Mining in Bisbee

Chapter 6

The Art of Open Pit Mining

A look at the men, methods and machines

1917 - 1975

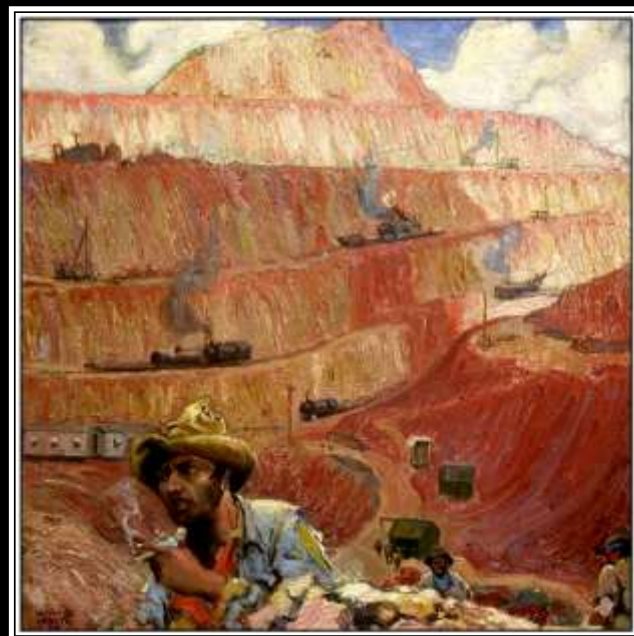
Slide 1

MINING IN BISBEE

THE ART OF OPEN PIT MINING

A look at the men, methods and machines
1917-1975

Trains in the Pit, Bisbee
William Davidson White
Oil on panel, 14 x 20 inches
1923



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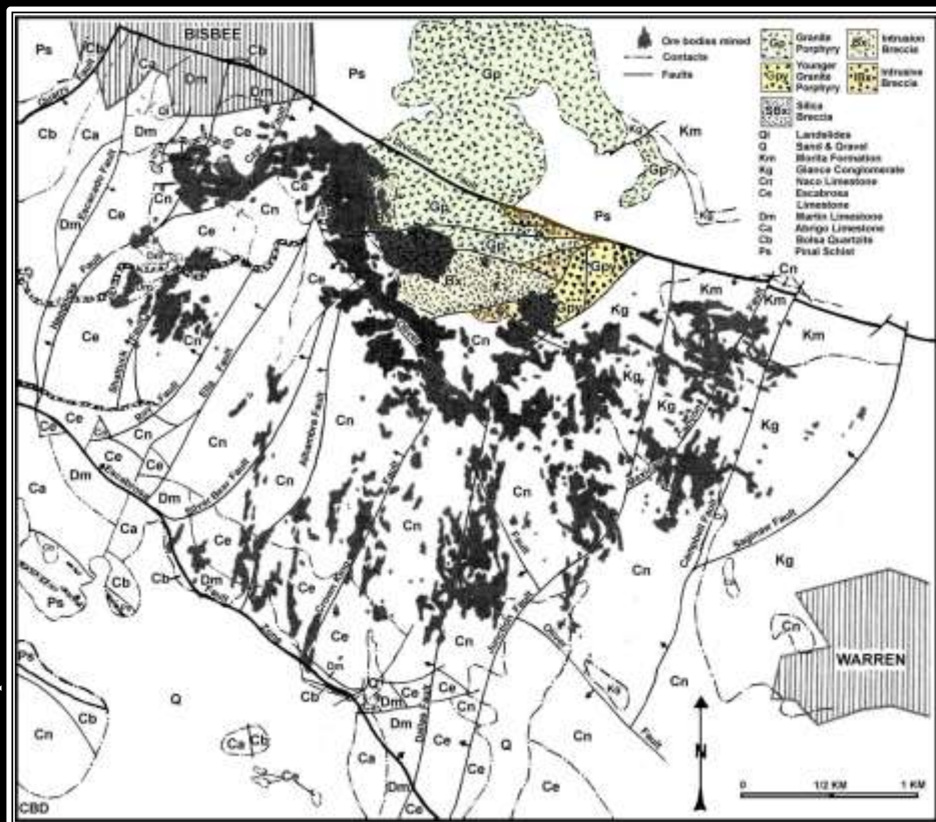
Part 6

Slide 2

Generalized geology with ores mined underground

Rich copper deposits in the limestones ringed the very low grade, porphyry mass that formed Sacramento Hill. These limestone replacement deposits were high grade and it was these ores that attracted the attention of all for the first 25 years of mining at Bisbee.



After Graeme - 1981

The many sulfide replacement deposited in the limestones at Bisbee were invariably pyrite dominate, though other species were always present. Copper and/or lead/zinc sulfide minerals were typically present in much lesser, but economically important amounts. Most of the economic deposits were copper/iron/sulfur combinations with only modest amounts of lead or zinc.

The limestone replacement deposits that resulted from the mineralizing events are generally arranged around the Sacramento Stock complex in semicircular fashion with offshoots radiating outward like the spokes of a wheel. This arrangement is the result of orebody concentrations in fractured and fault zones (Bryant & Metz, 1966). This crescent-like arrangement of the ores is a reflection of the shattered zone in the limestones, which surround the southern portion of the stock complex while the "spokes" reflect the fault zones and fractured areas (Bonilla, et al. 1916), (Bryant & Metz, 1966). This arrangement is clearly visible in the above illustration.

The replacement copper orebodies were almost always associated with large, low-grade bodies of siliceous pyrite and were commonly peripheral to the siliceous pyrite, along the footwall or keel, but with scattered orebodies within the mass as well (Bryant & Metz, 1966). For the most part, the economic portion of the replacement deposits was small, averaging about 25,000 tons of mineable ore (Bryant & Metz, 1966) even though the total sulfide mass would be several, if not many, times larger. There were some exceptions however, with a very few copper orebodies exceeding one million tons of minable ore (Bryant & Metz, 1966).

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Low grade copper deposits were plentiful

The American southwest was dotted with large porphyry hosted, copper deposits that were too low in grade to be exploited, often accompanied with smaller high grade deposits . Bisbee was no exception with the hard, red mass known as Sacrament Hill in its midst and surrounded by a number of rich underground mines.

Typically, ore grades of at least 5% copper were needed to make even a modest profit. None of the many porphyry deposits in Arizona met this basic requirement. Still, there was a very real need for new copper deposits as the uses for copper increased and these porphyry deposits were just too big to ignore.

The serendipitous development of cheap bulk mining techniques and, equally important, the discovery of a way to concentrate low grade minerals combined during the first decades of the 20th century to bring hope for these often gargantuan porphyry deposits. The initial investment that would be required for development was also huge, much bigger than anything before.

Sacramento Hill – 1904,
Graeme Larkin collection

__The Sacramento Stock complex__

The term complex is used to describe the Sacramento Stock as it is actually composed of two distinct porphyry units as well as several breccias. The older of the intrusives is a highly altered, quartz porphyry, which was intensely silicified and pyritized with 15 to 18 percent sulfide (Bryant & Metz, 1966) by the first phase of mineralization and was almost totally devoid of ore minerals. This intrusion event also caused the development of a large intrusion breccia along the south side of the stock, which later became very well mineralized and was an extremely important source of ore for the underground mining as well as the two open pit mines.

The younger intrusive is described as a quartz-feldspar porphyry (Bryant & Metz, 1966). It was moderately altered, first by hydrothermal fluids and then by supergene activity. This unit was reasonably well mineralized and was the principal source of ore for both open pit mines.

Both of the intrusive units have been dated at 180 ± 3 million years (Phelps Dodge, personal communication, 1972). Lowell and Guilbert have ascribed the younger age of 163 million years to these units.

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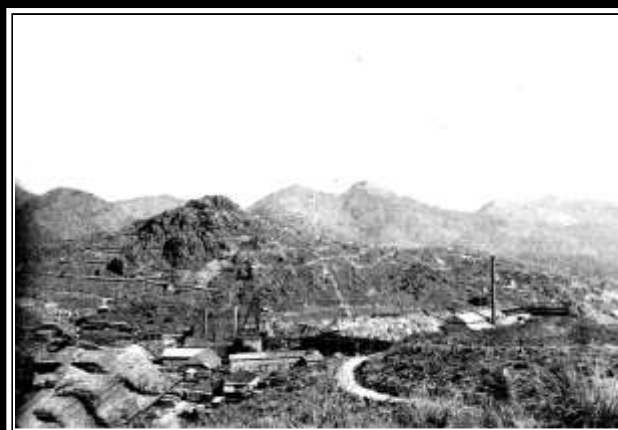
A massive exploration program is undertaken

Hundreds of feet of drift were driven with no luck. Then in 1909, underground workings were extended to areas under the hill and the first ore hit in mid-1911. Nearly 20 thousand feet of additional crosscutting raising were undertaken. In 1913, a number of surface churn drills were brought in to help in the exploration effort. Some 160,000 feet of drilling was completed before the deposit was understood to be in two parts – East and West. The West orebody appeared to offer the hoped for opportunity , but further work was needed to develop a mining plan.

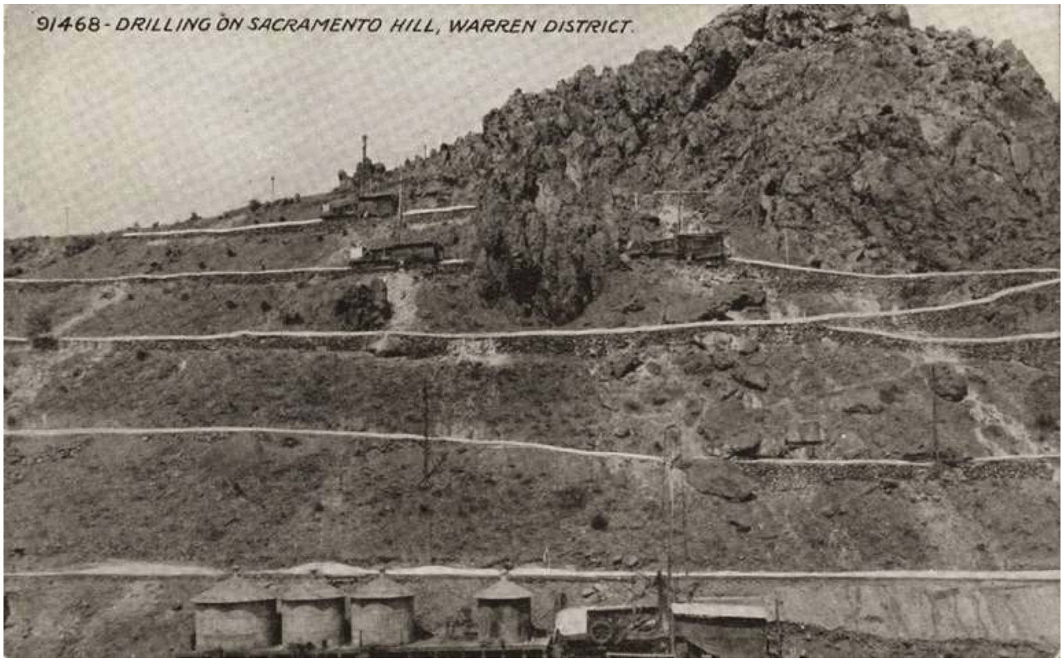
Three churn drills on the side of Sac hill – 1915
Graeme Larkin collection



Churn drill sites (white spots) on the flank of Sac hill – 1915
Graeme Larkin collection

Huge amounts of exploration work were required to fully delineate the mineralized areas, as the ore grade material was largely restricted to just a few of the units which composed the Sacramento Stock. Further, the original copper mineralization, as emplaced, was very low-grade (for the time), particularly in the porphyry units.

It was only ore grade where near-surface oxidation had remobilized some of the copper and re-deposited it on other sulfide minerals lower in the stock complex. This process, known as supergene enrichment, was responsible for making most of the World's copper porphyry deposits economic, including Sac Hill.



Postcard view of the ongoing exploration drilling on Sacramento Hill – 1916.
Graeme Larkin collection

Sacramento Hill in1916 with the many exploration drill sites evident as light-colored streaks caused by the drilling residue flowing down the hillside.
Graeme Larkin collection

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Open pit mining is new, expensive and very risky

With the potential exploitation of a large, low-grade, porphyry hosted copper deposit came the need for extensive exploration, metallurgical testing, detailed mine planning and new approaches to engineering. And too there was the immense capital outlays for prestripping, new infrastructure and the massive equipment. Years of work in all. Mining copper had never been a poor man's game and now , with these new, more complex deposits, the cost to just get into the game increased ten fold. Many of the mining and processing techniques were new and unproven for universal application. The risk were enormous and more than a few failed.

The Copper Queen was well aware of the risk and looked in depth at other options to mine the higher grade West Orebody. A number of underground approaches were explored and Gerald Sherman reported that mining by top slicing and open pit would yield similar economic results, with either scenario requiring a concentrator.

However, there was a problem with the underground approach, a most serious one, there were not enough experienced underground miners available. This shortage had plagued all mining companies for years and with no reason to think it would change, the decision was made to step into the new world of open pit mining. Time would prove this to be a wise choice, as the shortage of experienced underground miners continued and indeed, continues to this day.

Gerald Sherman was a well experienced and capable engineer and then Mine Superintendent at Bisbee, who would later become the Consulting Engineer of the Copper Queen Branch of Phelps Dodge Corp. His opinions were greatly valued by the company and the path he had suggested was one which was both extraordinarily expensive and risky. Yet the Copper Queen had to do something at Bisbee as its mineral reserves were being depleted with little prospect of substantial growth other than the porphyry ores.

Some years before, the C & A had skillfully outflanked the Copper Queen and purchased most all the ground that potentially contained new orebodies. This placed a huge burden on the Copper Queen, if it was to stay a major producer in Bisbee. A substantial tract of land had been added in 1916 through the purchase of the holdings of the Warren Reality & Development Company as well as the Rough Rider claim group, totaling some 2,074 acres, but these new properties were speculative at best (indeed, over time no mineralization was ever found in these properties; however, ample water was developed as needed for the Copper Queen Concentrator). Thus, a decision was taken in 1916 to proceed with the open pit, but cautiously.

Prior to 1917, Phelps Dodge and Company was a highly profitable, closely held company with the great majority of the shares held by the decedents of the founders. For the previous 37 years, it was these individual who financed **all** of the development at Bisbee and elsewhere, effectively using their own money. It had become a public company only in 1909, but had remained with few shareholders. They were now faced with an investment decision which was so huge it could potentially ruin them financially if it went wrong.

While history does not record the reasons that drove Phelps Dodge and Company to become a more widely held public company, with a larger capitalization, the coincidence with the decision to develop the Sacramento Pit is interesting.

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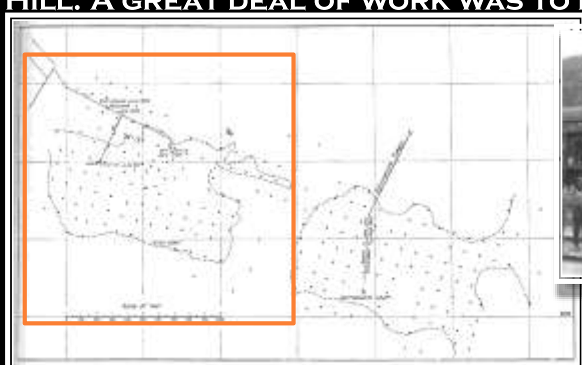
Open pit mining, a new concept

The concept of surface mining using steam shovels to dig blasted rock and load it into railroad cars had been used in the iron mines of Michigan and for copper at Bingham Canyon, Utah with reasonable success in 1907, but the art of combining steam shovels with rail haulage was brought to perfection in the construction of the Panama Canal, completed in 1914. There is little doubt that this wonderful project instilled confidence in the management of Phelps Dodge to try the same at Bisbee just a few years later.

By chance, the Sacramento shaft had cut 300 feet of 1.5% copper bearing porphyry while being sunk in 1904. At the time, it was of no economic value and of little interest. Yet encouraged by the success in Utah, a decision was made to look closer at what might be under that rugged knob; Sac Hill. A great deal of work was to be undertaken.



Shovels in the Panama canal
C - 1913
Bob Edwards collection

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Sac Hill exploration to 1916 with the West Orebody outlined, Graeme Larkin collection

The whole world watched with great interest as the Panama Canal project cut its way across the isthmus. This, the most ambitious and expensive project ever undertaken to that point in the history of America, was of particular interest to mining men everywhere. After all, this was a massive earth moving project and the methods used might have practical application in the mining industry.
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In fact, the work at the Canal refined techniques already employed in the iron mines of Northern Michigan and in copper at Bingham Canyon in Utah, the first open pit copper mine. Shovel/rail earth moving was now a proven and viable for the new concept of bulk mining of low-grade ores. New copper mines at Chino in New Mexico, Ruth in Nevada and Ajo in Arizona were to further refine this new way of mining. The Sacramento Pit at Bisbee would benefit from the experiences at these mines and contribute new ideas to the growing information base of open pit mining.

