeams around the center post by a mule or a burro hitched to crossbeams, thereby crushing the ore in the pit. The crushed ore was intermittently taken out of the pit and spread over a courtyard or patio in low heaps. It was then sprinkled with mercury and chemicals (common salt and copper sulphate) and mixed by mules which were driven over every part of the heaps. Chemical reactions took place to free the silver and enable it to be taken up by the mercury. The heaps were trodden by the mules every day or two until amalgamation was complete, which might require a month. Lastly, the material was agitated with water in large tubs and the mud poured off through the plug holes. The amalgam settled to the bottom, was collected, and panned out in bateas or put into filter bags and squeezed to remove the surplus mercury. The liquid mercury passed through, and pasty amalgam of silver remained in the bag. The amalgam was heated in retorts, the mercury driven off as vapor to be condensed in a cool chamber for use again, and the silver residue was melted down and cast into bars. According to the 1880 U.S. Census there were five operating arrastras in Arizona at that time.

Many old arrastras, some still in surprisingly good condition are found throughout southern Arizona. The two at Santo Tomas north of Sells are good examples. However, the beautiful old arrastra at Oro Blanco was razed by the U.S. Forest Service.

Another early amalgamation procedure, the Barrel process, was used only on complex argentiferous ores. An early Spanish author describes the procedure as follows: preceding amalgamation the sulphide ores were roasted until all the base metals in the ore became oxidized to such a degree that they would not unite with quicksilver, but the gold and silver would. The ore was then placed in large wooden casks and water, lime and quicksilver added. The casks or barrels were then set rolling by machinery for several days until the silver had formed an amalgam with the mercury. The whole mass was then poured into troughs and the scoria (or waste) was washed from the amalgam. The amalgam was gathered and put into a stout leather bag with a cloth bottom. The unabsorbed mercury drained out and was saved for future use. The amalgam, resembling lard (this author suggests packed snow), was then cut into cakes, placed in a retort and fire applied. The mercury, in form of vapor, was driven through an orifice and led by a pipe into water where it was condensed while the silver remained pure in the retort.

Evidently the rolling of the barrels was accomplished by an adaption of the arrastra set-up by burros walking in a circle around a center post, pulling the barrels which were revolving on an axle through the center of the barrel.

Usually, if base metals predominate in silver ore intimately mixed with the sulphides, roasting and smelting is required. Then the roasted sinter may be leached or the ore is smelted, i.e. reduced to a fluid state by heat. The slag (waste) is drawn off and the heavy metal residue of silver and base (usually lead) bullion is recovered and further refined.

During and immediately following the Civil War, rich placers and gold ledges were located in Arizona. At first all processing was accomplished in a relatively crude manner. The ore was hand cobbed and crushed manually, followed by arrastras or stamp mills and gravity separation. Panning was the fundamental prospecting and recovery tool.

Also employed was the ancient Spanish method by which gold dust was winnowed or dry-air classified by the use of wind or a gentle air blast similar to the method used to separate wheat from chaff. A relatively cheap portable dry-washer utilizing a mechanical bellows enabled prospectors to work dry washes far from water. It was said that on a day of good visibility in the Arizona desert near Quijotoa, Quartsite, and La Paz small puffs of dust were visible for miles, rising like Indian smoke signals from these contraptions. Ancient gold recovery methods had again become popular.

Vulture Mine

When Henry Wickenburg first discovered the Vulture mine in 1863, he did not post notices on the claim for three years. Activities of the Apaches hampered his operation. After the Vulture Company acquired the property in 1866, a 40-stamp amalgamation and concentration mill was installed which processed an average of about 50 tons per day until 1872. Mining, milling and hauling costs were about $15.00 per ton. Approximately two million dollars worth of bullion was obtained from the ore in spite of reported extensive high-grading, estimated to have been as much as 20 percent of production.

In 1873, Smith and Taylor located a claim on the western extension of the Vulture and operated a 5-stamp mill at the Hassayampa River for six years to produce about $150,000 worth of bullion.

Later in 1873, the Arizona Central Mining Company was formed to work the Vulture and Smith-Taylor claims. An 80-stamp mill was built at the mine and produced an estimated two million dollars by 1888.

In 1907, a faulted segment of the ore body was found and a 20-stamp mill operated until 1917.

In later years, sporadic activity on old dumps and low-grade concentrates, plus extensive shaft and lateral work, did not provide any significant additional ore.

Then in 1931, a 10-stamp battery and amalgamation and concentration mill ran for another few years. The old gravity tailings dump was run through a 100-ton per day cyanide leaching plant to recover the last traces of gold.

Clifton-Ajo

High-grade copper ores were shipped to Wales from Ajo as early as 1855 and copper mining started at Clifton in 1873 but these ventures were not so profitable as the mining and processing of high-grade gold or silver. Free milling gold ores were fed to stamp mills or arrastras along with mercury and water. The resulting amalgam was recovered by simple washing techniques, batea panning, or some type of table or rocker. The mercury was distilled from the amalgam, condensed and caught in a variety of water traps and the gold residue left in the retort.

The first copper concentrator in Arizona treated oxidized ore at Clifton averaging 6.5 percent copper ore which was not suitable for smelter feed. Early in 1886, William Church* produced a 23-percent concentrate in a plant consisting of a jaw crusher, a set of rolls and three revolving trommels. Each of the resulting six sizes of ore were fed into separate jigs. There were no tables because the Wilfley table had not yet been developed. The tailings from this plant ran 3.92 percent copper and recovery was about 55 percent.

** of the Detroit Copper Mining Co., later the Arizona Copper Co., which evolved into Phelps Dodge Corporation.*

Ruby

Mining and milling operations at Ruby were similar to many Arizona mining camps. The first people came in as early as 1840-50 but the Civil War pulled out the military and the Indians took over the area. After the war, troops returned and resettlement began. In the 1870's, mineral discoveries were made and exploration and development of the mine took place. Most ore beneficiation was by hand sorting and/or a simple gravitational separation with some amalgamation. Water was scarce and the old methods of reduction were inefficient and not profitable. One problem was to get the metal out of the ore, the other problem was to get the concentrates or bullion to market. Isolated remote camps in rugged terrain plus Indian attacks made costs very high. Ore bodies were rich and large enough, but until railroads advanced into the mining camps, the development was relatively slow.

About 1899 a ten-stamp mill was erected and a pan-amalgamation system installed. The venture failed because of poor recovery and high freight costs. There were other attempts to operate but none was successful until the Gold Field Consolidated Mines Exploration Company took charge in 1916 and built a new mill using flotation for the first time. Few records were kept but the mine and mill operated successfully until 1940 when the ore played out, the mine closed, and the mill was moved to Sahuarita.

E. D. Gardner was largely responsible for the early success of this complex multi-flotation plant at Ruby. Later, when the Frailey family acquired the town site in the early 70's, a number of tests were run by metallurgist R. J. McCrary in conjunction with the Arizona Bureau of Mines. The results using the Humphrey's Spiral showed interesting results in the old mill tailings but depressed lead and zinc prices did not warrant further action at that time.

Tombstone

In January 1878, the Tombstone Mill and Mining Co. installed and operated 10 stamps at Millville (later Charleston) on the San Pedro river. Later, the Corbin Mill and Mining Co. operated 15 stamps starting January 12, 1880 and by January 31 shipped the first bullion. The Grand Central Mill, 10 miles north on the San Pedro came on line shortly thereafter. The TMMC reportedly processed a large amount of low-grade ore first; reason, to "thoroughly fill all cracks before treating the high-grade ores". At TMMC, raw ore was fed through a "rock-breaker", presumably a jaw crusher. This device was of wrought iron (not cast) and had toggles and set-screw jibs to minimize break-downs. The rock-breaker operated at 2 rpm and the crushed product fed a rotary dryer through an inclined chute. The discharge from the dryer fed the stamps which operated at 100 drops per minute. A double-discharge from the stamp mortars led to cars which carried the pulp to four amalgamation pans stirred by revolving mullers. Mercury (called quicksilver then) was kept always in the stamp batteries, plus mercury was shaken in a fine shower from a buckskin sack into the pans. Quantities of coarse salt and sulfate of copper were added to the pans to assist the amalgamation by breaking down the base metal combinations with the silver.

Below the amalgamation pans were two large settlers and the tramway crab-cars which ran the amalgam into the retort room. The usual run was about 15 tons per day on a continuous 24 hour-per-day operation.

Two retorts and a melting furnace completed the TMMC Charleston Mill. The retort residue was melted and cast in iron brickmoulds to form solid bars of a silver-gold bullion; one-fifth gold, four-fifths silver.

The gold color however, did not show. Quicksilver was very costly and was "never wasted". Special care was taken to condense and recover all the distilled mercury from the retort.

Harshaw

The Hermosa Mill at Harshaw operated 20 stamps, start ing in 1879-1880, to process a reported 75 tons per day, "the largest mill in Arizona" at that time. The Harshaw Mill ceased major operations in 1890-91 with only scattered, small tonnage mining taking place since that time.

Total Wreck

The Total Wreck came into full operation early in 1883. Equipped with twenty 950-pound stamps and fourteen amalgamation pans, the mill could process 70 tons per day.

At first, after crushing in the stamps, the ore was washed into a number of large wooden tanks. Workers mixed the pulp and mercury and shoveled the ore pulp into shallow rocker troughs and then washed it into settling pans to complete the amalgamation process. Recovery was about 80-84 percent.

Later, when the owner, Nathan Vail, converted the mill to a "revolutionary new" process devised by Mahlon P. Boss (Millwright), the resulting recovery increased to 86.4 percent.

In the "Boss" system a continuous stream of finely crushed ore passed from the stamps through a long series of mercury-filled sluices and eventually dumped into deep settling pans. This process allowed for an increase in mill production and required fewer car-men and pan-men. In addition, the loss of expensive quicksilver was reduced 10 percent.

The mill ceased to operate in 1887 when the mine closed down. Sporadic mining has occurred since then with no significant milling operations.

Mammoth

About 1895, the Mohawk Mining and Milling Company erected a 23-stamp mill near Mammoth to handle ore from the Tiger Mine. A 3-inch pipeline led from a pumping plant on the San Pedro River, 4 or 5 miles distant and 700 feet lower. Capacity was 500,000 gallons per 24 hours (about 350 gpm). All ore processing was by gravity tables plus pan amalgamation and the precious metals were the principal source of revenue. In 1930-35, the Tiger was an unusual operation, i.e. eight metals recovered from the same shaft: copper, lead, zinc, gold, silver, tungsten, molybdenum and vanadium. For metallurgy students at the University of Arizona, it was an educational experience to visit the old mill and see jigs, tables, a Humphreys spiral, two-stage grinding and an Aikens classifier; bulk flotation and cleaner cells, an hydraulic cone classifier, sand-vat and slime leaching, Merrill Crowe precipitation, Butter's leaf filter and Dorr thickeners plus a small drum filter. All this in one small 40 to 60 ton per day mill.

Gold Basin

Gold was first discovered in Gold Basin, Mohave County, about 1880, 30 miles north of Mineral Park at the north end of Hualapai Valley. Subsequently, Grass Springs was the scene of an early example of "no thought given to mineral processing prior to the start of mining" (and milling) operations. The first mill was constructed with local capital before the participants realized they were 18 miles from the nearest water at Grass Valley. So, with characteristic hope and enterprise, they built one of the "best wagon roads ever seen" and hauled ore to a relocated mill.

Unfortunately, none of them knew anything about working gold ores. First, they tried amalgamating plates alone; then, they learned about blanket sluices (without success); then two tables of a Frue concentrator proved unsatisfactory.

No attempt was ever made to work any concentrates into bullion. Such concentrates as were produced gave work to teams and to railroads for hauling and to mills elsewhere for the production of bullion. Later, about 1890, an arrastra was put up near a small spring about four miles west of Gold Basin and thereby a few miners made a little money. The district produced high quality ore intermittently up until the early 30's, but, after the 1883 fiasco, investors were advised to "stand-off". A mine is never a mine until efficient and economical ore processing has been proven.

Gold Bug

Beginning about 1895, ore from the Gold Bug mine was the principal supplier to an unusual milling operation near the Colorado River. A large Huntington mill with four rollers crushed 150 tons of ore per day from about $\frac{3}{8}$ inch to a minus 28 mesh. The mill operated at 75 percent solids and 100 rpm. This mill was considered to be more efficient than stamps and required much less water. The mill shut down about 1910.

Octave

At Octave in 1899, A. E. Hurley operated one of the first integrated gravity concentration and cyanide plants in Arizona. The 40-stamp mill ground the ore to produce $2 million in gold before closing in 1910 or 1912. Several revivals occurred, the most spectacular being ASARCO's 1930 lease which produced another $2 million.

Congress

Beginning in 1894, Congress became an active producer and by 1902 supported two 40-stamp mills and a countercurrent decantation, cyanide leaching plant. When shut down in 1910, Congress had produced nearly $8 million in gold.

In the early 1970's, D. W. Jaquays conducted a successful cyanide leaching operation at Congress on several large, carefully constructed heaps of selected mine dump material. A total of about 300 thousand tons of ore was processed and the Merrill-Crowe zinc precipitate was melted and refined on-site to recover the gold. Soluble copper in the ore presented some problems but carefully controlled metallurgy resulted in an economically profitable operation.

Carbon adsorption was attempted but did not prove to be satisfactory for the Congress plant.

Asbestos

Beginning about 1920 Jacquays mined and processed long-fiber, low-iron chrysotile asbestos from a number of mines near the Salt River, north of Globe. The mill at Cutter was a fine example of dust control. Each operation was completely hooded and vacuum controlled. Results of several expensive studies indicated that the mineral chrysotile was *not* the carcinogenic agent that other asbestoid minerals have been found to be.

Wet Smelting

In Arizona in the past decade or two, several unique wet-smelting processes have been considered which purportedly were less expensive than conventional smelting. At the same time, these wet processess eliminated much of the cost of compliance to stringent EPA regulations.

CYMET Process

Beginning about 1970-72, Cyprus Metallurgical Processes Corporation of Cyprus Mines initiated a $9 million research effort to construct and test a pilot plant for a process which was considered to be totally pollution free.

The CYMET process converted concentrates of base-metal sulfides to soluble chlorides. At the same time, about 70 percent of the sulfur was oxidized to the elemental form and recovered. There were no noxious chemicals discharged, water was processed and reused, and high-purity iron and copper metal were recovered at a cost competitive with the conventional pyrometallurgical process.

Treadwell Process

About the same time, Anaconda was reported to have expended more than $7 million in an effort to develop a similar process, first introduced by the Treadwell Corporation. Technical problems and financial considerations cancelled work on the Treadwell process at an early stage.

Chromic Acid Process

In 1971 at the University of Arizona and at Inspiration Consolidated Copper Company, a hydrometallurgical recovery of copper from copper sulfides and native copper was accomplished using chromic acid. This U.S. patented process by Robert Shantz and Frank Christman consists of four interrelated steps: 1) chromic acid leaching, 2) iron removal, 3) copper electrowinning and 4) chrome-VI regeneration. Recoveries of 97 percent were attained consistently with a variety of feed-stock. Operating costs were estimated to be competitive with those of conventional pyrometallurgical processes, plus the environmental concerns were much less.

CLEAR Process

Another wet-process to produce high-purity copper wire-bar was developed by the Duval Corporation about 1977. The Duval CLEAR process dissolved copper sulphide concentrates in a chloride solution and then recovered the soluble copper by electrolysis on a cathode bar. The lixiviant was regenerated by electro-oxidation and a by-product iron sulfate was produced which could be utilized in agricultural fertilizers. A major advantage was the total operating cost wich was claimed to be about half as much as the conventional smelter equipped with all the mandated environmental controls for toxic emissions.

Duval hoped to use this process to produce about 25 percent of its copper.

Some system similar to one of these processes may have a chance of being used in the future when new smelters are being considered but there may be unanticipated drawbacks which have not shown up at this writing.

Hypo Leach Operations

In June 1976, 71 Minerals Ltd, Sierra Metals Corp., proposed underground leaching of silver ore in old stopes at the Toughnut Mine at Tombstone. The plan called for the old stope-fill gob to be sprayed in-place with a dilute solution of sodium hyposulfite, the main ingredient of photo-fixing solution, also called "sodium thio-sulfate" or "Hypo". As opposed to cyanide solutions, hypo is non toxic.