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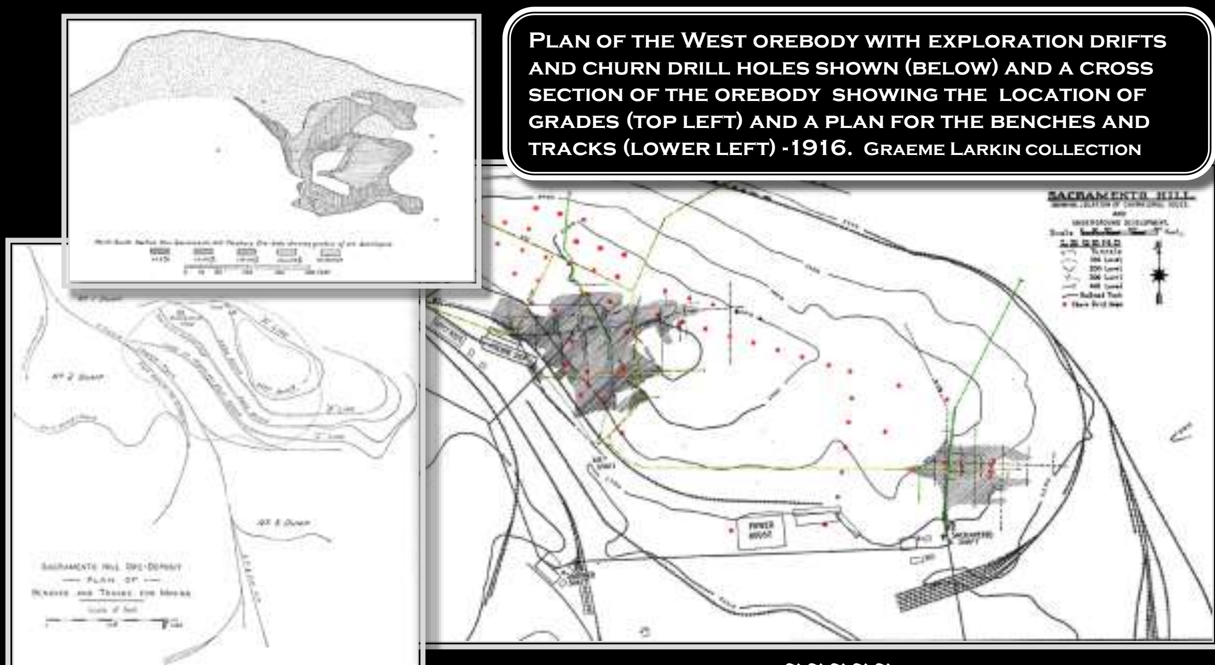
Planning for the Sacramento Pit

Huge upfront costs were associated with an open pit which required a great deal of engineering, study and planning to justify. Then highly detailed open pit mine plans were developed using cost from other operations such as Utah Copper, Chino Copper and Nevada Consolidated. Nothing could be left to chance, a failure here could severely damage even destroy the company financially.



Plan of the West orebody with exploration drifts and churn drill holes shown (below) and a cross section of the orebody showing the location of grades (top left) and a plan for the benches and tracks (lower left) -1916. Graeme Larkin collection

The design and development of an open pit mine is a massive engineering undertaking which encompasses a multitude of disciplines. Transportation of ore, leach and non-mineral material is a prime consideration as it is a cost driver. The installation of rail is an expensive venture as the severe topography in the pit area forced deep cuts and many miles of rail at the slope of 2½% to reach dump sites.

Slope stability was always a concern. The steeper the pit wall slope, the less non-ore material that must be moved, but with steepness comes the risk of failure. A balance must be struck to be both safe from slope failures and maintain an efficient stripping ratio.

The scheduling of ore to the concentration and no-ore material to their respective points of deposition required substantial advance planning to assure the availability of both men and equipment at the right time and place.

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The best way to treat the ore is studied

All of this new mineral discovered was great, but it was not ore unless the contained copper can be economically recovered. Beginning in 1914, various recovery schemes were tested on bulk samples extracted from the underground workings at an experimental concentrator built near the Sac shaft . Gravity separation was tried first and gave a recovery of 75.5% and a concentrate (con) grade of 6.5% copper. Froth floatation, which had only been developed in 1912, was tested next with a recovery of 87% and a con grade of 10.0%, a clear improvement, but this was a patented process. Royalties had to be paid to the discoverers. The test work would continue for several more years in the hopes of finding a way to treat the ore without paying this fee. In the end, a combination plant was built, which began operation in 1923. Over the years, many changes and improvements were made to increase recovery and make a higher grade con, as the low con grade had placed a burden on the smelter.

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Experimental concentrator near the Sac shaft – 1915 Graeme Larkin collection

The direct smelting of the low grade material was economically unfeasible. Some way to concentrate the ore minerals and increase the grade of the smelter feed was a must. As the metallurgy of these ore types was relatively new to the mining industry and complicated, it would take several years before the ideal mix of grinding/reagents and equipment that would yield a good concentrate grade while achieving a reasonable recovery. It was also very important to maintain a minimal tonnage level of ore processing, or throughput, which maximized the potential capacity of the plant equipment. For the Copper Queen Concentrator, the design capacity was to be about 4,000 tons per day.
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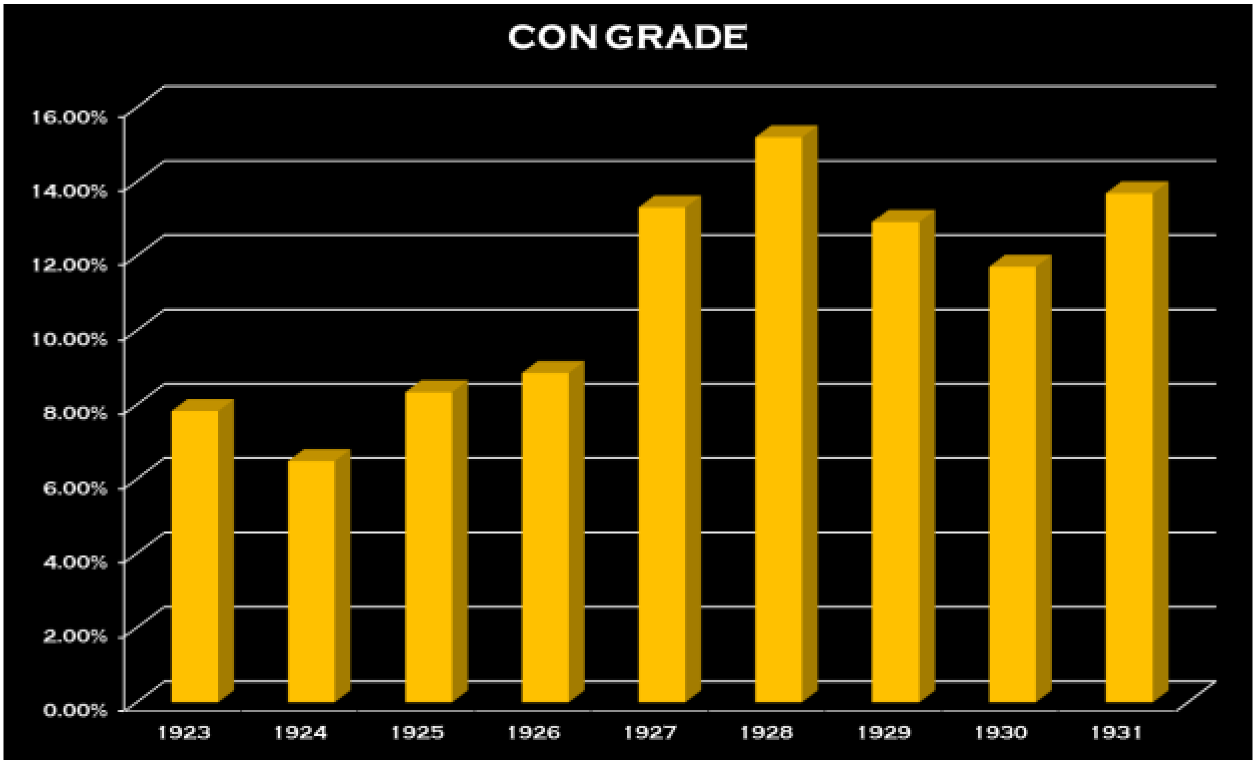
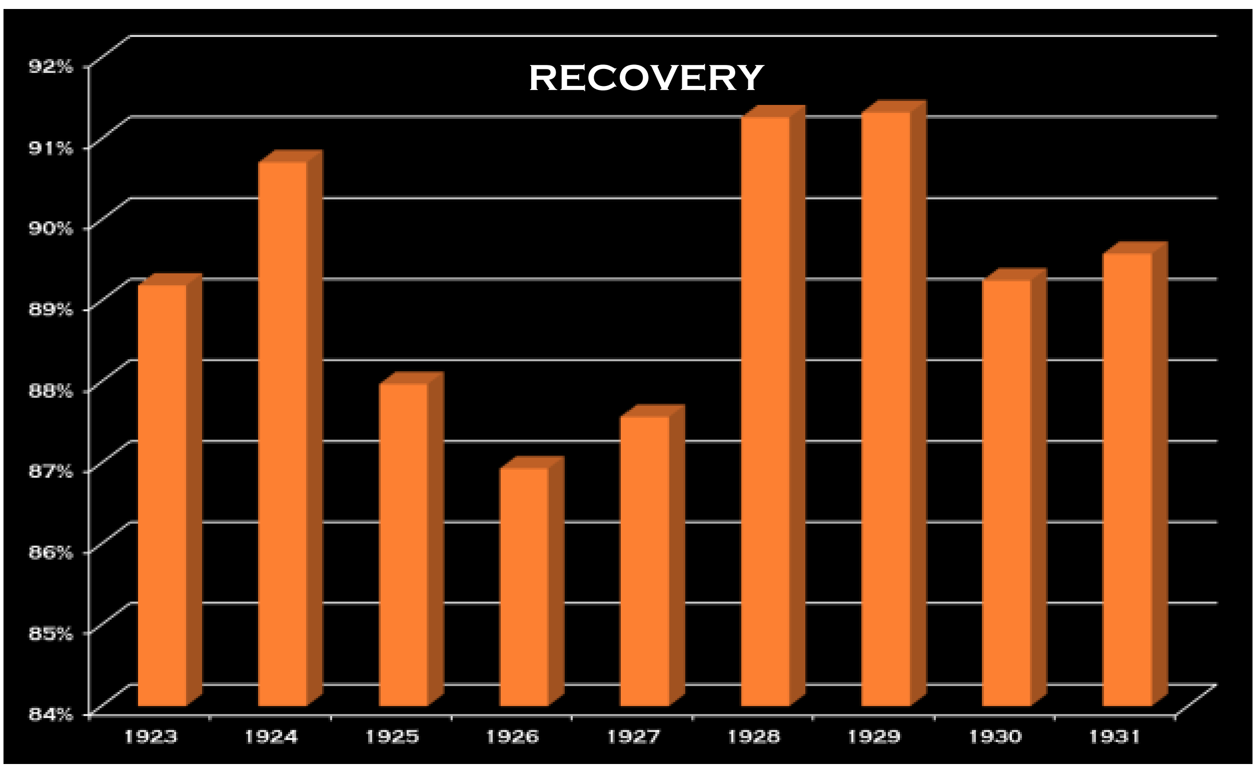
As shown in the graphs below, it took a while for concentrator to produce a concentrate above ten percent. This was only after extensive test which included grinding the ore finer, improved classifiers, incorporating different floatation cells and reagents. In the end, the patented Calloway process was used with a royalty paid to the process inventors. The graphs represent all of the ore processed including that mined by glory hole methods after the pit had closed.





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A decision is taken to develop the Sacramento pit

June, 1916 – a decision was made to go forward with the development of the West orebody as a steam shovel open pit. It was to be Arizona's second such mine, as open pit mining at Bisbee started in January 1917, just days after similar operations started at Ajo.

The estimated total costs for the project –$6,283,900 – a huge sum for the era. Some 6.2 million tons of 2.5% porphyry ore had been identified, of which 5.2 million would be recovered from the pit and 875,000 by underground methods from the pit bottom, once the pit became too deep for rail access. To get all of the ore, some 16,530,000 tons of overburden were to be moved. This gave a stripping ratio of 1.00/3.20, high for the times. Substantial prestripping would be required at an estimated cost of $2.09 million.

Mining equipment would cost $566,000 and a new power plant an additional $640,000. A 3,000 ton per day concentrator was to be built as well, at an estimated cost of $2.1 million, which included developing a source of water of the plant. Using numbers from the very few similar operations, mining costs were estimated at $0.86 per ton of ore. If only it were to be! Sac Hill held some surprises, mostly bad ones and it was not long before they appeared.

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Processing copper ores by floatation requires substantial amounts of water, something the Copper Queen did not have. Efforts to secure some of the abundant water the C & A pumped from the Junction Mine were unsuccessful for unrecorded reasons. Thus, a new source was sought. In the end, the C & C Shaft near Warren was chosen and after a great deal of effort, adequate water was found on the 1800 level.

A schematic of the water capture and pumping setting in the C & C Shaft is shown at the right.

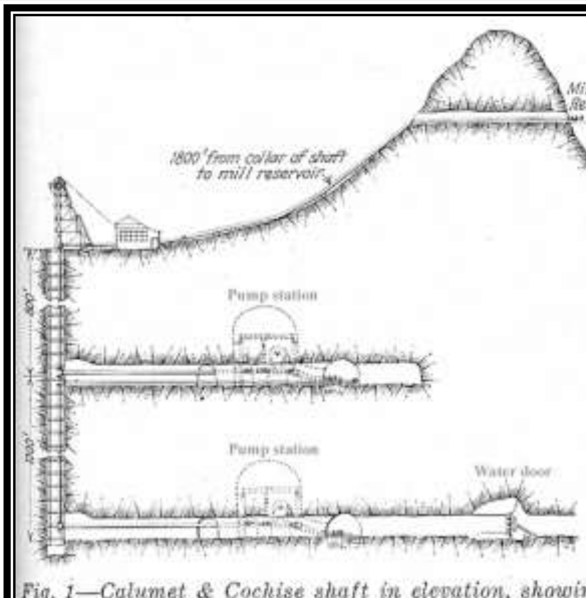

Fig. 1—Calumet & Cochise shaft in elevation, showin[g] the 800-ft. and 1,800-ft. pump stations
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Equipment is purchased

The initial costs associated with starting an open pit mine are always high. The purchase of the necessary mining and support equipment is an important, but relatively small when the total costs are considered. It is more a factor of when can the required equipment be manufactured and delivered, as most of the items needed are only built when orders have been placed. This type of equipment is not sitting in a store somewhere waiting for a customer.

Many large or specialized pieces of equipment have very long lead times , thus orders must be placed as soon as a "go" decision has been made to have any chance of a timely delivery. This is still true today, with several years wait common.

Porter, saddle-tank locomotive in the Sac Pit – 1918 Graeme Larkin collection

Equipment	Units
Steam shovels	7
Locomotives	15
Dump railcars	75
Churn drills	7
Air drills (heavy)	15
Air drills (pluggers)	33
Rail cranes	2
Powder car	1

Principal equipment purchased in 1916/17

Churn drill on Sac Hill 1915 Graeme Larkin collection

In any mine, material handling is the driving factor in equipment selection and the timing of the delivery of the digging and hauling equipment.

Little of what mines used at the time is readily available, with most requiring months if not years of lead time to assure a timely availability. This remains very true even today for most large machinery, mobile equipment and electrical distribution equipment. With the ordering of such equipment came the payment of a substantial portion of the total costs, adding to the upfront costs associated with the huge financial undertakings that are required for open pit mine development.

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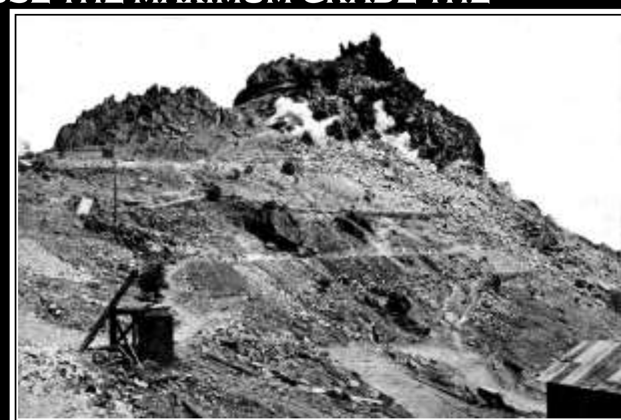
Hard rock and lots of it

Some of the hardest rock ever mined at Bisbee was on the top of Sac Hill, right where stripping needed to start. Before the initial big blast to start stripping could be drilled, access had to be carved into the craggy hillside to bring in the big drills. This was not a simple task in the age before bulldozers. Every foot had to be drill and blasted then cleared by hand or by animal.

Meanwhile, shovels were busy on gentler terrain nearby, making the cuts for rail access to begin the long, long ascent to the 5540 elevation bench on top. Long because the maximum grade the locomotives could climb was 2½%

Local residents watch a shovel loading cars while digging a rail cut into Sac Hill – 1917
Graeme Larkin collection



Blasting roadways into Sac Hill – 1917
Graeme Larkin collection

Looking more or less west toward a smoke-filled Bisbee from near present-day Warren with Sacramento Hill in the center of the photograph. USGS photo by F. L. Ransome, 1902.

Graeme Larkin Collection

Sacramento Hill stood monument-like at the mouth of Mule Gulch as the rock of which it was made was hard, very hard and resistant to erosion. This was because it had been intensely silicified by the early mineralizing fluids making it the most weather resistant rock around. The rock on north side had been broken by the Dividend fault, while that on the west, south and east sides had been altered by hypogene and supergene processes that made them quite soft and easily eroded.

In the end, the hardest rock ever mined at Bisbee was that on Sacramento Hill. The Copper Queen quickly found it to be resistant to digging as well as highly abrasive. All steel implements that came in contact with the rock– shovel buckets, railcars, etc. all suffered substantial wear from handling this rock and required frequent repair.