About 75 thousand gallons of solution were applied in a test run lasting from mid-July to October 1977. Only about 20 percent of the ON-solution was recovered and the final overall extraction was negligible. About the same time or a little earlier (c. 1974 or 1975), a similar experimental Hypo-leach was attempted underground on a smaller scale at the Vekol Mine with even less success. Hypo is most effective on the silver halides and then only on ores in which any manganese present does not occur as a complex manganese-silver mineral.

About a year later, 71 Minerals attempted an acid leach on a small portion of one of the old cyanide-leach dumps near the Contention at Tombstone. Some gold was recovered by adsorption on a resin rather than activated charcoal. The precipitated gold was very spectacular until it was proven the gold film was only a few-microns thick; the amount of metal was very small, the resin was quite expensive, and the acid leach was dangerous, expensive, and relatively inefficient.

Solvent Extraction Process

The first plant in Arizona to employ the liquid-ion-exchange process was the Bluebird of Ranchers Exploration and Development Co. at Miami; start-up was in March 1968. Bluebird used LIX-64® for the first three months before changing over to LIX-64N. Kenneth L. Power and Clement K. Chase, however, operated a pilotplant using LIX-63 on solutions from an ammonia leach circuit at Silver Bell, about 1964-65 before Power moved to Bluebird in 1967.

The second copper solvent-extraction (SX) plant was at Bagdad where Dave Lincoln and Ray Jones put that plant on line in August 1970 after a preliminary pilot operation beginning in July 1966. Initially, only Bagdad (and later Anamax) produced finished copper in Arizona of a quality good enough to be registered on the London Metal Exchange. SX-produced copper is potentially of better quality than conventional copper electro-refined from blister, because only sulphur, oxygen and lead are the entrained contaminents.

Cyprus Johnson went on stream in the spring of 1975 with an SX plant designed to be portable. This set-up was moved to Cyprus Sierrita during spring, 1987. Originally designed for 2500 GPM, this plant is now adapted to handle 4000 GPM including an additional wash stage. Reagents, specifically LIX-84, are now more selective.

Currently, solvent-extraction plants are operating at Sierrita, Inspiration, Ray, Bagdad, Morenci and Magma San Manuel, Miami Copper and Pinto Valley*. At Morenci, there are now three separate extraction plants with about 7 miles of pipelines feeding one tank house. The Cyprus Casa Grande property (Lakeshore) also has an SX plant on-site.

Pure solvent extraction (SX) employs an organic phase as the extractant. During copper SX, the LIX reagent extracts a copper ion and liberates two hydrogen ions. In contrast, tri-butyl phosphate extracts a neutral species such as uranyl nitrate, $UO_2(NO_3)_2 \bullet 6H_2O$, with no ion exchange involved.

* *Miami Copper and Pinto Valley are now part of Magma Copper Co.*
® *LIX is a registered trademark of Henkel Corporation*

Miscellaneous

At Jerome in 1920, mine water containing copper from the United Verde flowed from the Hopewell tunnel into precipitation flumes loaded with tin cans and other scrap-iron. The precipitation of the copper from solution as so-called "cement" copper recovered metal which otherwise would have been lost.

A similar arrangement at the Inspiration Leaching Plant in 1925-35 provided clean-up from wash down, spills and leaks from the plant. A small amount of copper was salvaged but cloudbursts continued to wipe out everything and the project was discontinued.

In 1911, the tailings from Miami, Inspiration and Old Dominion mills ran about 1.0 percent, more than the head assays in later years; i.e., from about 1940 to date.

In the 1920-30 era, salt was mined in the vicinity of Camp Verde, crudely beneficiated and then stored in bins adjacent to the railroad tracks near the Clemenceau smelter. However, it was reportedly "taxed out of business by the County" by the late 30's. The mineral industry, particularly mills, smelters and refineries, have always contributed a large share of County and State taxes, student scholarships, summer jobs, and post graduate employment to Arizona mining and metallurgy students. Also, in 1947, the Mines and Metallurgy Building on the University of Arizona Campus was constructed with funds from Phelps Dodge.

Because of new technologies and rising metal prices, reprocessing of old mill tailings, placer spoil piles, old slag dumps and other discards from previous ore processing operations was, and still is, quite common. Some dumps have been re-worked as many as four times.

Old vanadium mill tailings at Shiprock have been retreated to recover uranium and similarly vanadium-rich tails for uranium and radium; many old gravity tails, e.g. Mammoth and Old Dominion are reground and floated. Some copper smelter slags are being crushed, ground and returned to the flotation circuit (Magma San Manuel). Bag house products, smelter stack dust from Cottrells and cyclone collectors provide a source of gallium, ruthenium, arsenic and a host of other useful products.

Old mined-out caved areas or gob-filled stopes are a source of relatively inexpensive copper when subjected to controlled in-place leaching and solution recovery. Notable examples are the caved areas at Miami Copper and at Ray Mines Division of Kennecott.

In the past 10 or 15 years, the pyrite-rich dumps discarded from the copper-zinc flotation cleaner circuits at the Iron King Mill at Humboldt in the pre-1940 era have been retreated to produce "Ironite" fertilizer. This acidic ferric-iron product is a valuable addition to fertilizers and is particularly needed by the alkaline soil in much of Arizona.

In June-July 1956, the Arizona Bureau of Mines conducted a series of pilot runs in a small one-ton-per-day plant at the College of Mines in Tucson. A continuous, closed circuit provided the basic engineering data for the design and construction of the Cyprus-Pima Mill, a 3,000 ton-per-day plant, ultimately expanded to more than 50,000 tons per day. This venture was unusual because of the relatively large extrapolation from pilot plant capacity to final plant design. George H. Roseveare, long time metallurgist for the Arizona-Bureau, conducted the test runs with the assistance of Robert T. O'Haire.

A leach-precipitation-float technique has been tried successfully on low-grade copper ores containing mixed oxide and sulphides minerals; notably at Inspiration Consolidated Copper Co. in the 1930's. The oxides are leached with sulphuric acid and the soluble copper precipitated with fine iron, usually shredded cans.

Then the cement copper and sulphides are recovered by a bulk flotation in an acid circuit, using, in one instance, American Cyanamid's Minerec reagents.

At the Continental Test Facility near Florence in 1975-76, the iron was produced by gaseous-reduction of iron oxide from roasted pyrite.

The magnetite sands recovered by magnetic separators from desert washes south of Florence have long been considered as a possible source of iron ore by such companies as Krupp and Kaiser but the 1 to 3 percent titanium in the ore (as ilmenite) was not acceptable for the production of industrial steel.

Magnetite concentrates from this area have been used in the preparation of high-density aggregates and stemming material, especially for explosive tests in deep drill holes and adits at the Nevada Test Site.

Old Reliable

In March 1972 at the Old Reliable Mine, near Copper Creek, five million tons of 0.8% copper ore was shattered by the three-stage detonation of over four million pounds of chemical explosive. Ranchers Exploration and Development Company started in-place leaching in September and continued testing intermittently for several years. This was a first-try at large scale leaching in place.

Solution distribution was by RAINBIRD surface sprays with a 97-percent solution recovery. At 1000 to 1200 gallons per minute, acid consumption to maintain the proper pH in the pregnant OFF solutions was about 20 tons per day or about two pounds of acid per pound of copper produced. In addition to the iron launders for the recovery of the cement copper, the U.S. Bureau of Mines conducted a series of tests using a special cone-type precipitator.

Ranchers staff forecast the production could be as much as 30 million pounds of copper at 50 percent recovery in five years, at a cost estimated at that time to be in the range of 30 cents per pound.

Availability of fresh water limited the operation but the feasibility of leaching certain large low-grade copper deposits in place was established. The costs of operations were proven to be so low that sub-marginal low-grade deposits now became viable ore reserves, providing of course, that the specific site met the criteria for solution control.

Prominent Men

One of the pioneers in the development of mineral processing in Arizona was Dr. James Douglas, a graduate of Queens College and later a professor of chemistry at Morrin College, Quebec.

In the 1870's, Dr. Douglas was Officer-in-Charge at the Chemical Copper Co. in Phoenixville, PA, where he was co-inventor of the Hunt-Douglas Process for the extraction and refining of copper and made the first electrolytic copper marketed in the U.S.

Dr. Douglas became interested in mining because of investments made by his family. Consequently, in 1880 he visited Bisbee, Morenci and Globe and gathered information on the mining and ore processings in these areas. Then, based on this experience and foreknowledge of copper metallurgy, he aided Phelps Dodge in 1881 to take their first plunge into copper mining. As early as 1910, he foreshadowed the leaching plants of the future with an experimental copper leaching plant at Douglas which proved the commercial feasibility of sulfuric acid leaching and electrowinning. The pilot plant at Ajo followed and then Inspiration, and the many other successful copper leaching and electrolytic recovery plants in Arizona.

Dr. Douglas' son, James Stewart Douglas, followed his father in the mining and mineral processing business and earned the name of "Rawhide Jimmy" because he used untanned cowhides to cover wear-points in ore bins and transfer chutes and thereby reduced maintenance costs.

Another prominent metallurgist in early Arizona mineral processing, Dr. Louis D. Ricketts, developed many of the milling and refining techniques for complex copper ores. Originally a graduate geologist from Princeton University, Dr. Ricketts was chiefly responsible for the design and construction of the first large concentrators at:

Old Dominion, Globe, c. 1888-90
Detroit Copper, Morenci, c. 1890-95
Inspiration, Miami, c. 1910-15
New Cornelia, Ajo, c. 1910-12

and leaching plants at New Cornelia, 1914-16 and Inspiration, 1922-25. The latter plant was the model for the ferric sulfate-sulfuric acid and also was (c. 1933-34) the first to use the leach-precipitation float process.

Prior to 1907, most of Dr. Ricketts work was for Phelps Dodge interests. He reportedly pioneered the use of conveyors; he connected crushers, screens, classifiers, washing and ore processing machines with belt and bucket conveyors and aerial trams.

Ricketts made changes in the mill at the Old Dominion in Globe that made the company more profit with a lower-grade ore (4-5%) than it was making earlier with approximately the same tonnage of high-grade (12%).

In late 1887, Dr. Ricketts devised one of his few failures, a complex leaching plant for the mixed basic sulfide-oxide ore in Copper Basin. The process was workable but reagents and energy costs were prohibitive.

At Inspiration in 1915, he brought into full operation the froth flotation concentration process, one of the major breakthroughs in the copper industry. His technical knowledge and achievements particularly in copper metallurgy were outstanding.

In 1883, James Colquhoun went to Clifton as an assayer for the Arizona Copper Co. In 1892-1894, he built and operated the first commercial acid plant and successful leaching operation in Arizona 20 years before New Cornelia's modern plant at Ajo. Acid was made on-site by the ordinary chamber process. The jig tailings were leached in small lead-lined tanks seven feet deep. Downward percolation was employed using three strengths of acid. Precipitation was accomplished in copper barrels filled with light scrap iron, revolving in vats of copper-rich leach solutions.

James Colquhoun's innovative development in 1892 of the sulphuric acid extraction of copper from low-grade oxide ores and precipitation of cement copper was a significant contribution to the mineral industry of Arizona.

Further, Colquhoun's was the first to employ gold-type concentraton shaking-tables on low-grade porphyry copper ores. Having used this technique as early as 1887, he was some 20 years ahead of his time. It was not until the 1905-1910 era that major milling operations enjoyed success with this technique on previously worthless low-grade ores.

Without the techniques developed by Ricketts and Colquhoun, the copper industry in Arizona could not have continued after all the richer ore bodies had been exhausted and only relatively low-grade ores remained.

Historical Events Related to Mineral Processing in Arizona

1000 AD Archeological evidence indicates that as early as 1000 AD crude mining operations with the accompaning hand sorting, washing, and pulverizing were performed on cinnabar and hematite ores by native Indians in Arizona. Shafts were dug, galleries excavated, and waste material stripped followed by sorting of ores, and crushing and pulverizing of selected samples.

Other mineral products mined and processed were pottery clay, native copper, turquoise, building stone, metal oxides for paint and flint chert for weapons and tools.

Coal was used for fuel in prehistoric times. Five thousand tons of salt were mined and hand sorted near Camp Verde.

1582 First silver ore discovery in Arizona near Verde Valley.

1604 First gold found near Santa Maria.

1705 Rich silver "platas y planchas", near Nogales.

1915 Flotation introduced at Inspiration—first large scale flotation in the U.S.

1917 Large scale leaching at Ajo. New Cornelia Copper Company purchases Ajo Consolidated Copper.

1926 Large scale leaching operations started by Inspiration.

1936-7 1,000 tpd pilot plant operated by Ben Cody, Phelps Dodge, Morenci to design new 30,000-tpd concentrator.

1956 San Manuel started operation of 35,000 tpd flotation concentrator.

1959 Miami Copper terminated underground mining after 48 years of continuous operation. Leaching in-place of acid-soluble copper continues from mined-out areas and unmined low-grade ore.