Sacramento Pit C-1928. Note the boulders behind the shovel and the hard toes protruding into the digging pit

Graeme Larkin Collection

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The Big Blast that started the mine

More than ten tons of explosives were loaded into the drill holes on the top of Sacramento Hill and many townsfolk came to watch the show. The blast was perfect from an engineering standpoint but disappointing from a spectators. The defiant, rocky top of Sac Hill was gone, now track had to be laid to bring in the shovels and trains to the hilltop as well as to the dump sites on the nearby hills. In 1917, 4½ miles of rail were laid for mining and rock disposal.

Two views of the initial blast on Sacramento Hill with spectators in the foreground of both 1917. Graeme Larkin collection

The first blast of any size on Sacramento Hill was a much anticipated event. Many workers and townsfolk's sought vantage points to watch as more than ten tons of explosives were detonated at one time. Few could imagine that such a massive explosion could be anything but spectacular. They were to be disappointed.

However, mining blast are calculated and controlled events with little more than a muffled roar and dust. It is always planned to just break the rock and displace it only a bit - not throw it some distance where it must gathered up to load out. In any event, the top of Sac Hill was now broken and in a way that it could be mined. To be sure, a number of large boulders were formed and would need secondary drilling and blasting, but all-in-all it was a successful blast. Much more about breaking this difficult rock remained to be learned however.

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Shovels and trains soon make their way to the top

Graeme Larkin collection

Workers looking at the damage from a small slope failure of large boulders which hit this shovel and buried the jackarm - 5540 bench, Sac Hill - 1917

both from the Graeme Larkin collection

Mining of the 5540 bench on Sac Hill - 1917

The very hard rock created a huge number of large boulders and dangerous conditions. Progress was slow and often stopped. This new way of mining was neither simple nor straightforward. Many lessons were to be learned, many costly lessons. ~~~~~~

All of the steam shovels of these early days were rail mounted, with a boom that swiveled on the stationary frame. Thus, the shovel would dig all it could reach with the maximum boom extension, then drop back to allow for the tack to be extended about 25 to 30 feet. A slow and laborious processes to be sure, but no machines to assist, such as bulldozers, were available at this time. Hard toes and oversize boulders often required the shovel to retreat while these obstacles were drilled and blasted.

Toward the end of the mine's life, a single caterpillar-track type shovel was added. This was to be the last shovel kept in use to load small cars to be dumped into the glory holes after standard railroad equipment could no longer reach the pit bottom due to the steep incline.

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The difficult conditions are reflected in the costs

Prestripping continued until the end of October 1921 with some 6,650,070 cubic yards moved. In all, $5,439,757 had been spent moving this material, some 160% more than estimated. Worse yet, copper prices were falling and dramatically. The pit was closed and construction of the mill suspended. The fate of the project was uncertain.

Even the underground mines were closed for a few months due to low metal prices. Many men left the district for higher paying jobs elsewhere, particularly in California.

In 1923, a decision to continue with the construction of the mill was made in spite of the huge costs overruns. In the end it would cost $4,303,748 -- 100% more than planned. Men were hired and operations started anew.

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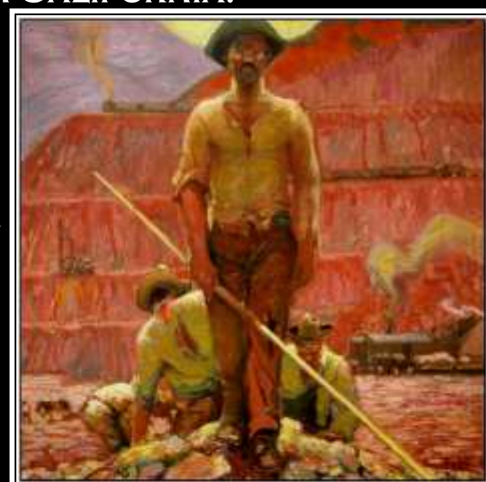

In the Sacramento Pit, Bisbee
Oil on panel, about 14 x 20 inches (1923).
University of Arizona Mineral Museum collection

Even though mining costs were calculated by using the experience from other similar operations, the difficult conditions presented by Sacramento Hill had a staggering impact on the total pre-stripping cost. Hard, impossibly hard rock made blasting difficult and digging conditions inefficient. Boulders and hard toes slowed the shovels to a crawl and punished them mercilessly, pushing down-time for repairs and maintenance costs upward.
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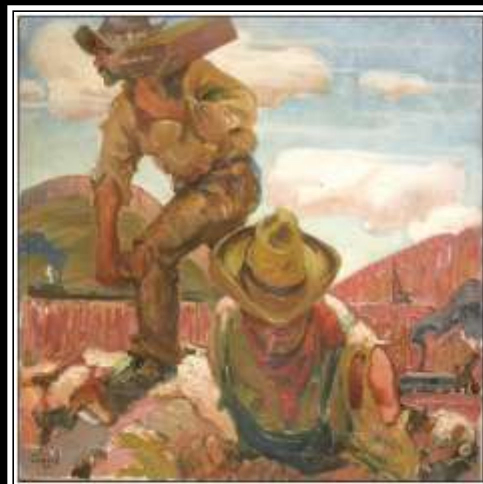
Breaking the rock is key

Mining men have long said "Powder is cheaper than steel," meaning it is cheaper to break the rock by blasting it well, than to fight it with the steel of the mining machinery or crushing equipment. It took years of experimenting with blast hole sizes, hole patterns and explosives before a reasonable fragmentation of the rock was achieved. The cost of learning how to break the rock on Sac Hill was high in both dollar and human terms. Five men were killed and six injured in 1918 when a blast exploded prematurely . This was to be the worst accident to ever occur at Bisbee.

Large boulders in a digging pit -1917
Graeme Larkin collection



Blaster Men, Bisbee
Oil on panel, about 14 x 20 inches (1923).
University of Arizona
Mineral Museum collection

Inasmuch as open pit blasting is so well established as a practice, it seems odd that it took so long to develop. Much had to do with the nature of available explosives at the time. Dynamite and black powder in 12½ pound packages were the most commonly used, with dynamite largely confined to use in the toe holes.

The black powder was poured into a hole containing a Cordeau Bickford fuse, an explosive fuse much like the Primacord of today, which served as a primer for the black powder. The blasts were fired using electric blasting caps attached to the fuse and a plunger- type electric blasting machine was used to detonate the cap. Such a blasting machine is depicted in the painting above.

When black powder explodes, it does so at a relatively slow velocity, something which did not break the rock well, as the energy released by the blast was over a bit of time. Faster explosives and blasting agents give a shorter, more concentrated impact. Over time, black powder was replaced for this and safety.

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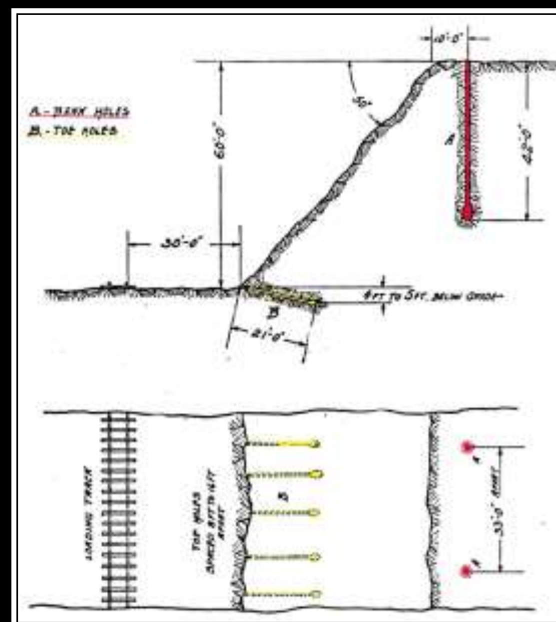
Blasting

Blasting the rock required a combination of bank holes and toe holes, both of which were sprung at the back to create a small chamber to hold more explosives. First, a string of the toe holes were shot and cleaned up by the shovel , then bank holes shot one at a time and cleaned up after each shot. A good deal of shovel time was lost by this approach.

The shovel had to be backed out for each blast. Moreover, the high benches were dangerous to work under with the shovels.

Drilling toe holes in the Sac PIT- 1925
Graeme Larkin collection



Blast holes for 60' bench 1923
Graeme Larkin collection

The complicated blasting procedure illustrated above had been imported from the Iron Range, where the rocks were more brittle and, while even harder, broke a bit easier. In the Sac Pit the near-surface rock tended to be naturally fractured and thus absorbed some of the shock from the blast, often producing boulders.

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High benches were a hazard

The learning curve at the Sacramento Pit was steep, as few similar mines were in operation, the engineers at Bisbee learned much, most through trial – and –error. As open pit miners learned the world over, bench height and slope stability was a science unto its self. Men must work under these manmade cliffs and design errors could be costly.

While there were tense moments at Bisbee, no one was killed because of unexpected and sudden slope failures.

Steam shovel almost completely covered by rock caused by a failure of the bench face, C – 1918.
Graeme Larkin collection

The bench failure illustrated above does not look to have been a sudden, catastrophic one. The relatively small rock size and the fact that the shovel was not overturned suggest the wall raveled loose rock in a manner which trapped the rail-mounted shovel, but almost certainly slow enough to allow all nearby to retreat to a safe area.

While the shovel is buried, the boom location and condition suggest little damage to the equipment because of the rock slide. Such events were among the many things to learn about and to avoid in this new mining game of open pit mining.

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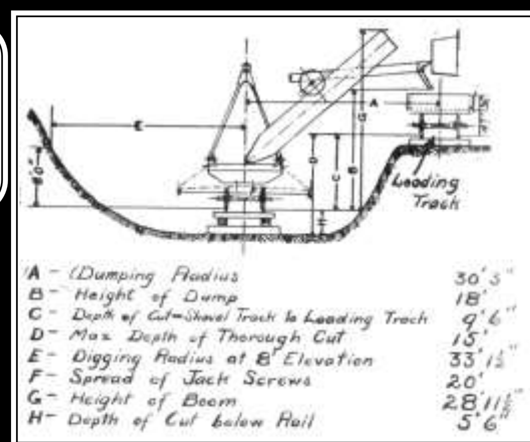
Loading by shovel

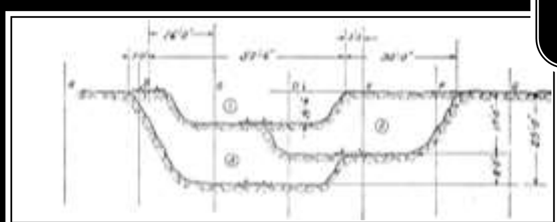
The need to eliminate high benches and the associated risk brought out several different approaches. All were tried with the hope of improving safety and shovel productivity.

In the end, 30' benches were adapted which improved the safety aspect, but did little to improve shovel productivity. The rock was just too hard and every blast created a number of oversize boulders. Digging was difficult and punishing for the shovels.

Loading under a 60' bench - 1922
Graeme Larkin collection



Undercutting approach to eliminate high benches 1920, Graeme Larkin collection

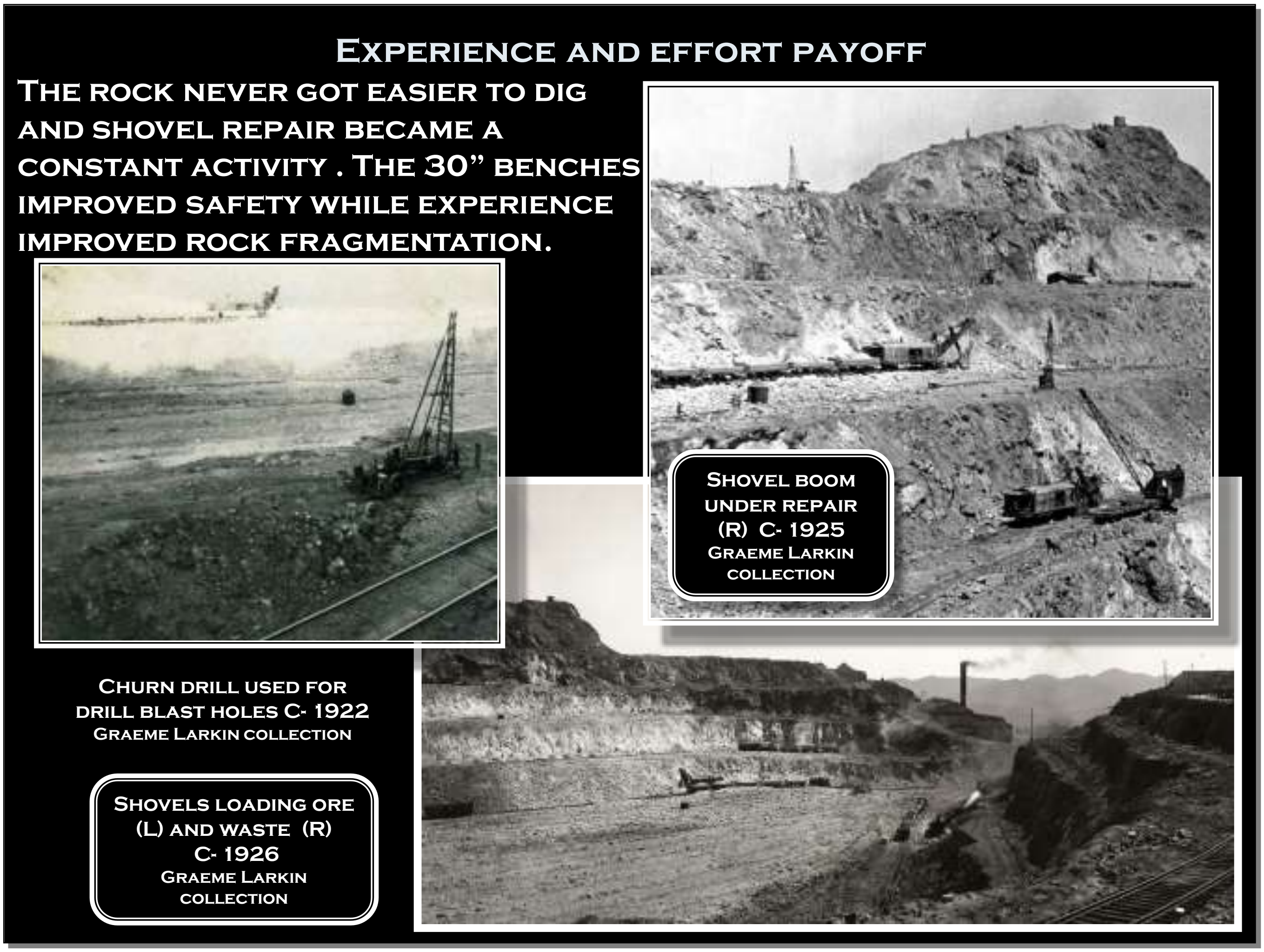


Plan for sequential undercuts to eliminate high benches -1923, Graeme Larkin collection

Everything was new in open pit mining. To be sure, much had been learned at other such mines, but in reality, each mine is different enough that the local conditions dictate what the best approach might be. The undercutting approach to mining that had been so successful in the Panama Canal construction was employed for a short time. While it was great for cutting trenches, drop cutting like this is not the most efficient way for a shovel to operate.

Before long, most mining was undertaken by carrying the bench level and forward, except when it was essential to begin a new level. This required drop cutting, which was a slow and much less efficient way to mine.

Slide 19



By the time ore was needed at the Copper Queen Concentrator in late 1923, rock fragmentation and loading had greatly improved. The ability of the pit to supply the needed ore was assured. The substantial pre-stripping that had been accomplished provided a number of working faces in ore so that a problem in one ore producing area did not stop the flow of ore the crusher.

Slide 20

A concentrator is built to handle the ore

The low grade ores from the pit required concentration of the contained copper minerals to make the costs of smelting reasonable. By the end of 1923, the Copper Queen Concentrator was fully operational and copper concentrates of 8 + % being sent to the smelter in Douglas.