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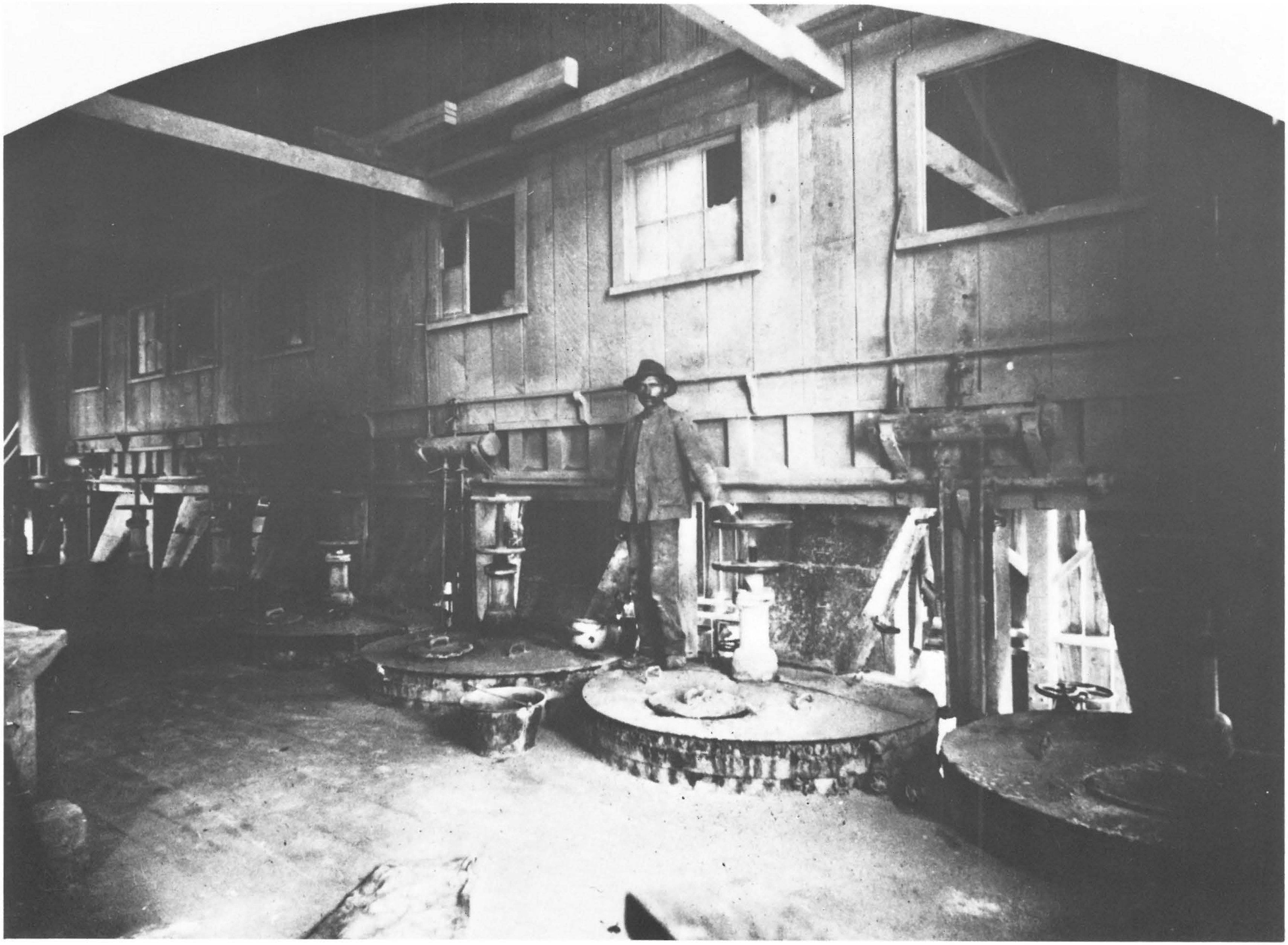
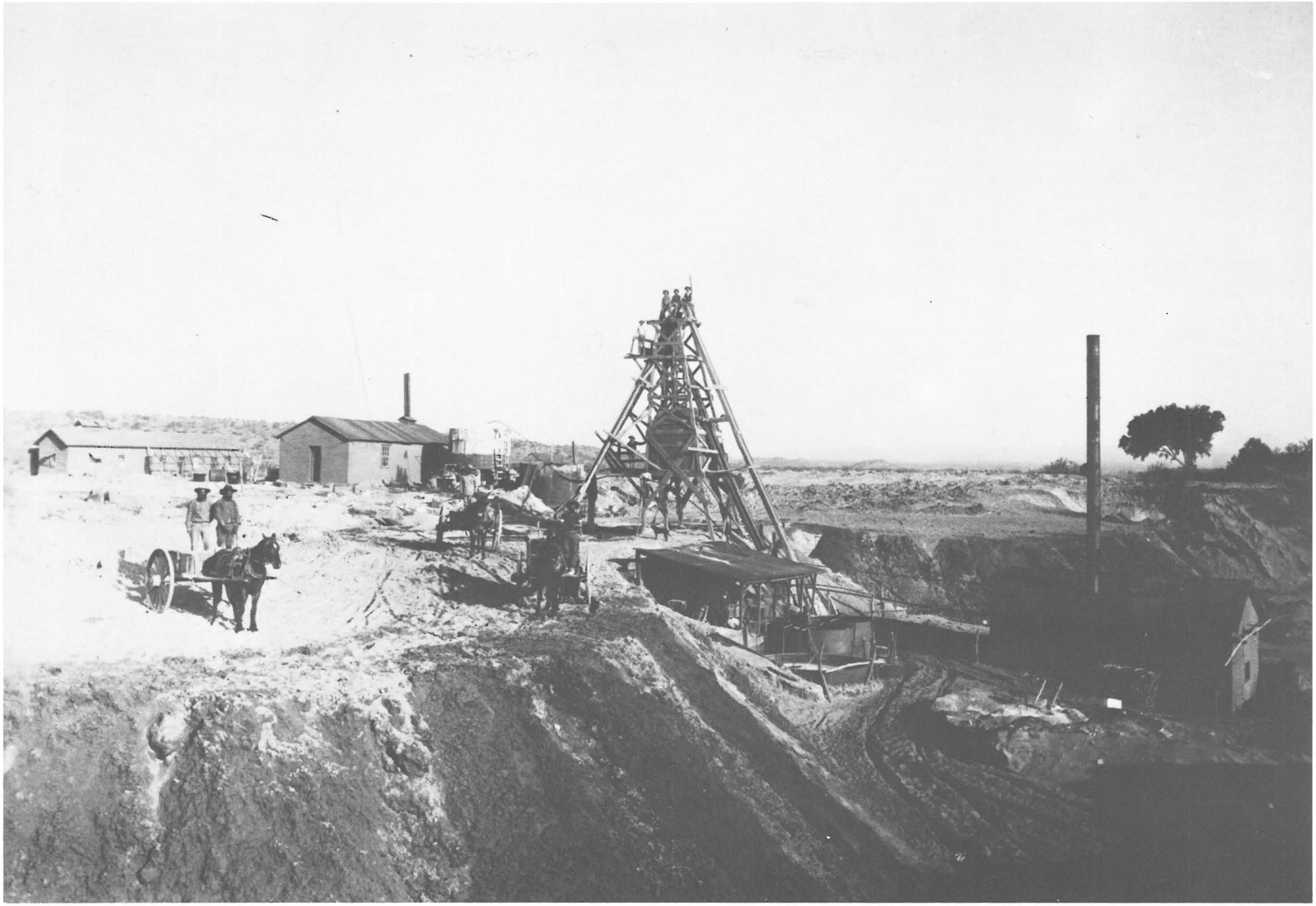
Several arrastras in which broken ore is being pulverized. *Courtesy of the Arizona Historical Society/Tucson.*

Homemade retort used to separate mercury from gold amalgam. Mercury vapor is condensed to liquid and recovered in beaker containing water. *Courtesy of the Arizona Geological Survey.*

Stamp mill at Pinal City treated ore from the Silver King mine. c. 1882. *Courtesy of the Arizona Historical Society/Tucson.*

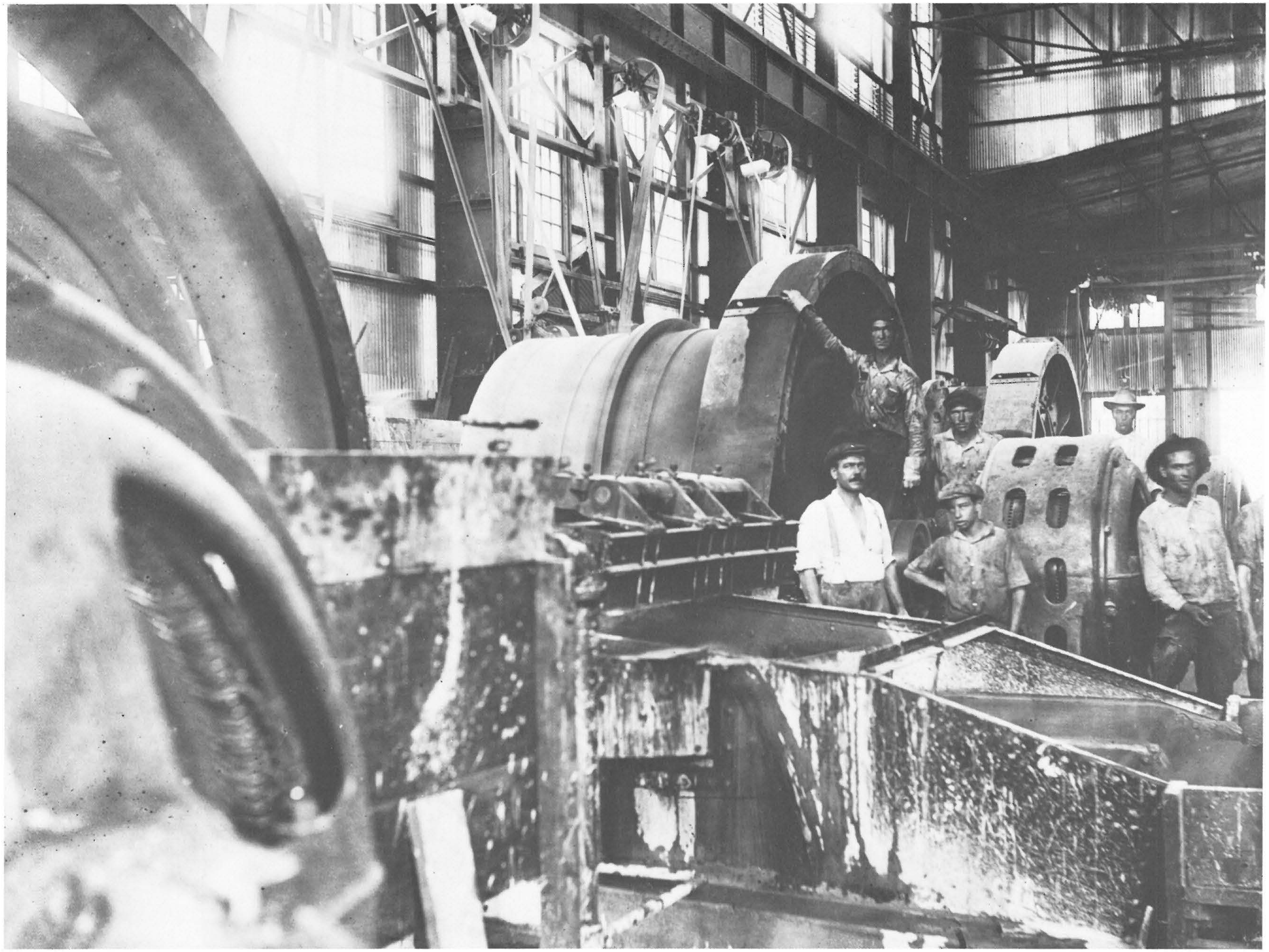


Amalgamation pans in the mill at Pinal City, c. 1882. Ore from the Silver King mine. *Courtesy of the Arizona Historical Society/Tucson.*

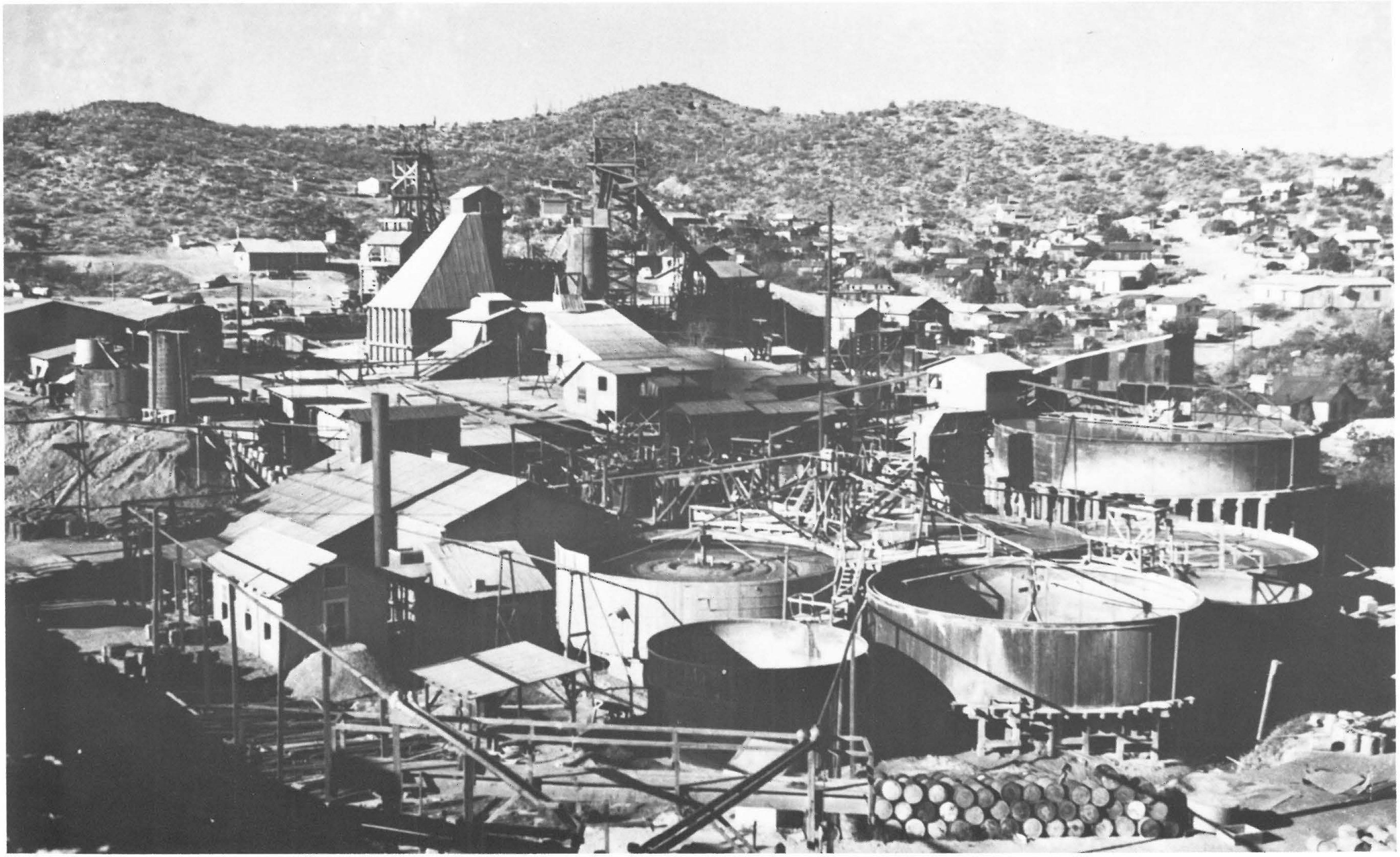


Reportedly first commercial application in United States of cyanide leach to mine tailings. Vulture mine, c. 1892. *Courtesy of the Arizona Historical Society/Tucson.*

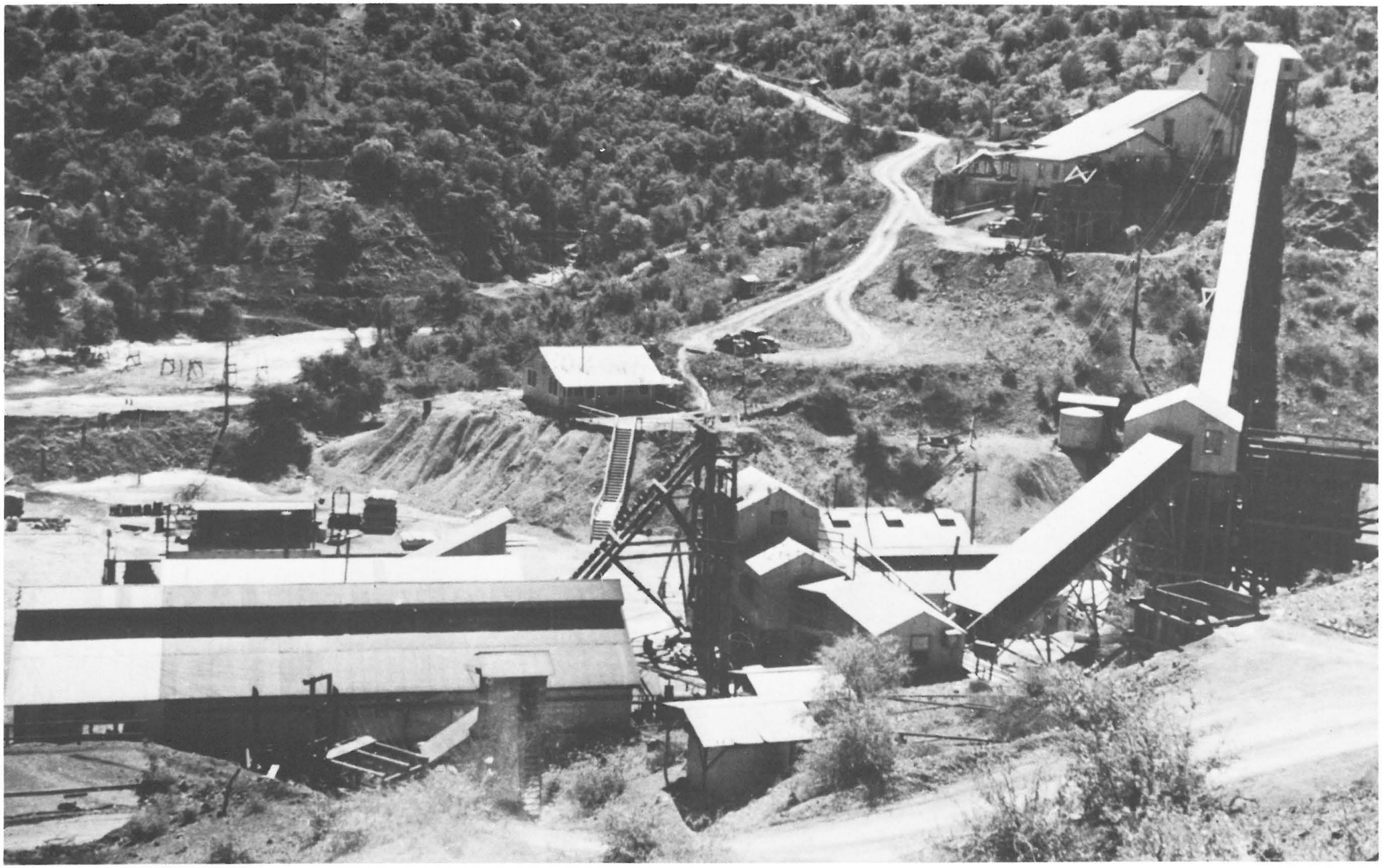
West Yankie mine and concentrator in Clifton-Morenci district, 1906. Tailings in Ryerson Canyon (right center). *Courtesy of Walter Douglas, II.*