Postcard view of the Copper Queen Concentrator near Don Luis C- 1938
Graeme Larkin collection

Construction of the Copper Queen Concentrator – 1921, Graeme Larkin collection

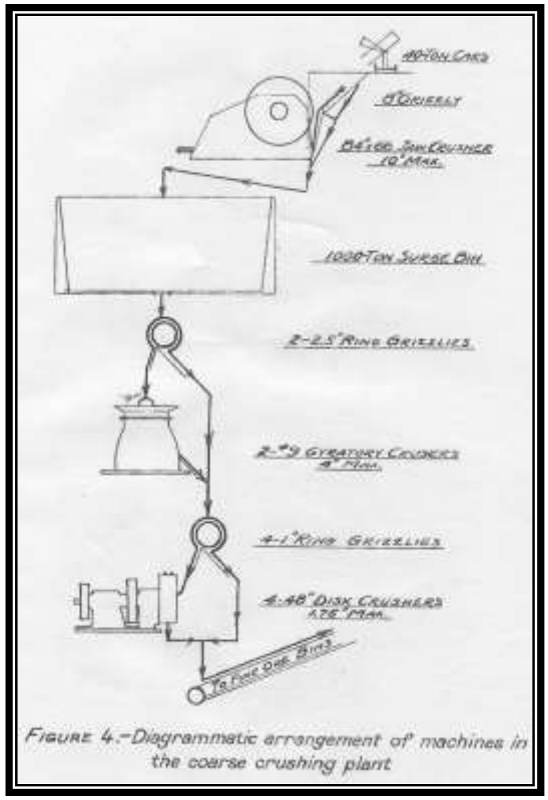
A backup power plant was constructed near the concentrator as well -1922
Graeme Larkin collection

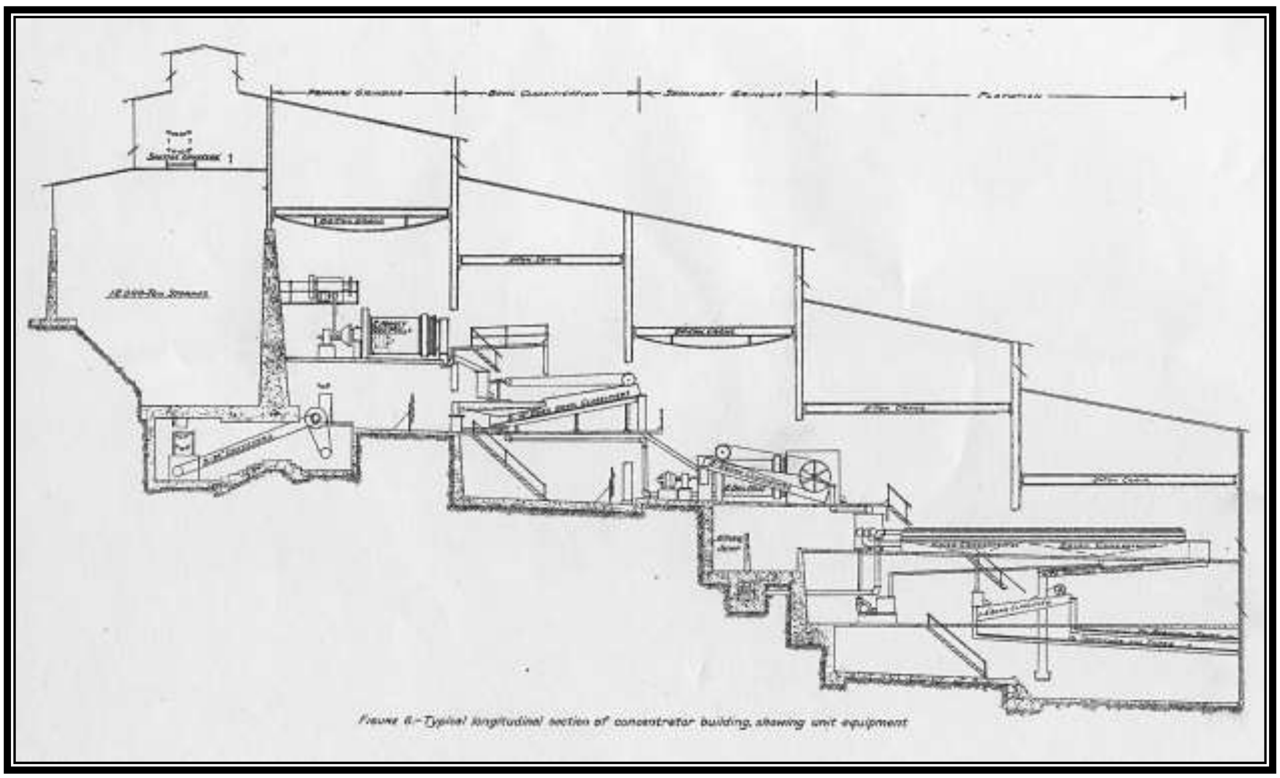
The building of the Copper Queen Concentrator made the Sacramento Pit possible. While it took some time to sort out all of the nuances of the complicated ores from the pit, it eventually became a smooth operation. By the end of 1931, the concentrator was shut down, never to fully operate again. While sections of the concentrator were renovated in 1940 in anticipation of mining the East Orebody underground, the failure to effectively mine the tonnage needed for the concentrator caused it to remain closed.

In 1944, a 450 ton per day lead/zinc mill was added appendage-like to the concentrator. This operated through 1949 when it was closed due to a lack of available ores.

This whole complex was ultimately razed during the 1990s and the area fully reclaimed. Even the diesel power plant was later removed.

Schematic diagram for the crushing section of the Copper Queen Concentrator
Graeme Larkin collection





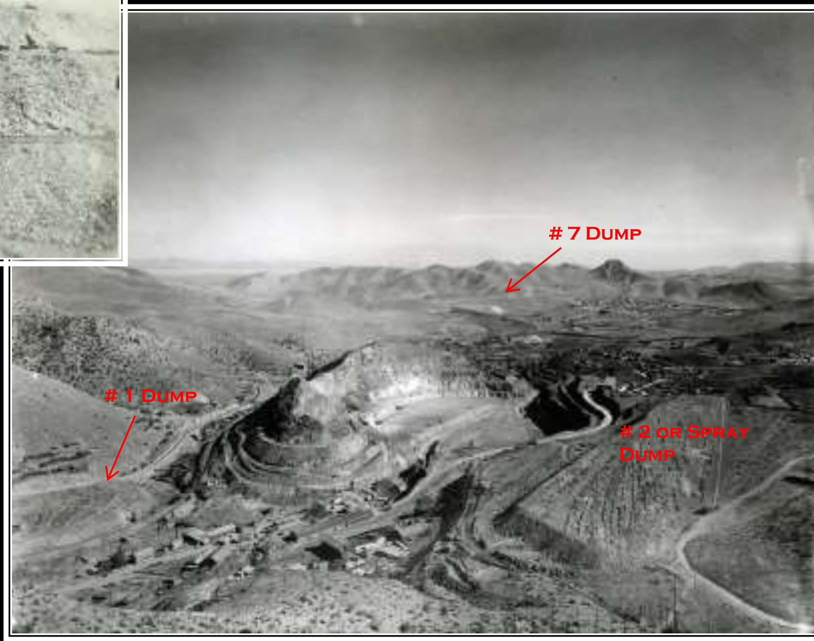
Cross section of the concentrator showing unit equipment
Graeme Larkin collection

Slide 21

Many tons of non-ore material were handled daily

Appropriate storage of the millions of tons of non-mineral rock was an important part of the mine planning. Several sites were used, including the #7 dump near Warren that was to be used later.

Each day, trains carried thousands of tons non-mineral material and leach rock to storage sites. C- 1922
Graeme Larkin collection



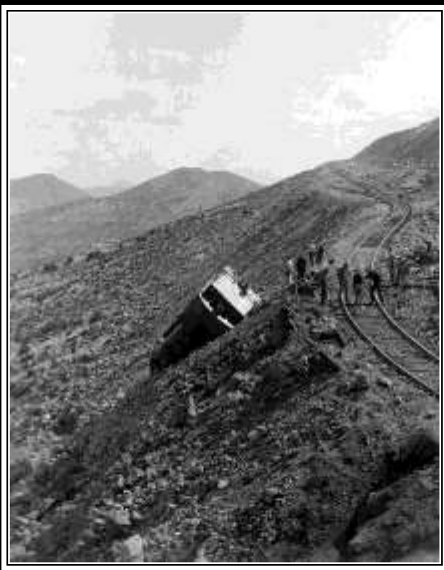
The Sac Pit in 1926 (R) with two of the non-mineral rock storage areas indicated.
Graeme Larkin collection

The disposal of non-ore material was a significant part of the costs associated with mining – then and today. Both the horizontal and vertical distances are important considerations when deciding where to deposit the material. Non-mineral material rock was hauled to the closest available locations. For several of the sites, switchbacks were needed in the rail layout to gain the needed vertical elevation. Also, because the rail often was laid at the maximum grade of 2½%, fewer loaded cars could be pulled by the locomotives.

The decision was taken to accept the longer, almost flat haul to the Number 7 dump to reduce costs and forego the purchase of more locomotives and railcars. In the end, the decision was a good one as the flat haul reduced costs and created an additional site to store very low grade material for future leaching.

Slide 22

Sites for the storage of non-mineral rock were scares



As Phelps Dodge was essentially land-locked by the C & A, innovative approaches toward the storage of non-mineral material were required. Thus sites high above Lowell were also used, but not without mishap, as shown in the photo to the left. Heavy rain had softened the rail bed and the locomotive derailed, but with only minimal damage.

Locomotive derailed while on route to place non-mineral material in a storage site high above Lowell. C- 1922
Graeme Larkin collection

Storage areas for non-mineral material above the town of Lowell, 1927. Graeme Larkin collection

As can be seen in both of the photos above, the railroad was set at constant steep grade to achieve the maximum elevation possible to accommodate the greatest possible tonnage. These small dump sites high on the hills are less than ideal for non-mineral rock disposal, but they were close and the land owned by PD.

Copper recovery from very low grade rock

The recovery of copper from mine waters and low grade ores had long been a practice at Bisbee. Test work on the low grade material from the Sac orebody indicated that it would work here as well. A plant and recovery facility were built.

Postcard view of the concentrator with the leach rock storage site visible in the middle ground C- 1935
Graeme Larkin collection

Left, the 40' high leach rock piles with the precipitation plant in the foreground C- 1926
Graeme Larkin collection

Rock that contained less than 0.7% copper but more than 0.3% copper was treated by leaching, with the copper recovered via precipitation.

Test facility near the Sacramento Shaft for the development of a precipitation plant to recovery copper from leach material to be produced from the Sacramento Pit -1915
Graeme Larkin collection

The recovery of copper from mine waters and from low-grade material had long been a part of copper production at Bisbee when the work on Sacramento Hill was undertaken.

Mine waters from the Czar and Holbrook mines were captured and pumped to a surface recovery plant where they were passed over scrap iron in wooden launders. These very acidic waters contained as much as three pounds of copper per thousand gallons and were a part of the natural supergene oxidation process. In any event, it was an operating necessity to control the “copper water or it would destroy mine rail and tools, so it was natural that the potential of the pit low-grade material be considered for leaching.

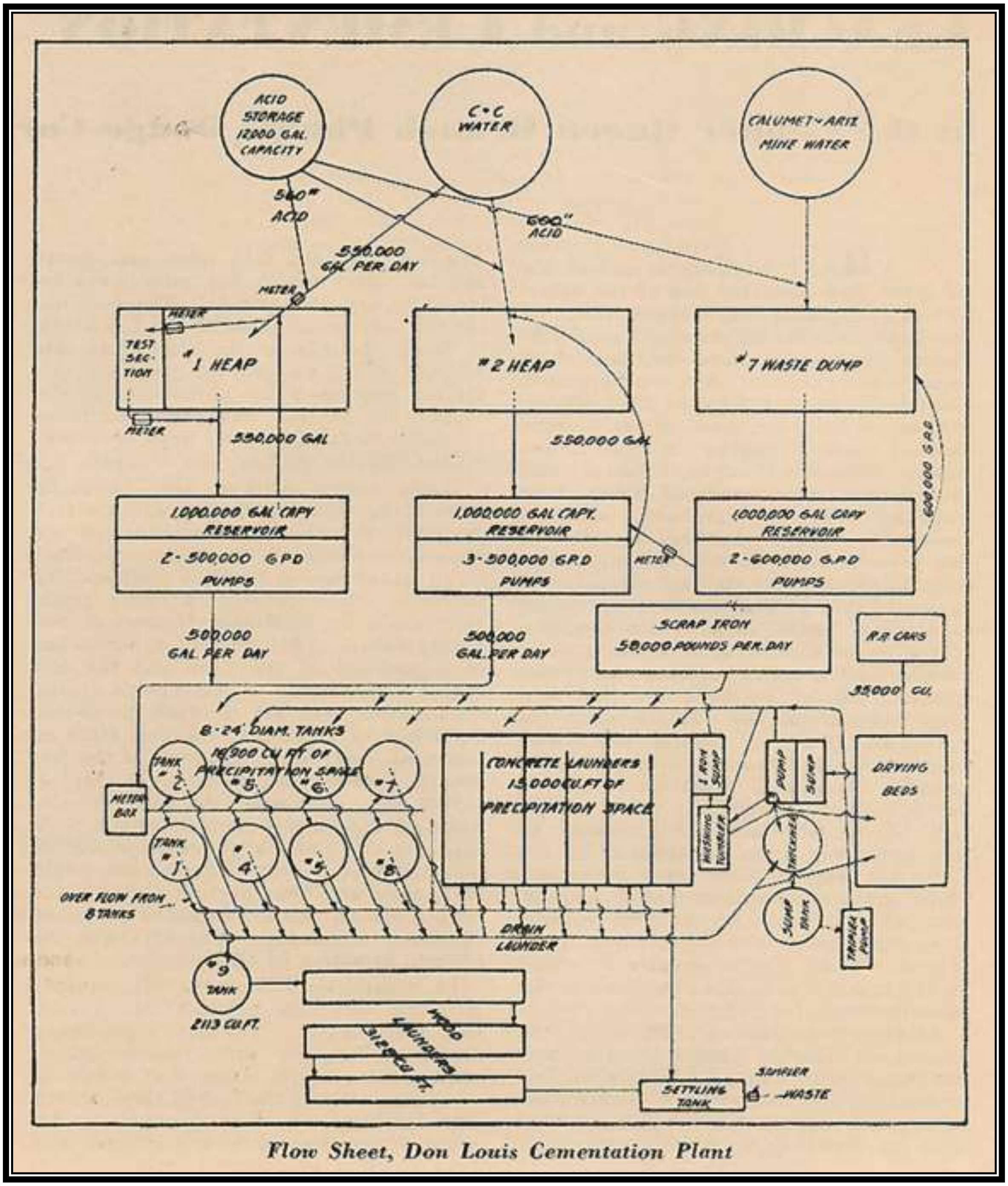
As this potential source of additional metal was well understood before the pit was ever started and a test plant constructed and operated using material recovered from the exploratory underground workings along with the ore used for metallurgical testing. The results of the test heaps were very encouraging and no doubt, the expected copper recovery from the leach material was incorporated in the financial model used to justify the project

Small amounts of sulfuric acid produced at the Douglas smelter were added to the leach solutions to expedite copper dissolution and enhance recovery. The development of additional water in the C & C mine in 1926 allowed for the irrigation of the Number 2 dump.

Placement of leach material on the Number 2 dump near Don Luis by train, C -1926. The leach cells on the surface are being developed in preparation for the addition of the leach solutions via the launder along the right side of the dump
Graeme Larkin collection

The stockpiling of the 12+ million tons of leach material on the Number 1 dump near the Czar Mine, using water from this mine, and the Number 2 leach dump near the concentrator as well on Number 7 dump was a wise move, as much copper was ultimately recovered from this very low-grade material.

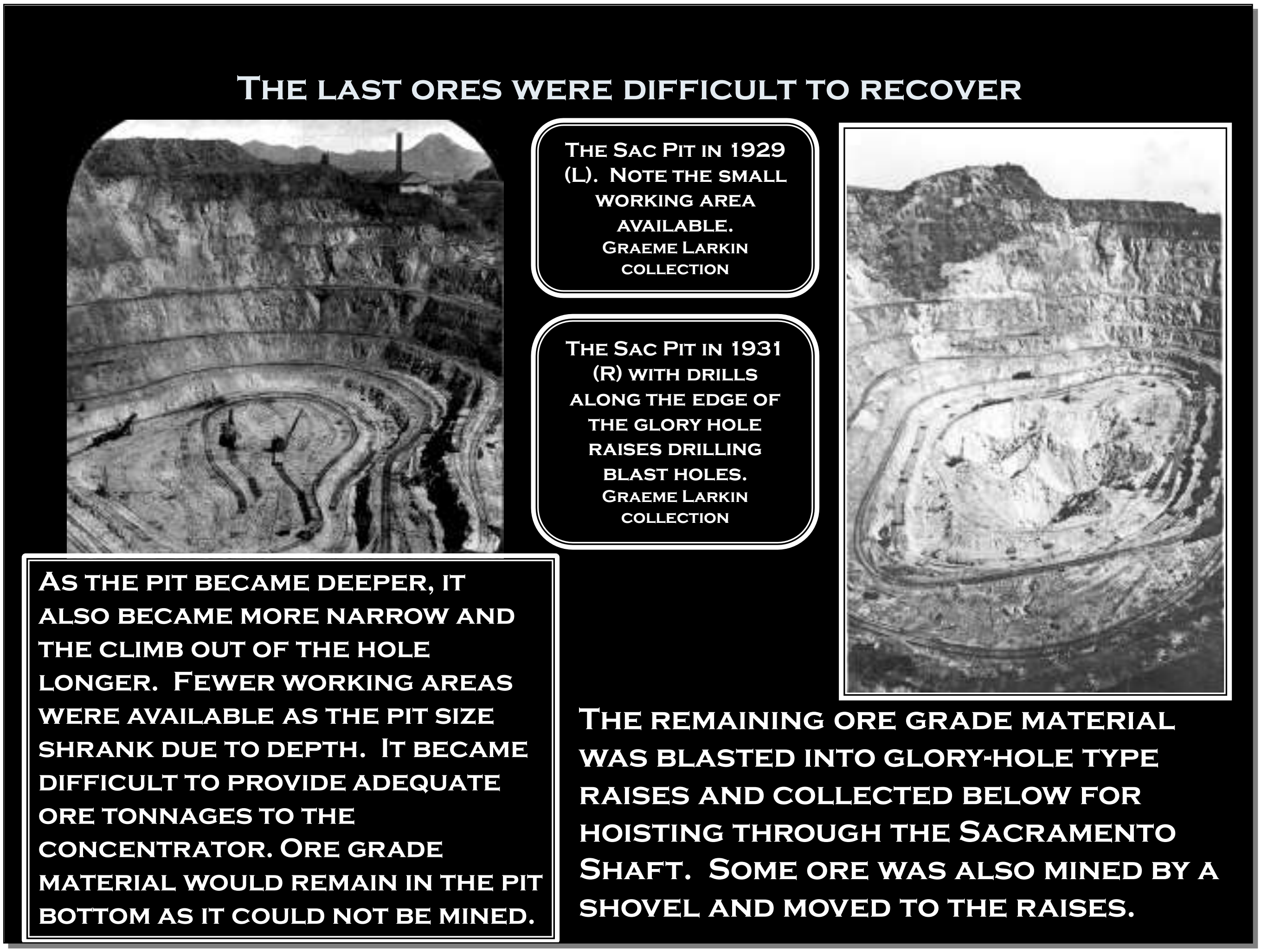
This plant was a typical copper precipitation plant, using scrap iron, upon which, the copper precipitated while the iron went into solution forming a high copper sludge, which was washed out of the redwood leach cells and concrete leach launders to a drying pad, dried and sent to the smelter. The precipitate produced by this plant averaged 68% copper.