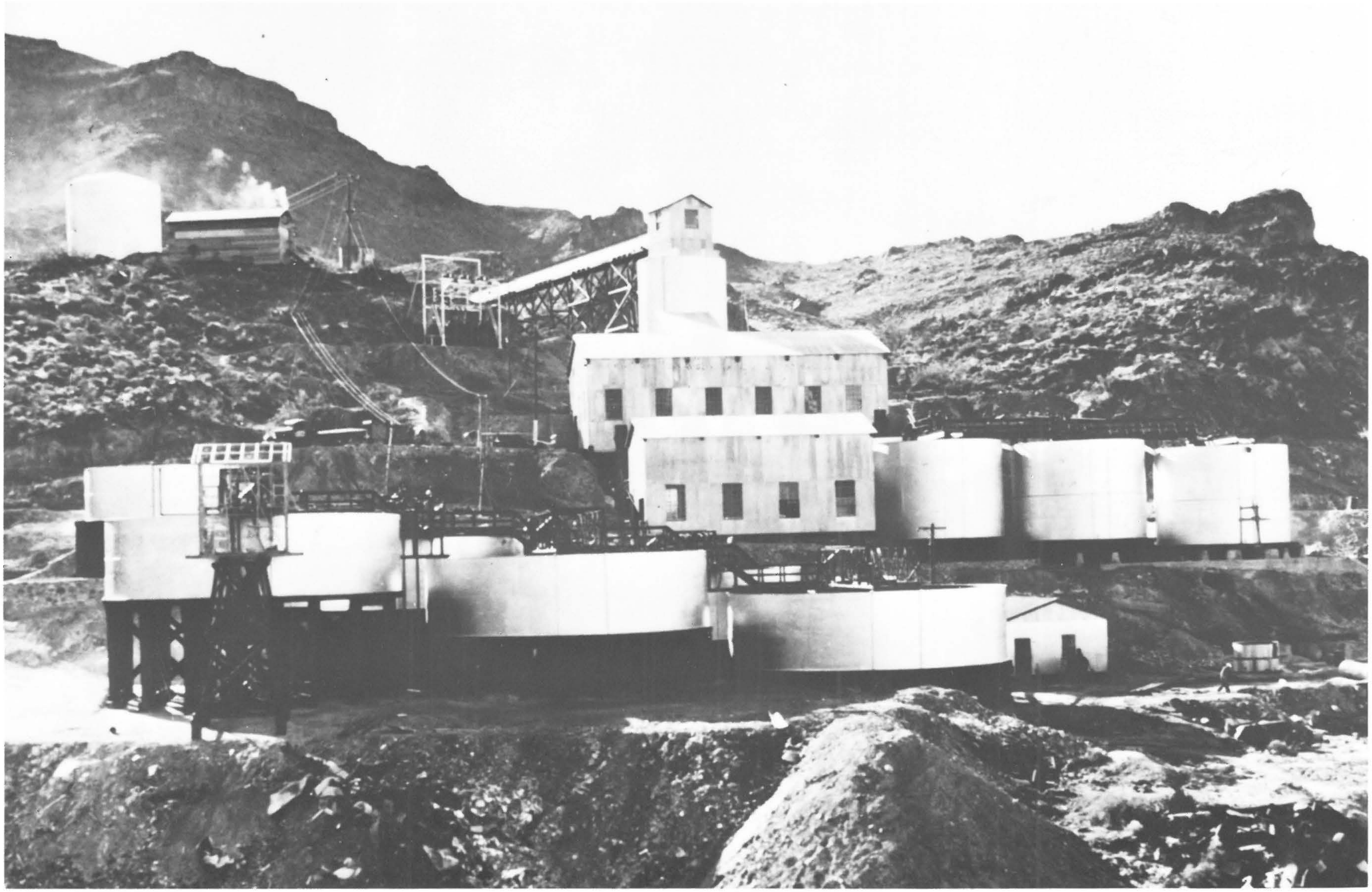
Concentrating mill at Ray mine, c. 1915. *Courtesy of the Arizona Historical Society/Tucson.*



Mammoth-St. Anthony Ltd. concentrating facility, Old Hat district, 1937. Town of Tiger in upper right. *Courtesy of George Argall.*



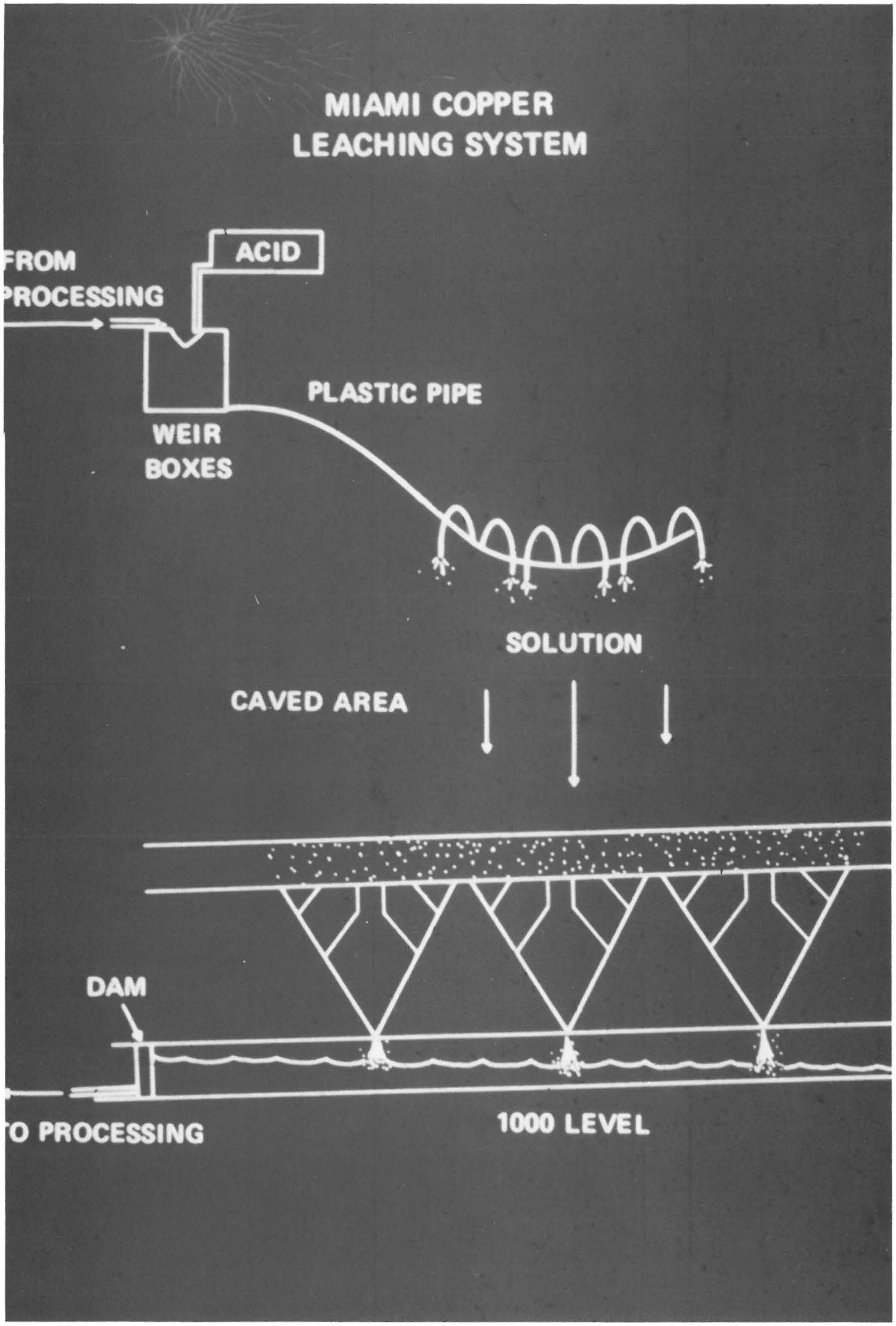
Trench mine and mill operated by American Smelting and Refining Co., Harshaw district, c. 1935. *Courtesy of George Argall.*