Flow Sheet, Don Louis Cementation Plant

Flow sheet of the leach system and the Don Luis Cementation Plant -1928
Graeme Larkin collection

Slide 24



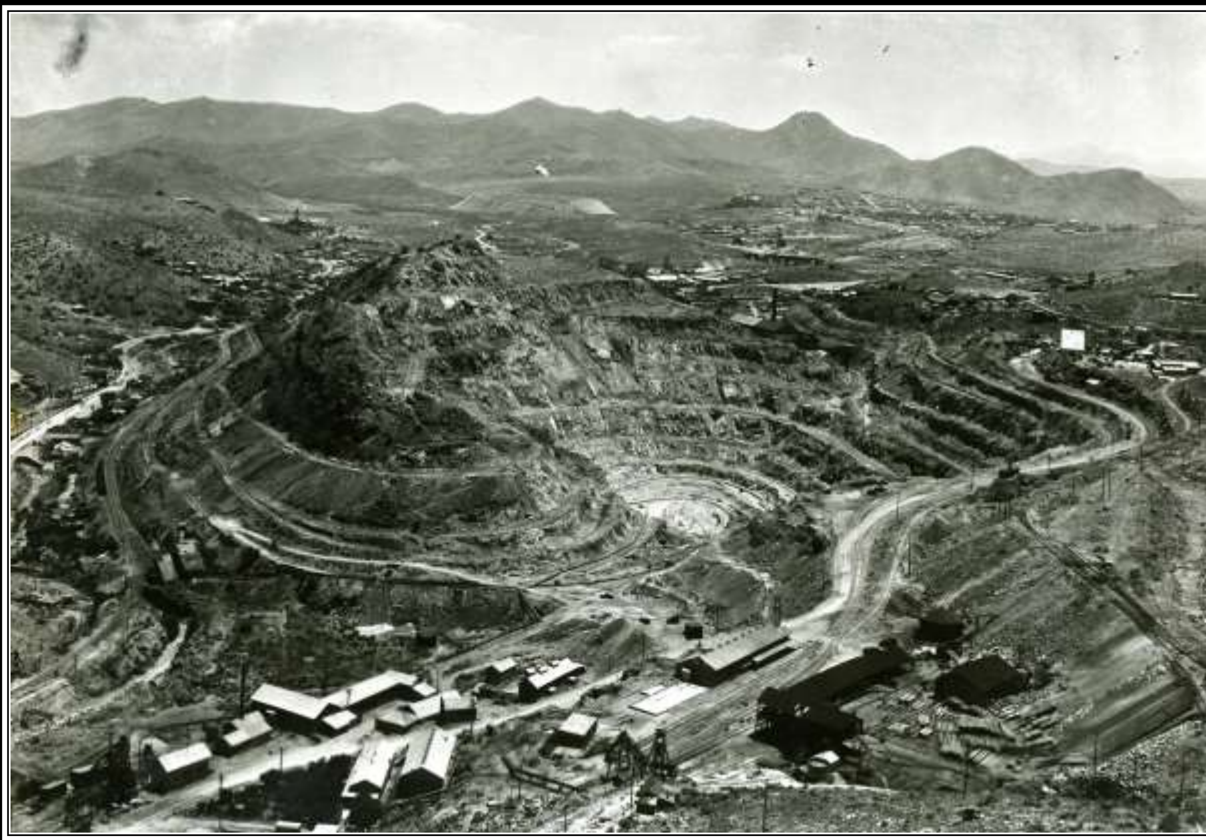
The Sacramento Pit operated until September 1929, and then the remaining ores were extracted via the "Glory Holes" in the pit bottom. The glory holes were raises which had been driven from the 500 level of the Sacramento Shaft. By blasting the sides of these multiple, parallel raises, the broken rock could be removed below. Soon, the continued blasting caused the raises to become one large hole at the top, thus the name "glory hole."

This was terminated in October 1931 due more so to the low copper prices than a total exhaustion of ore. It was never resumed as the depression and World War II made other ores more attractive.

It would be left for the Holbrook Extension of the Lavender Pit Mine to finally exploit the small, remaining tonnage from the bottom reaches of the West Orebody.

Slide 25

When completed, the Sacramento pit was considered an engineering masterpiece, a place to visit and tell your friends about



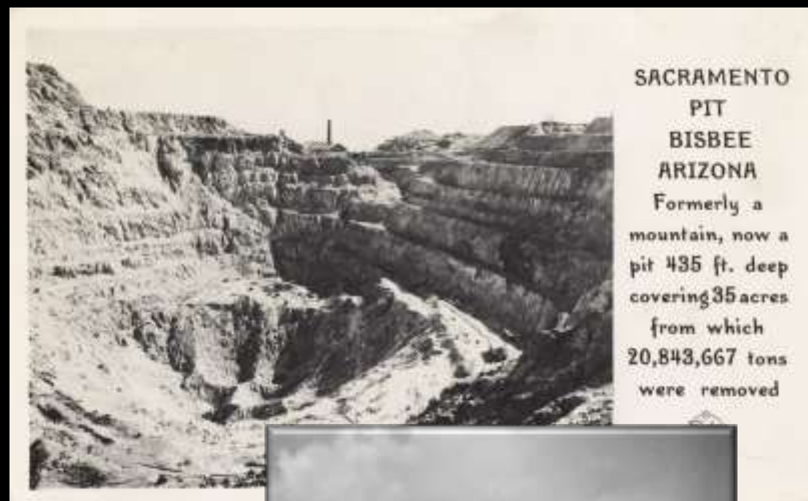
Sacramento pit in 1930 after 33 million tons of material had been removed — Graeme Larkin Collection

Among my cherished childhood memories are times spent looking into the long closed Sacramento Pit. It was awesome thinking that it was created by man.

To be sure, in the context of the many truly giant open pits around the world today, it was almost insignificant in size. In reality however, the Sacramento Pit and others of its era were the precursors of the great mines of today that provide the essential copper from very low-grade deposits at prices that keep copper affordable. The engineering marvel that was the Sac Pit helped lead the way.

Slide 26

For the next 20 years, the Sac Pit was to be a much-photographed tourist stop



Postcard views of the Sac Pit
C - 1935
Graeme Larkin collection

When mining via the glory holes was stopped in 1931, the limited amount of equipment that had been used to supplement production – a single caterpillar track shovel, a few 3½ ton mine cars and a tractor to pull the cars, were essentially abandoned on a bench in the pit. These are quite visible in the photos above.

The cost of removing them was greater than the value of the equipment. At least that was the case before World War II, when scrap steel became an important resource in support of the War effort. During 1942, these items were salvaged for scrap and became a part of the American War Effort.

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The experience gained was of greater value than the profit made, if any was to be had

In April 1923, at a time of modest copper prices, the first concentrates were shipped to Douglas for smelting – 15 years and many millions of dollars after the first work began. The time needed to develop the mineral discovered by years of exploration and testing was such that the copper market peaks of 1916 - 1919 were missed. The investment and operating costs were both well beyond those estimated during the pre-development studies.

Did the Sac pit make any money for Phelps Dodge during its operation from 1923 - 1930? Probably not much, if any, but a good deal was learned. This experience undoubtedly prepared PD very well for the future, as in 1936 planning began to develop an open pit mine at Morenci, the prestripping for which was started in 1937. To be sure, this experience was enhanced a bit by that from operating the New Cornelia open pit mine at Ajo for a short while following its acquisition.

The experience of Phelps Dodge with the Sacramento Pit prepared the company to fully enter into the business of mining copper by open pit techniques. That the planning and initial work at Morenci was undertaken in the depth of the Great Depression speaks of the faith the directors of the company had gained in this relatively new way to mine low grade copper. This was the real value that the Sac Pit brought to Phelps Dodge.

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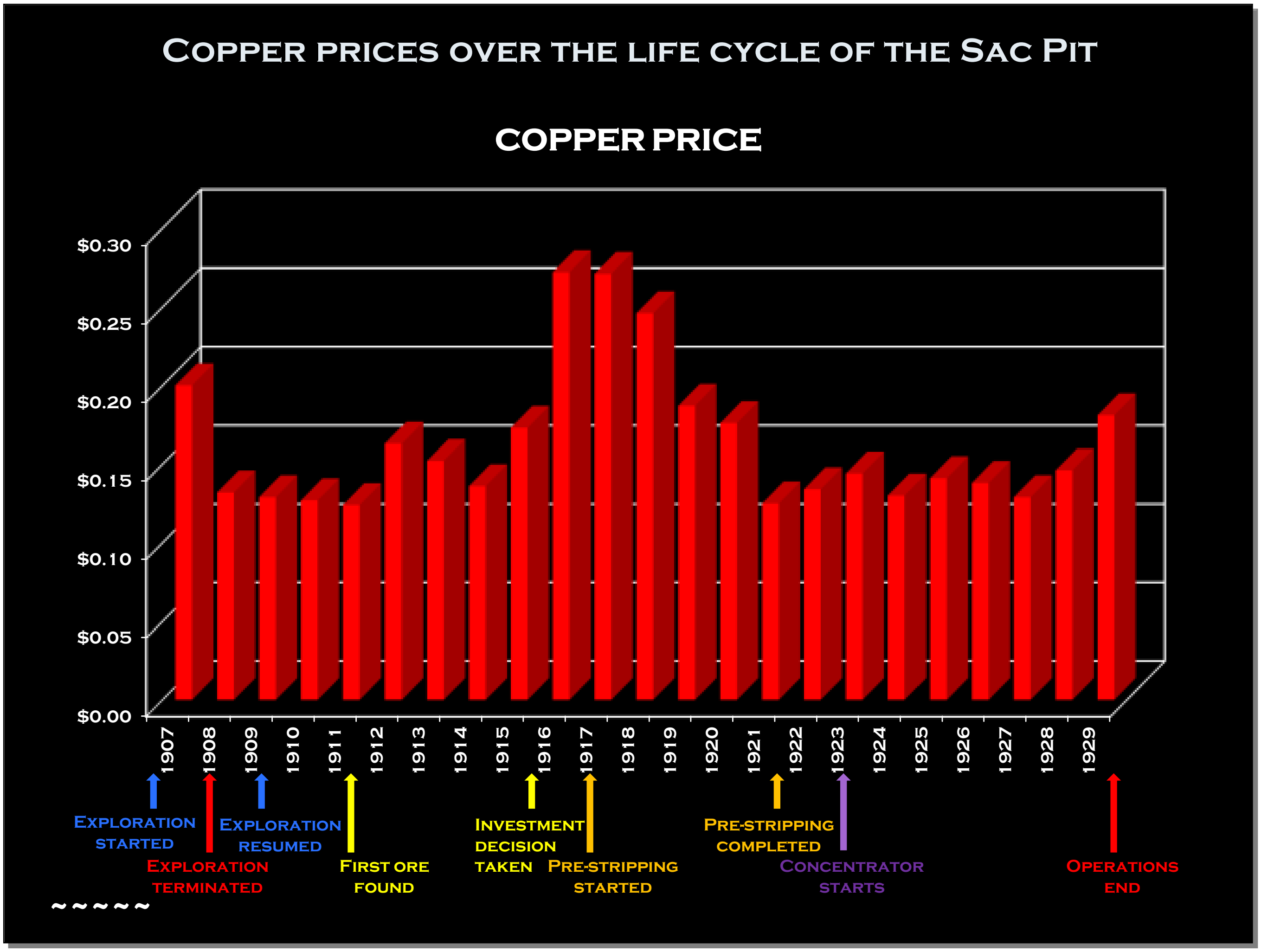


The above graph demonstrates the long lead time required to bring an open pit copper mine into production as well as the dramatic swings in the metal prices which can occur during the life of the process. It remains much the same today. To be sure WWI distorted the market conditions, but this is the nature of commodities.

However, if we look at the context of the times, when there were a great many more unknowns than there are today. It must be recalled that the mining and recovery processes to be used were still in their relative infancy. Thus, the decision to invest was taken relatively quickly, just some four years from the first discovery of ore. Even today, this would be fast when one considers all of the exploration work needed to define the orebody, the exhaustive mine planning needed to get rail up this very rugged hill, not to mention the metallurgical testing. In the latter case, it must have been very disheartening to have the ore produce such a very low grade concentrate when other such plants could make a con three to four times richer, but this was the reality of these difficult ores.

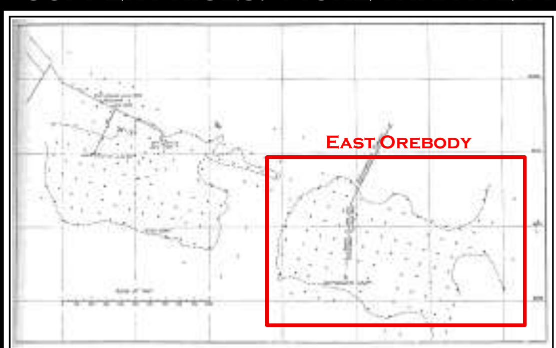
Perhaps the positive investment decision was prompted by the escalating copper prices brought on by the conflict in Europe. In any event the price peak was missed and the Sacramento pit only produced copper during periods of ordinary copper prices. In fact, because of the low price for copper in 1921/1922, the completion of the concentrator was delayed and the pit essentially closed down for much of 1921 and for all of 1922.

lide 29

Open pit mining returns to Bisbee

The existence of substantial amounts of porphyry type ores outside the limits of the Sacramento Pit had long been recognized. This was called the "East Orebody." Efforts to mine this area by block caving were only partially successful because of hard rock. Some blocks simply would not cave, in spite of repeated efforts and substantial work.

By the late 1940s, it was clear that the only way to exploit this important resource was by open pit mining, but there were many challenges facing PD, not the least of which was the enormous investment at a time of low copper prices. More than a little faith was required to take the next step.



A 1916 plan of the West and East Orebodies indicating drilling and drifting for sampling. The Sac Pit mined the West part.
Graeme Larkin collection

In March 1950, detailed planning along with intensive engineering study and design work were begun with the encouragement and support of visionary VP and General Manger, Harrison Lavender, for whom the mine would be named some years later, following his untimely death.

In truth, large open pit mines are engineering marvels and this one is no exception. Much was to be done; some incorporating new ideas and concepts for the time, but which would become standard for mining in such pits World-wide.

World War II did much to make America aware of the need to be self-sufficient in the basic elements of industry, such as copper (an awareness since lost to the desire not to change the landscape). This awareness did much to bring back open pit mining as did important improvements in open pit mining equipment as well as enhanced mineral recovery processes.

Improved mining and earth moving equipment meant lower costs, costs that could now allow for the mining of lower grade ores and the movement of much more non-ore overburden to expose the ores. This has been the story of the American mining industry, one where technological improvements make yesterday's waste into today's ore. This is a never stopping trend and one which may one day bring back mining to Bisbee, as much copper remains in the hills. It need only be economic to mine. Of course, an anti-mining political environment could make it too time intensive and costly to happen.

Slide 30

First, the metallurgy had to be sorted out

The ores mined in the Sac Pit were difficult to process, yielding only a 10 to 14% Cu concentrate, at best. This was unacceptably low. Most of the copper occurred as a thin coating of chalcocite on pyrite, rendering separation difficult. Testwork developed a way to make a concentrate of between 16% and 18% Copper, better, but still low by industry standards. Nonetheless, it was now a “go” metallurgically.

The high-pyrite/low copper concentrates from the Lavender Pit were all to be smelted at the Douglas facility, which was to be enlarged to accommodate the additional tonnage.

Mineralized porphyry of Sac Hill with some gossan. Graeme Larkin collection

Gray chalcocite as a thin veneer on pyrite. View - 5 cm. Graeme Larkin collection

The nature of the ores in the East orebody was quite similar to those mined in the Sac Pit - difficult. Separating the copper containing chalcocite from the non-ore pyrite was difficult, as the later supergene chalcocite was simply a very thin coating on the earlier pyrite.

Finer grinding helped in separating the pyrite from the ore minerals, though some copper was lost in the process. However, a truly good copper concentrate of 20% to 30%, common in the industry, was never to be achieved. Nevertheless, an acceptable balance between recovery and concentrate grade was reached in the labs. Most importantly, this balance was maintained in the concentrator after it was built.

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It took men of vision to see the potential

At the time, the East Orebody was not an obvious target for open pit development. The orebody was quite small at 41,000,000 tons, with a reasonable reserve grade of 1.14 %Cu. There were also 31,000,000 tons of leach material at a grade of 0.42% Cu and 70,000,000 tons of non-mineral material to be moved, for a stripping ratio of 2.46/1.00. The prestripping required was substantial and a new, much larger concentrator would be required to handle the volumes of ore required to make it even close to economic.

A very generalized outline of the proposed open pit on the East Orebody and its relationship to Johnson Addition, Upper Lowell and Jiggerville. Photo C – 1950.
Graeme Larkin collection

Complicating the pit design, the site was constrained by mountains on three sides and a thick cover of non-mineral rock on the other. A rail pit would be too small to justify development. The maximum grade of 2½% would require too much space and never reach the deeper ores. Also, a number of private homes and businesses sat on the east side of the deposit. Any pit large enough to accommodate rail haulage would require the purchase of even more of these homes and businesses, while totally decimate Lowell.