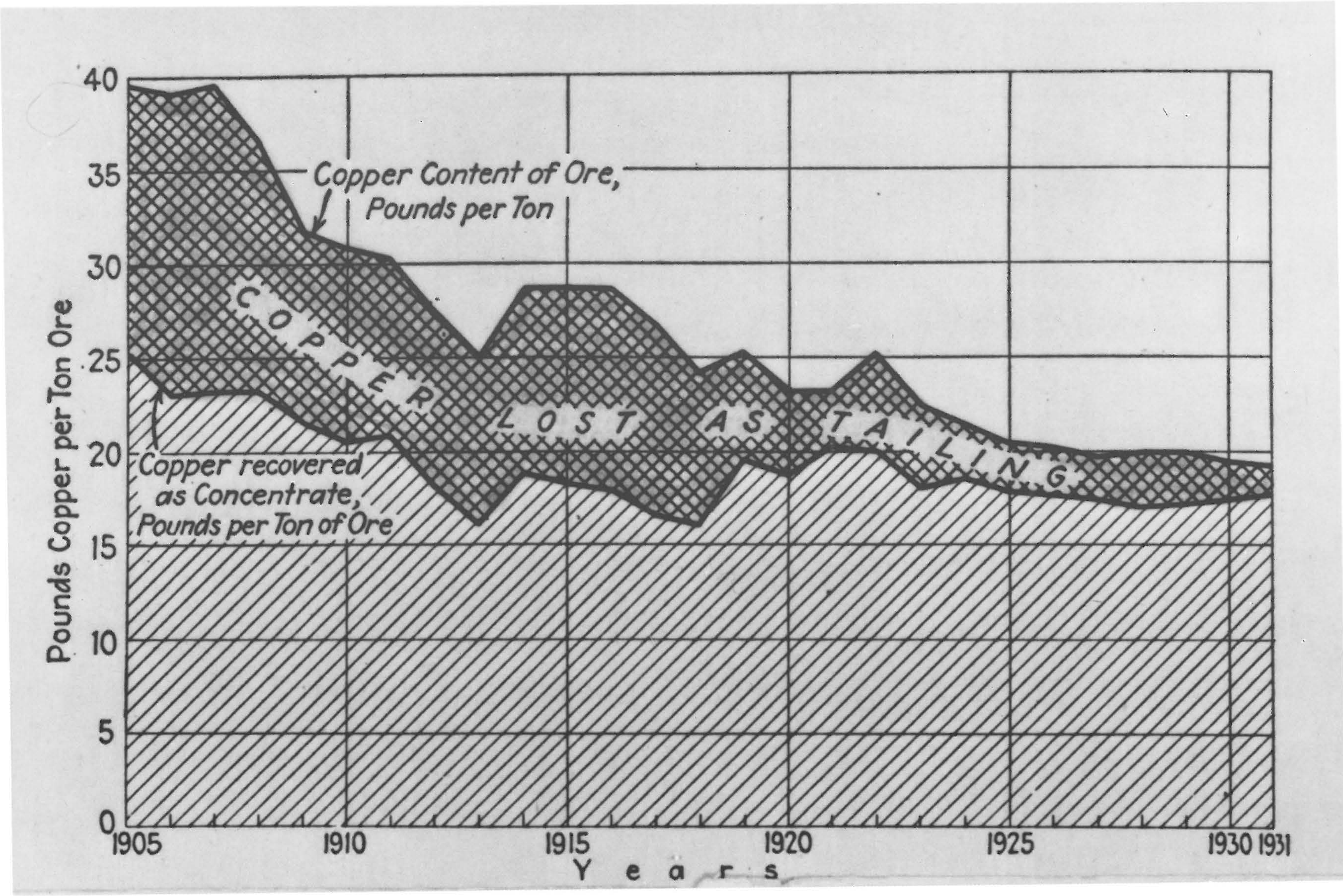
Gold concentrating facility—Gold Road Unit of United States Smelting, Refining and Mining Co., Oatman district, 1937. *Courtesy of George Argall.*

Dilute sulphuric acid sprayed on leach pad of copper ore.

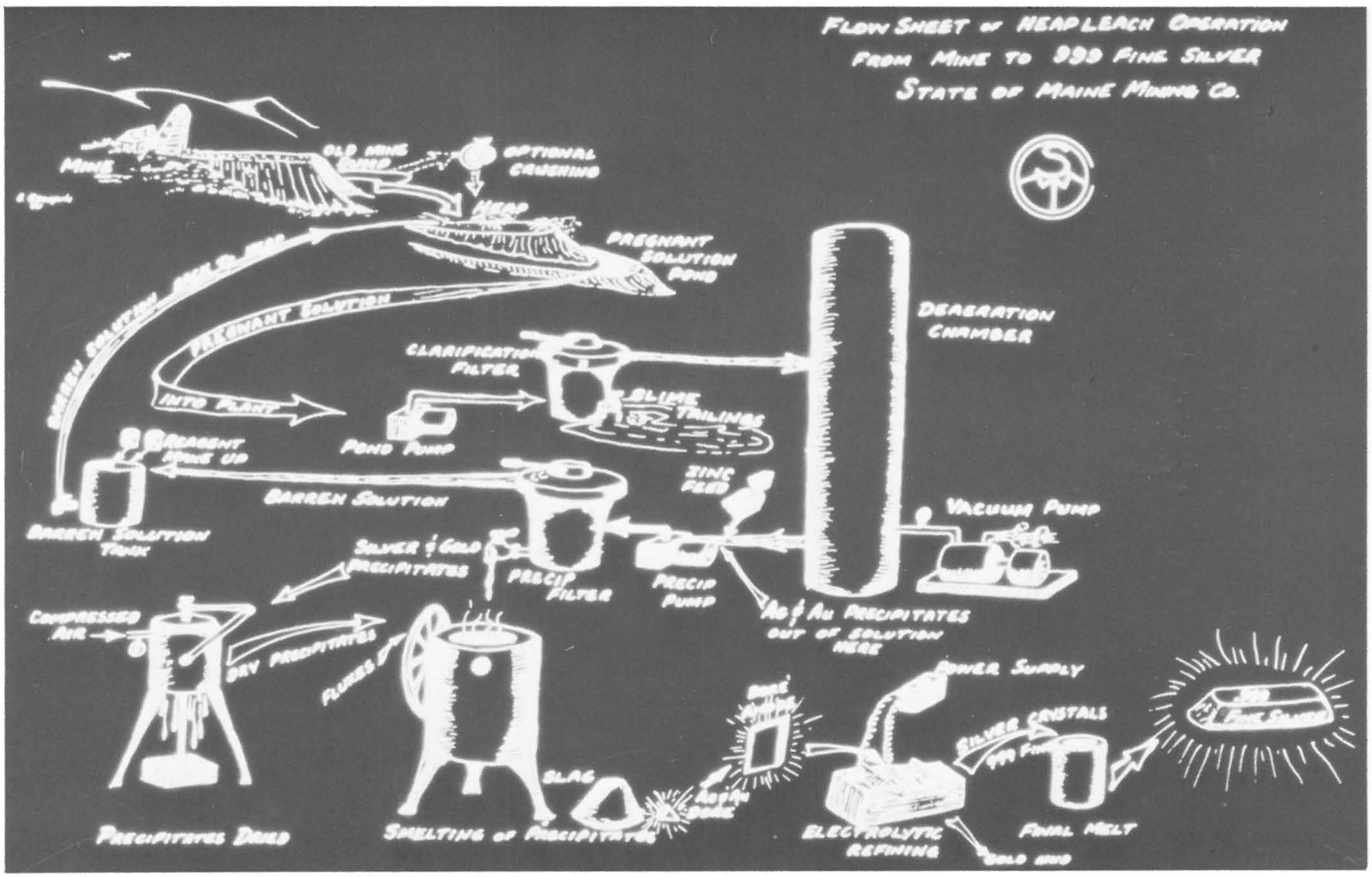
Copper leaching ponds at the Ray mine, c. 1974.



Leaching in place at Miami Copper. *Courtesy of J.B. Fletcher.*



Improved recovery due to advance in metallurgy. *From* Porphyry Coppers *by A.B. Parsons.*



Example of cyanide heap leach and Merrill-Crowe recovery. *Courtesy of State of Maine Mining Co.*

James Colquhoun (1896), manager and later president of the Scotch-owned Arizona Copper Co. A brilliant innovator, he developed the first leaching plant in Arizona. *Courtesy of the Arizona Historical Society/Tucson.*

HISTORY OF MINING IN ARIZONA

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