Trucks, while small at the time, could easily manage a six percent ramp over great distance and up to ten percent for short stretches. These and other factors combined to force a relatively new type of open pit mine to be considered – a truck/shovel operation. At this time, several other Arizona copper deposits were being developed using trucks and larger trucks were on the horizon, so the decision was taken to go with trucks. While today this seems an obvious choice, at the time it was a major shift in thinking.

A new type of pit is planned

Because the site was topographically constrained, a truck/shovel type pit was required. To this point, there were few such open pit copper mines, as most used rail haulage. At this time, both Ajo and Morenci were rail, while the tiny Jerome pit had used small trucks, but for very short hauls.

An electric shovel loading rail cars in the New Cornelia Mine at Ajo C - 1940
Graeme Larkin collection

Dependable haul trucks of any size had yet to be developed and the small size of Bisbee's pit required ramps far too steep for rail use. In 1950, the largest proven haul truck had a 25 ton capacity, half the size of a single rail car as then used in the mines at Ajo and Morenci.

The long haul required for disposal of most of the non-ore material would be expensive and a substantial number of these relatively small trucks needed. It was just not practical, thus a plan was made for a combined haul, with trucks dumping directly into rail cars at the pit's edge for the long haul to the Number 7 dump and final storage. In all, some 46 million tons of overburden were to be moved before ore production began.

In 1950 open pit mining using off-road haul trucks was in its early stages. Haul cost are a big part of operating costs and to this point there were no truly large haul trucks available. The non-ore haul of several miles to the Number 7 dump with the 25 ton trucks would have been far too expensive in terms of the number of trucks required and operating expenses.

A P&H model 1600 electric shovel loading a 25-ton capacity Mack haul truck in the Lavender PIT Mine – 1953.
Graeme Larkin collection

Site preparation

Before any development work could begin, some 260 homes and 16 businesses had to be relocated. This included the purchase of the surface rights from 72 individuals. There was near universal support for the project, as all had a desire to assure the future prosperity of Bisbee. Before long, equitable agreements were concluded with all of the property and home owners.

Also, the section of the railroad that ran from Lowell to Bisbee and to be abandoned and a part of highway US 80 rerouted.

A cutback in the area of Johnson Addition, in preparation to relocate US 80, seen in the foreground, 1951.
Graeme Larkin collection

Johnson Addition, during 1951, as the buildings were being moved. Note the shovel working above.
Graeme Larkin collection

Major Pit Mining Equipment

Source: *Engineering* May 1956

Description	Size	Number
Electric shovels	5-yd	2
Electric shovels	6-yd	3
Haulage trucks	25-ton	27
Diesel electric locomotives	125-ton, 1200-hp	2
Side dump railroad cars	43-cu yd	24
Crawler mounted bulldozers		5
Rubber tired bulldozers		2
Motor graders	No. 12	2
Rotary drills	7⅜" Bit	3
Wagon drills	3½" Piston	5
Jackhammers	55-lb	20
Portable compressors	315 CFM	4
Rotary compressor—Skid mounted	210 CFM	1
Mobile unit—Mounted compressor	105 CFM	1
Water wagon trucks	10-ton, 1600-gal	2

Early mining was overburden removal

Millions of tons of non-mineral rock covered the East orebody, all of which had to be removed at some point. The first three years of operation were devoted to mining enough of the overburden to expose sufficient ore, in several areas of the pit, to assure a steady flow of ore to the concentrator , once it was ready. Yet again, the top of Sacramento Hill was attacked to remove the covering rock, but most of the rock to be moved was located toward the east, near the Junction mine.

Initial prestripping near the Junction mine, 1951.
Graeme Larkin collection

Mining on the top of Sacramento Hill, 1951.
Graeme Larkin collection

While not much remained of Sacramento Hill, a full third of what was still in place had to be moved to allow access to the deeper ores. Most of the pre-stripping was related to the thick deposits of the post-mineralization Glance Conglomerate overburden to the east of Sac Hill.

Substantial amounts of the non-ore material mined from these two locations were dumped into the Sacramento Pit for disposal. Before long, the old pit was full, indeed because of the short haul distance, non-ore material was stacked to a level almost equal to the truncated top and the remainder of the pre-stripping material sent to the Number 7 dump.

A partially filled Sacramento PIT Mine – 1953. The blocky material on the left was from Sac Hill, while that on the right is overburden from near the Junction.
Graeme Larkin collection

Prestripping and development of the pit

The several years of prestripping coupled with the development of the necessary infrastructure – pit repair shops, support facilities, offices and the concentrator were, individually huge undertakings. Many millions of dollars were spent before the first ton of ore passed through the concentrator. Years would pass before this initial investment would be recouped, but this is the nature of open pit copper mining. As copper is a commodity, the price is determined by the international market, not the producers. Low metal prices can extend the pay-back period by years.

The Lavender Pit in 1952 , prestripping is well advanced with the concentrator foundations in the right –center and the main pit shop on the right edge. A shovel can be seen center-left and blast hole drills on the top of Sac Hill. Graeme Larkin collection

Phelps Dodge took the decision to do all of the construction related excavation for the concentrator and the relocation of US Highway 80 using the equipment purchased for mining. This was done simultaneously with the pre-stripping and worked seamlessly**.**

25-ton capacity Mack haul truck used to carry fill material in the concentrator area – 1952.
Graeme Larkin collection

SLIDE 36

THE CONCENTRATOR

ALWAYS PRUDENT WITH CASH, PD BROUGHT IN A USED 48" GYRATORY CRUSHER FROM AJO AS THE PRIMARY CRUSHER, STEEL FOR THE TRESTLE FROM THE CRUSHER TO THE COURSE ORE STORAGE CAME FROM THE JUST-CLOSED OPERATIONS AT CLARKDALE, ARIZONA AND MOST OF THE STRUCTURAL STEEL FOR THE CONCENTRATOR FROM DISMANTLING THE CONCENTRATOR OF THE PD-OWNED, MOCTEZUMA PLANT IN NACOZARI, SONORA.

THE PLANT DESIGN CAPACITY WAS 12,000 TONS PER DAY (TPD) PLUS MODEST AMOUNTS OF UNDERGROUND ORE. FROM ALMOST THE BEGINNING, THE CONCENTRATOR EXCEEDED ITS DESIGN CAPACITY WITH A NORM OF 19,000 - 20,000 TPD THROUGHPUT FOR MOST OF ITS LIFE. WHILE IT CONTAINED MANY USED COMPONENTS, IT WAS A FINE PLANT AND SERVED THE OPERATION WELL FOR 20 YEARS. TO MINIMIZE ORE HAULS, THE PRIMARY CRUSHER WAS LOCATED IN THE PIT ON THE 5050 ELEVATION LEVEL AND WAS DESIGNED FOR DIRECT DUMPING BY THE 25 TON TRUCKS.

THE LAVENDER PIT CONCENTRATOR SITTING ABOVE LOWELL, 1954.
GRAEME LARKIN COLLECTION

The reuse of important amounts of structural steel and equipment from other Phelps Dodge properties did much to help the project economics by reducing the upfront capital cost. Some could (and did) argue that the reuse of old plant parts and salvaged structural steel was unwise, as it forced the plant design to meet the equipment available and that the reuse and modification of the old steel took more time than the use of new materials would.

While there was validity in both arguments, P D had long exercised strict fiscal control and this was to be no exception. At the time, it was the correct move for a marginal project during uncertain economic times. In my view, the decision to reuse materials did not adversely impact the quality of the finished concentrator of hamper the efficiency of the plant throughput or performance.

To be sure, a larger primary crusher would have been a plus when the 65 ton trucks were introduce, but no one could have foreseen the rapid changes in metallurgy that allowed for these trucks.

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The finished project was impressive

The massive undertaking was a success! In all, it was most impressive, even beautiful to a miner. Everyone who passed looked in amazement at the pit and support facilities, even those of us who saw it everyday, never tired of looking at the trucks and shovels at work or of watching the daily blasts.

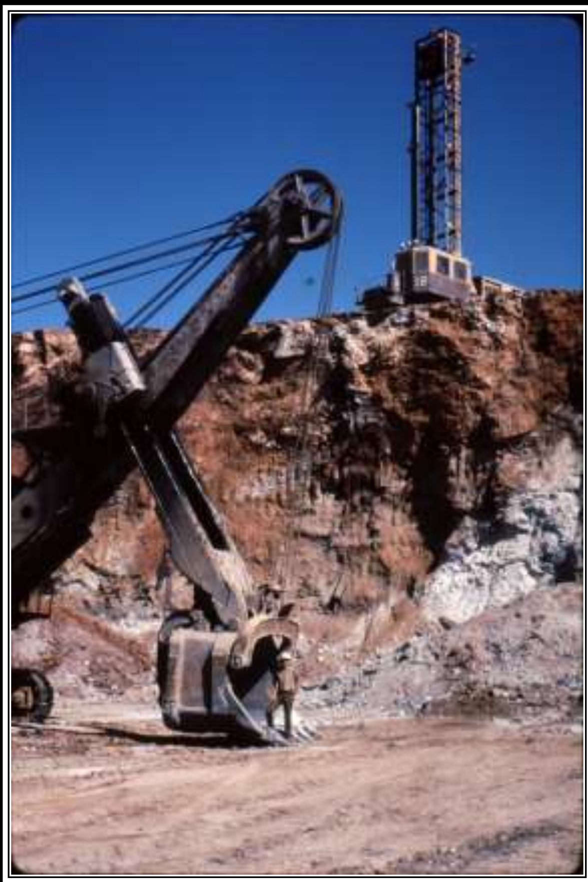
The Lavender Pit and concentrator - 1957 , tailing thickeners in the right foreground, a railcar of lime from Paul Spur in the center and the three concentrate thickeners center-left. Concentrate drying and loading took place in the buildings to the left of the con thickeners.

Graeme Larkin collection

The integration of large, multi-component phases of a project is not a simple matter and the level of detailed engineering work, planning and, above all, coordination of activities is seldom obvious – unless done wrong. All work well at the Lavender however, a testament to the quality of engineers, schedulers and constructors involved.

Slide 38

Drill, blast, load, haul – the mining cycle



This was the mining cycle, much like the underground mine, but on a much larger scale. Also, it was pit-wide in that a number of working areas in the different stages of the mining cycle needed to be available – several in ore to meet the desired mill head grade, and others in non-ore material to expose ore for future mining.

To the left, a Bucyrus Erie 50 - R blast hole drill sits atop a 50' high bench with a P & H - 9 cubic yard electric shovel below. Scale can be had by noting the author in the shovel bucket.

May 1970 in the Holbrook Extension of the Lavender Pit Mine.

Graeme Larkin collection

For the 1950s – 1960s, all of the equipment used in the Lavender Pit was large and became larger over time. As the pit was expanded, two-nine cubic yard capacity shovels were added to the loading fleet and the haul truck capacity increased from 25 ton to 35 ton and finally to 65 ton.

Examples of all three haul truck types used in the Lavender Pit over the years are illustrated in the photo to the right. Number 10 - 25-ton; number 22-35 ton; 32 and above, 65 ton capacity – 1964.
Graeme Larkin collection

Slide 39

Mine planning was a vital engineering function

The concentrator needed some 20,000 tpd and to make this available, an average of 54,000 tones of overburden, leach and non-mineral material had to be moved for 74,000 tpd total material to be mined. On top of this, the ore needed to be blended for type and copper grade, thus numerous ore-working faces were required. This was no easy task and required substantial, long-range planning and scheduling

Rule #1 – keep the mill full! The unmineralized overburden that formed the East wall of the pit was the bulk of the non-ore rock that had to be moved to expose the ore. It was typical to have several of the nine shovels available in this material.

As a point of interest, this is also where the turquoise for which Bisbee is so famed was found – in the non-mineral material only.

Three shovels working in non-mineral material on the East wall of the pit - 1972. Graeme Larkin collection

In a large open pit mine, nothing can be left to chance. Each and every feature of the mine and all activities are planned well in advance. The cost in lost revenue of having a large concentrator standing idle for lack of ore is in the many tens of thousands of dollars per hour lost.

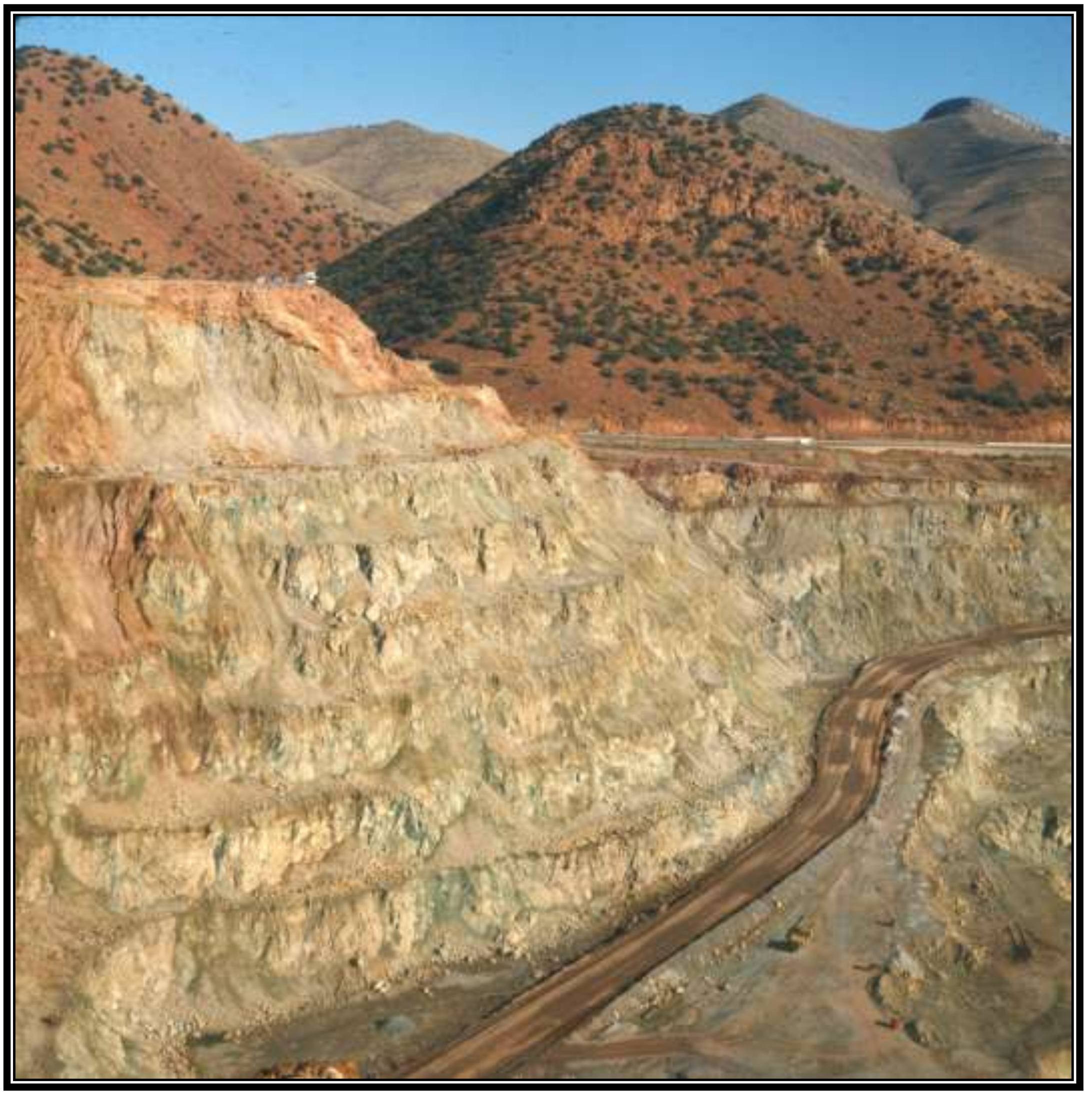
Thus, a number of important considerations govern the day to day operations of an open pit mine. Assuring the availability of ore material at a grade and with the needed characteristics (rock hardness for throughput, recovery to assure tons of concentrate produced, concentrate quality to assure the quality of the concentrates, both grade and other contained metals).

More often than not, these points were planned for some months or even years in advance and adjusted to accommodate changing conditions such as equipment availability minor changes in mine plans or unexpected changes in the nature of the ore. Daily refinement of the plans was essential with full time engineers tasked with the challenge of coordinating the needed changes with the mine operations staff.

All of the foregoing, and much more, were taken into consideration when planning the mine. The number of blast hole drills; size and number of loading units; compatibility of loading units with the proposed haul trucks; haul truck size and the number of units was considered as function of total material to be moved on a sustained basis coupled with the haul distance and the steepness of the haul road ramps were all taken into account when planning the mine, be it on a short term or life-of-mine basis.

In the above photo, three 65-ton capacity, KW Dart haul trucks climbing the 5% ramp towards the crusher - 1963. Note that the haul road is well maintained with no holes or spillage and has been well watered to minimize dust, an important health and safety measure. Also visible are the safety berms along the road to prevent a haul truck from accidently going over the edge of a bench.
Graeme Larkin collection

Haul road design and maintenance were important engineering task as the smooth flow of trucks from the mine kept the crusher full and the ore uncovered. Ramp grades were kept as flat as possible without adding excessive additional waste to the mine plan, as flatter ramps required more horizontal space. Simple considerations such as how to keep the haul roads free of spillage, curve radius and curve banking were important as these all impacted haul truck tires which are very expensive and sometimes not easy to secure. And too, the loss of a unit to change tires meant fewer tons moved.



A view of the haul road along the remnant of Sacramento Hill to the primary crusher - 1970.
Note that here too, the haul road is well maintained been watered in a manner to minimize erosion of the road surface. This can be seen in the regularly spaced wet areas.
Graeme Larkin collection

All of the shovels and drills were electric, operating on 2,300 volts. Getting power to the operating equipment was a planning issue which required constant consideration. Power poles were placed on stable slopes in several parts of the pit with drops made to the small round switch houses made from old smelter smoke stack sections. Each switch house had single master switch inside and a receptacle in the back outside to receive the heavy power cable head which was held in place by a screw-on ring. In many regards, the 800 foot long power cables were like extension cords, in that they allowed the equipment to work some distance from the switch house. Extra cable was placed in figure “8” configuration to allow the machine to move without tangling the cable. When the cable was moved hot, wooden handled cable tong was used as even a small break in the insulation was a risk for electrocution if touched by hand. Every rain storm showed just how many breaks were in the cable insulation, as even a little water on the ground would short out the cable.   It was always a race to change out defective cables in the rain to keep the equipment working.

A typical electrical power configuration, with the power line descending along the pit slope and two small switch houses at a drop next to a power pole. A connection of two power cables is in the center foreground and the slack cable is in the lower right foreground – 1965.
Graeme Larkin collection

Slope stability was always a critical engineering factor. Different rock units have differing strengths and fault zones are natural zones of weakness. All of these and more are considered.

Looking east through the Holbrook Extension – 1974. Note how stable the benches are on this relatively steep slope composing the south wall. The minor failure in the right center was the result of several factors combining – a protrusion of the wall (always a potential weakness); a dump on top adding weight; a small fault parallel to the pit wall and, perhaps most significantly, the rock at the toe was unstable because of much earlier underground mining in the Holbrook Mine.
The failure was well understood in advance, closely monitored and predicted to within less than ten minutes of the actual total collapse.

Graeme Larkin collection

The south pit wall is in very competent limestone. For the most part, it will stand at an overall angle of about 45^0 to 48^0. This overall angle means that for every foot of depth that is achieved, one foot of horizontal width must be cut. This is often referred to as a one-to-one slope.

One the other hand, the northeast wall is in the wide Dividend Fault zone and is totally unstable at anything above the angle of repose (the angle at which broken rock of a certain characteristic will stand if loosely piled).

During operations, the northeast wall was in near constant movement from failure. At one point waste was dumped over the steadily crumbling material to flatten the slope, in hopes of slowing this movement so that mining could take place underneath. This slope failure was more of an inconvenience than a danger and reached equilibrium only after mining ceased.

While there were several slope failures in the Lavender Pit, none were unanticipated and none were catastrophic. To be sure, some ore material was lost because of the relatively flat slopes imposed by the poor rock quality as well as inability to fully mine underneath these broken areas.

The northeast wall of the Lavender Pit in 1965 with the bulge of the failing pit wall quite obvious. Also apparent is the red/brown material dumped over the slope in 1962 in a futile attempt to slow the movement, as it was causing the highway above to subside a bit.
Graeme Larkin collection

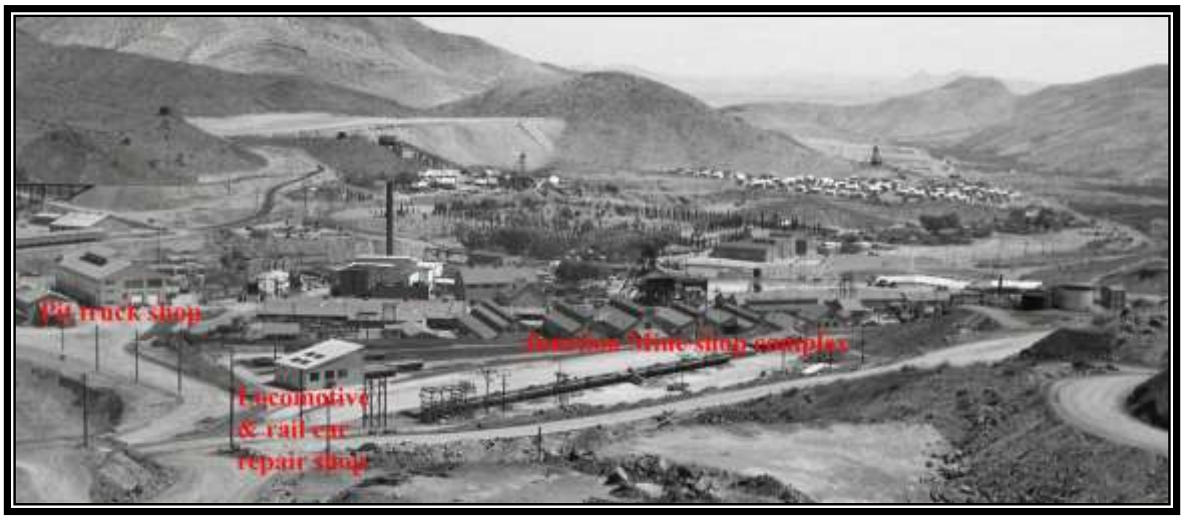
A contemporary view of the east wall of the pit in which the slope failure in the relatively weak Glance Conglomerate can be seen. While this failure began during operations, it caused few problems, although catchment berms were constructed as a precaution.
Graeme Larkin collection

Slope failure of an estimated 300,000 cubic yards in process of full failure in the Holbrook Extension - 1970.
Graeme Larkin collection

Side view of the same slope failure after it had stabilized -1970.
Graeme Larkin collection

No mining plan can be considered complete without fully considering servicing, maintenance and repair of the operating fleet and ancillary equipment. A large, multi-bay truck shop was constructed that allowed for all types of repairs, including the rebuild of engines, transmissions, drive trains and dump body reline. Also, a service and lubrication facility was nearby for the more routine, daily service needs.

The large equipment such as shovels and drills were serviced and repaired in the pit with the full support of extensive Junction Mine shops, which fabricated or repaired many of the components. In this regard, the Lavender Pit enjoyed a full complement of skilled and experienced craftsmen working from well-equipped facilities with excellent mobile support from specialized service and repair units.



Overview of the pit shop area as well as the Junction Mine yard with its many well equipped and expertly staffed shops - 1960.
Graeme Larkin collection

The concentrator benefited from the support of the mine shops as well. There was little that could not be fabricated or repaired by these skilled crafts men.

In the lower right of the photo, an 50 R blast hole drill is undergoing repairs as indicated by the high level to which it has been jacked and the presence of the drill repair crew truck. As a second drill has been brought in, the planned repairs must be thought to take some time.
Graeme Larkin collection

For most open pit mines, ground water is an issue that must be considered. Pumps feeding pipelines that climb to the edge of the pit are the norm and are a minor operating inconvenience when they must be moved for operational needs. Additionally, the water in copper mines is typically corrosive, requiring special pumps and pipe.

As the whole of the Lavender Pit area had been mined by underground methods, this was not a problem. While local ponding did occur, these pond were quickly emptied with the water filtering into any number of exposed underground workings.

Water from the pit drained into workings which ultimately channeled it to the acid water system on the 1800 level Junction Mine. From here it was pumped, along with other copper bearing mine waters, to the precipitation plant at the Campbell Mine for copper recovery.

Above: Ponded, high copper content – low pH water being pumped out of a drop cut following a summer rain – 1962.
Right: Mine timber from a raise intersected during mining in the pit – 1970.
Both photos from the Graeme Larkin collection

Slide 40

Drilling and blasting

A Bucyrus Erie 50 R blast hole drill is shown at the left in 1960. It drilled 12" diameter holes to 55 feet in depth. Smaller Joy drills and churn drills were used early on in the pit. The holes were loaded with ANFO for blasting.

Powder crew loading blast holes, 1970. Note the difference in colors in the blast hole cuttings
Graeme Larkin collection

Blasting the holes shown in the photo at the left, 1970. Note the different color dust columns — light color ore, dark waste.
Graeme Larkin collection

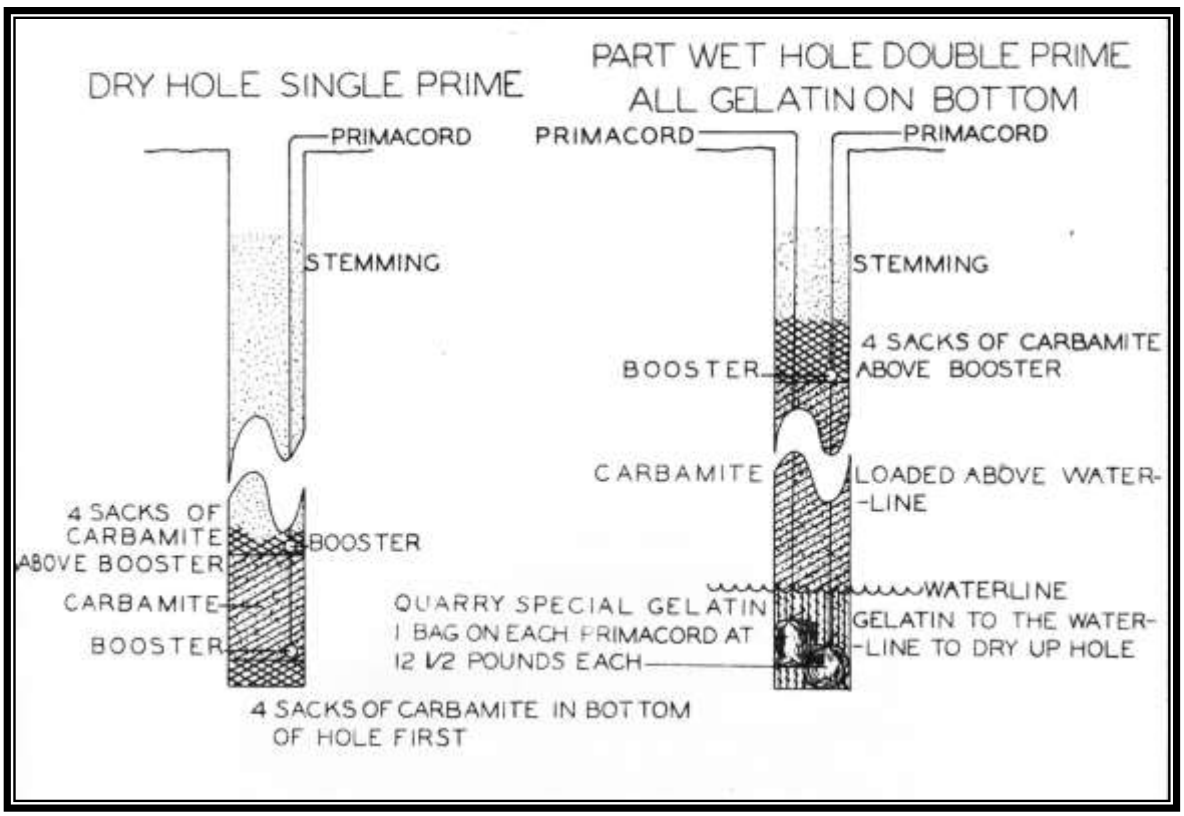
Over the 24 year life of the Lavender Pit Mine the blast holes were drilled by rotary drills using tri-cone bits. These drills applied a pressure of about 1,000 psi on the bit while rotating. This essentially chewed away at the rock with the course, sand-like material blown out of the hole by a constant flow of compressed air with a bit of water to control dust. Initially, the blast holes were 7 3/8 diameter and later increased to 12 inch diameter with the introduction of the larger 50 R drills. These holes were spaced from 12 to 20 feet apart, depending on the rock conditions.

A Timken tri-cone drill bit similar to those used at Bisbee

Once a sufficient number of blast holes had been drilled, each would be checked for depth to assure they were open and to see if any ground water was present. With this information a map was prepared to determine the amount of burden or rock in front of the holes, which defined the amount and type of explosives to be used.

Dry holes were loaded with Carbamite (ANFO) with boosters tied to Primacord to initiate the blast. Wet holes were loaded with water-resistant gelatin explosives which were also detonated by TNT boosters tied to Primacord. A single blasting cap fired by an electric blasting machine would initiate the Primacord.

Bucyrus Erie 50 R rotary drill in the Holbrook Extension of the Lavender Pit – 1970. This drill was capable of drilling 12" diameter holes to a depth of 55 feet. These drills operated on 2300 volts that was delivered the heavy insulated cable in the foreground.
Graeme Larkin collection



Schematic illustration of how to load a dry hole and a partially wet hole – 1962.
Graeme Larkin collection

A bank or primary blast on the east wall of the pit – 1966. The amount of heave (displacement) by the blast can be judged by the photo above. The close proximity of equipment to the blast is proof enough that little rock was thrown any distance
Graeme Larkin collection

Blasting boulders in a digging pit on the east wall of the pit – 1965
Graeme Larkin collection

Boulders and hard toes were drilled by small diameter pneumatic drills mounted on a mobile unit for what is referred to as "secondary blasting." Explosives would be inserted into these small holes and fired in much the same manner. Generally, only ore boulders were blasted so that they could pass through the primary crusher. Great care was taken not to put oversize rocks into the crusher, as it was very difficult to remove one and valuable operating time lost. Any shovel operator, who made a habit of loading large ore boulders, would soon find himself in deep trouble.

Non-ore boulders were loaded into the trucks, whenever possible. Only those too large to safely load into haul trucks were blasted, as there were no size constraints in disposing of non-ore material. And to this avoided the costs associated with re-drilling and blasting.

Interestingly, the sound and air blast from these relatively tiny secondary blasts were much greater than the substantially larger primary blast. While all pit blasts were loud and the accompanying vibration shook the town, I am unaware of any real damage caused by the 25 years of blasting. In Lowell, a couple of the older brick buildings required a modest amount of reinforcing, due as much to differential settlement of fill placed long-ago, as to the blasting (personal opinion).

Boulders of ore set behind the shovel in a digging pit during mining for later secondary blasting – 1960
Graeme Larkin collection

Slide 41

The ores are marked prior to mining

Contact between oxide ore (left) / limestone (right), Holbrook Extension – 1970
Graeme Larkin Collection

The small red flagging attached to the stake in the above photo marks the limit of the ore. Samples were taken at on regular intervals from all blast holes and assayed for copper content and type – oxide vs. sulfide, as oxide copper would not be recovered in the concentrator. Also, every blast hole was closely surveyed, as its exact location which was needed for locating and identifying the ore, leach and non-mineral in a process called “ore control.”

The massive primary blast moved the rock surprisingly little. The blast was to break the rock, not throw it any great distance. Thus, the assay data derived from the blast hole samples could be correlated with the blast hole survey information and the ore areas defined in the broken rock. These areas were then marked for mining by the ore control engineer. Continual remarking of the ore/leach/non-mineral contacts was necessary as mining progressed into the broken rock.

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The sulfide areas contained the ores sought by the company

Mining high-grade supergene sulfide ores in the Holbrook Extension – May 1970.
Graeme Larkin Collection

In the Holbrook Extension section of the Lavender Pit, it was the sulfide ore that were of the greatest interest. For the most part, the sulfides were in the porphyry or the intrusion breccia, which had formed in the limestones adjacent to the Sacramento Stock complex during intrusion.

While the porphyry ores were of reasonable grade, those in the intrusion breccia were locally very rich. For the most part, these had been mined years before through the Holbrook and Gardner mines, but important amounts remained, as did the lower-grade portions left behind by the early miners as waste.

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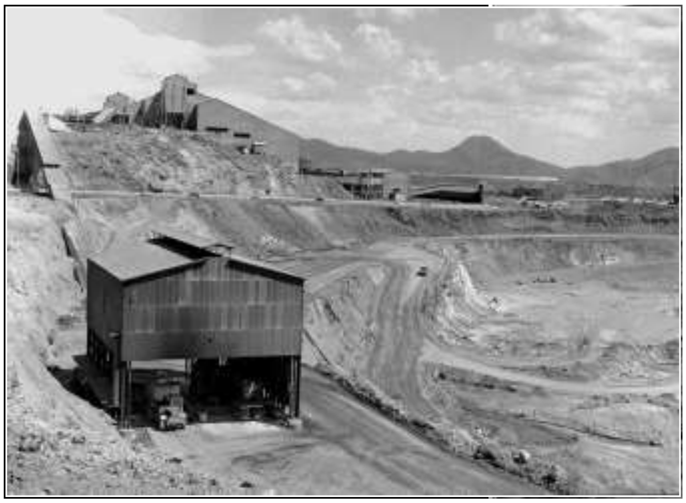
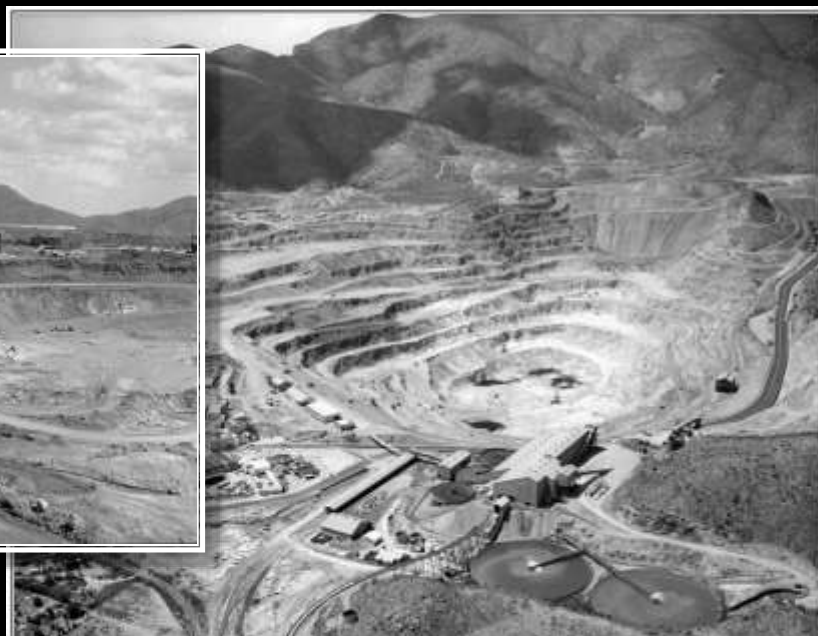
All ore grade material was sent to the primary crusher

Ore hauls were relatively short, as the primary crusher was located within the pit. The haul trucks could dump directly into the primary crusher, which reduced all rocks to less than six" in size and loaded onto the conveyor which crossed the highway and deposited the crushed rock in the course ore stockpile next to the concentrator.



A 35 ton haul truck dumping ore directly into the primary crusher, C-1956.
Graeme Larkin collection



The Lavender Pit – 1964: in general, the light areas were ore while the gray was leach and darker areas non-mineral.
Graeme Larkin collection

The choice of the primary crusher location was a great benefit as it was so close to the ore being mined. While it was originally designed to accept the direct dumping of the 25 ton trucks, minor modifications allowed for the 35 to trucks to do likewise. With the introduction of the 65 ton capacity units, the structural steel was raised and wing plates added to the receiving edges of the crusher and all worked well.

The gyratory primary crusher could accommodate rocks to 48" in size and render them to no greater than six inches in the maximum dimension. This crushed material was transported by the conveyor crossing the highway to a course ore storage area at the concentrator for further crushing and grinding.

Slide 44

Concentrate and Tailings

Ore from the pit was sent to the concentrator where the rock was ground to the fineness of talcum powder. The copper minerals were separated from non-ore minerals by froth flotation, resulting in a concentration of the copper minerals in powder form. This concentrate was dried and loaded into railcars and sent to Douglas for smelting.

Lavender Pit Concentrator -1957
Graeme Larkin Collection

The non-ore material, tailings, was thickened into a slurry of about 60% solids and sent by gravity through three miles of pipe to the tailings disposal area near Don Luis. This was the same tailings area used by the earlier Copper Queen Concentrator. Water was recovered for reuse, as the slurry was deposited.

Tailings storage area, upper right – 1977.
Graeme Larkin Collection

The Lavender Pit Concentrator was a very typical one for the time. It used three stage crushing, including the primary crusher, followed by ball mill grinding and then flotation. To be sure the ores it treated were difficult and the concentrate grade produced was low, even for the day, but it worked well. Almost from the outset it exceeded its design capacity by 50% by processing an average of 18000 tons per day with peak days of well over 20,000 tons processed.

Following separation by flotation, the tailings, that portion from which the copper minerals had been removed, were thickened (much of the process water removed) and sent as a slurry via a transite pipeline just over three miles toward Naco for disposal in the same tailings facility that had served the earlier Copper Queen Concentrator. Here, the remaining water was recovered and pumped back to the concentrator for reuse.

Slide 45

Oxide ores were mined for direct smelting

With the opening of the Holbrook Extension, substantial ore grade oxidized material was mined. As this type of material would not benefit from treatment in the concentrator, it was stockpiled and then shipped directly to the Douglas Smelter.

Because of the extra handling, a grade of 5% copper was required for these materials to be ore. Oxides of Less than 5% were placed in the leach area for copper recovery by leaching.

Loading oxides in the Holbrook Extension, May 1970
Graeme Larkin Collection

In the grand scheme of things, the amount of oxide ores mined and sent to the smelter was small. However, the low graded oxide material was mixed with the leach material so that the acidic leach solutions would dissolve the small amounts of the oxide copper minerals – malachite, azurite, chrysocolla cuprite, etc. - putting the copper into the leach solutions for recovery in the precipitation plant.

It was the mining of these materials that allowed for the recovery of many fine mineral specimens by the company and, of course by the men working in the pit.

Slide 46

Handling of non-ore material 1952-1963

From 1952 into1963, all leach and non-ore material was transported to the pit edge by the small 25 and 35 ton trucks and transferred into rail cars by dumping for transport to the appropriate part of Number 7 dump. After 1963, all was moved by truck.

Transferring non-mineral material from trucks to train for transport to the Number 7 Dump - 1954.
Graeme Larkin collection

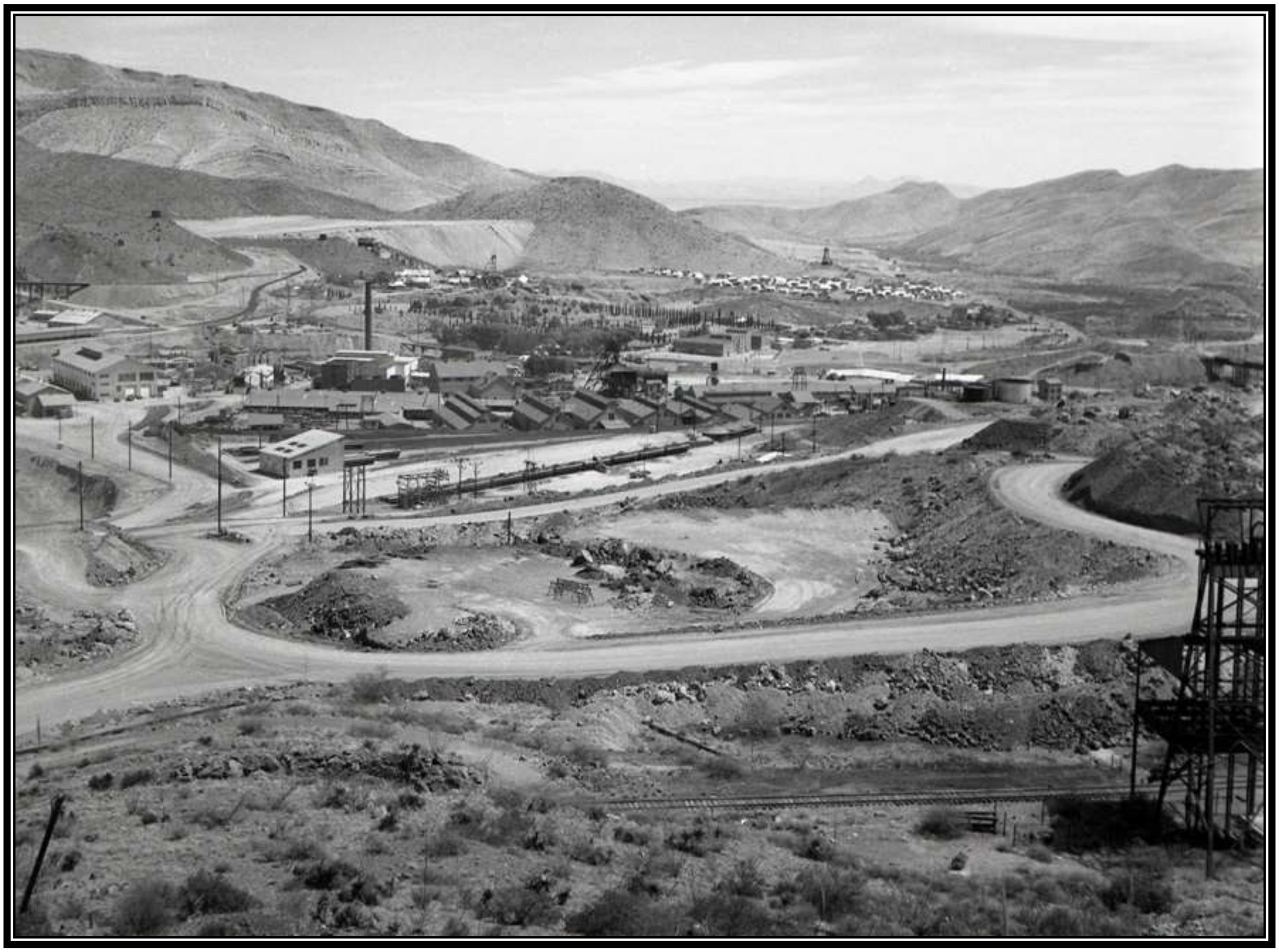
Dumping non-mineral material on the Number 7 dump by train, 1958.
Graeme Larkin collection

Number 7 Dump -1962, note the leach ponds on the left and the darker, non-mineral material on the right . This segregation of material on the dump continued for the life of the mine.
Graeme Larkin collection

The need to move the non-ore material to the distant Number 7 dump was not reasonable with the smallish 25 ton trucks. Too many of these trucks would have been required. Thus, a plan was made to transfer the material into rail cars for transport to the appropriate part of the dump. To be sure the double handling of the material added an additional cost, but it was cheaper than using the small trucks for this long haul.

The additional reserves which justified an expansion of the pit also justified the purchase of new, larger trucks now available. This came none too soon as Number 7 dump was reaching its capacity using rail haulage. The elevation of the dump needed to be increased to a height beyond that which rail could serve with its 2½% grade constraint.

By the end of 1963 the use of rail haulage had ended as a part of the Lavender Pit operations. The greater flexibility of the trucks allows the dump to be raised in several lifts, as can still be seen when looking at the dump side. The staged lifts also aided in better percolation of the leach solutions as the surface could easily be ripped by dozers without the worry of rail being in the way.



The truck/train transfer platform can be seen in the center of the above photograph. Spillage from over-dumping is being cleaned up by a front end loader – 1960.

Graeme Larkin collection

Slide 47

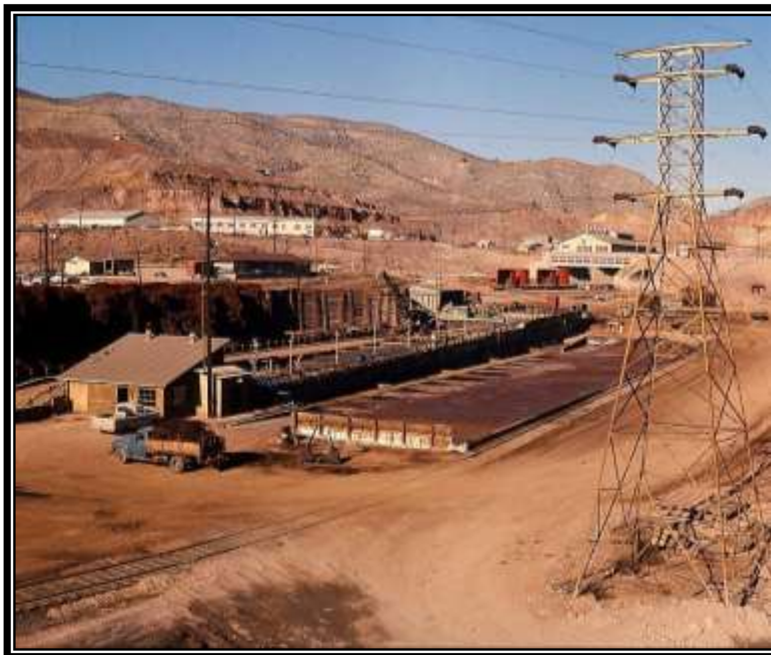
Leaching of low-grade on # 7 Dump recovers substantial additional copper

Slightly acidic water from the underground mine was ponded in cells on the dump, the water percolated through the broken rock, slowly dissolving the copper. The copper laden water was collected in the existing drainage and pumped to the Campbell precip plant for metal recovery.

Copper laden waters captured at the front of the dump in the existing drainage - 1977.
Graeme Larkin collection

Water being fed into a ponding cell on the top of Number 7 Dump - 1977
Graeme Larkin collection

Precipitation plant at the Campbell Mine - 1977
Graeme Larkin collection



Left: View of the Campbell precipitation plant with the red-brown, 80%+ copper precipitate on the drying pad prior to loading into rail cars – 1963.

In the background are red-orange truck bed for the 65 ton KW Dart trucks being brought in at the time.

Graeme Larkin collection

Slide 48

With non-ore material haul distance was very critical

Hauling rock is expensive, thus the closer to the digging pit it can be deposited, the better. Some early non – ore rock stripped to develop the Pit was dumped into the old Sac Pit. The rest was transported to # 7 dump.

Right: A view of the completely filled Sac Pit - 1964.
Graeme Larkin collection

Early non-ore material was used to backfill the Sac Pit - 1951.
Graeme Larkin collection

By 1965, it became obvious that the rock in the Sac Pit must be removed for the Holbrook Extension. When this was done, close sites were again used and much was placed in Uncle Sam Gulch near the Cuprite Mine.

Right: non- mineral material near the Cuprite Mine, 1973. Note also the layering of the Number 7 Dump in the middle-ground , as it was now being built by trucks and not trains.
Graeme Larkin collection

As is always the case, non-mineral material is dumped and stored as close to the point of extraction as possible. It may seem that the backfilling of the Sacramento Pit and subsequent re-mining of the material was a mistake that could have been avoided. Not so, as the very small size of the haul trucks available at the time precluded a longer haul and, indeed the operating costs saved early on, at a time when project payback was important, helped make the operation profitable.

To be sure re-mining the rock from the Sac Pit did carry a cost but the size of the equipment then available – both loading and hauling – kept this cost acceptably low and undoubtedly saved money over the long run.

Slide 49

Expansions to the original Lavender Pit

Lavender Pit Mine - August 1960, with the two expansions approximately outlined. The yellow indicates that started in 1962 and the red the one announced in 1965.
Graeme Larkin Collection

It is almost universally true that mines developed on copper porphyries always mine much, much more than originally envisioned. The Lavender was no exception. Two important expansions combined to add about ten years additional life to the mine. Lower mining costs because of larger and better equipment were available to move the heretofore impossibly thick non-ore overburden. Importantly, the new ores would not have to carry any construction costs associated with the concentrator or support facilities – they were already in place and largely depreciated.

Nevertheless, substantial amounts of exploration work were necessary. For the most part, churn drills were used, much as they had been used for 40 years.

The confirmatory work for the Holbrook extension was a good bit more involved as the area had been so heavily mined by the underground and too the Sacramento Pit had been backfilled with overburden, making drilling difficult. While churn drills were employed, exploration was undertaken via long abandoned underground workings on two fronts.

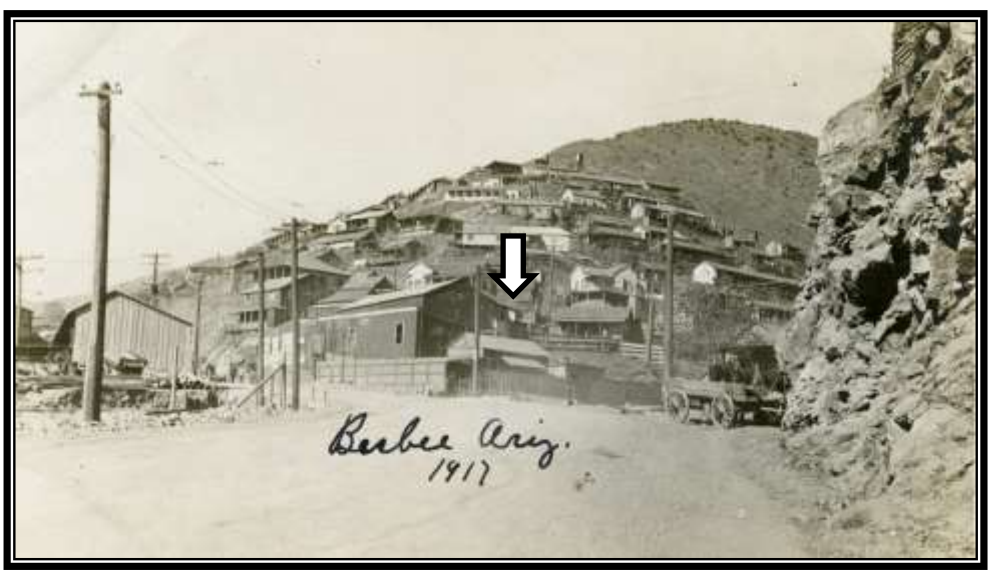
The first was accessing long-abandoned workings on the 400 level of the Gardner Mine where bulk samples were taken and a good deal of diamond drilling undertaken. Secondly a long disused ventilation shaft at the mouth of Debaucher Canyon was re-timbered down to the 200 level of the Holbrook Mine and made accessible for diamond drilling

Churn drill in operation near the Gardner Shaft in 1963 during exploration for the extension.
Graeme Larkin collection

A section of the old Bisbee smelter smoke-stack had been placed over this and one other nearby ventilation shaft, as a safety precaution before 1910. Painted a bright silver-color, in 1963 this one was used for access for most of a year. To the right, men can be seen salvaging lumber from a house that was to be demolished for the pit expansion.
Graeme Larkin collection

A 1935 view of the Dubacher Canyon area with the two ventilation shafts and their protective steel sections from the old Bisbee smelter in place and noted. The photo was taken from very near the location of the Holbrook #2 shaft.

Graeme Larkin collection



1917 view of Slag Dump Hill at the mouth of Dubacher Canyon with the air shaft indicated by the arrow.

Graeme Larkin collection

Slide 50

The expansion to the south and east

Cutback on the south wall – 1966. The wide spaces represent the removal of the red/brown overburden from the gray ore to make it available. A full seven shovels can be seen in this view, four mining ore and three in overburden, reflecting the advanced stage of this cutback.
Graeme Larkin Collection

First came the expansion to the south and east. Substantial thicknesses of post-ore Glance Conglomerate covered the mineralized material. Previously, the amount of non-ore to be removed relative to the ore added a cost burden that could not be supported by the copper grade.

Mining costs had been reduced by planning to employ large, more efficient equipment. As is so often the case, technology came to the rescue with improved steel metallurgy allowing for larger transmissions and drive trains to be developed and, thus larger trucks to be made.

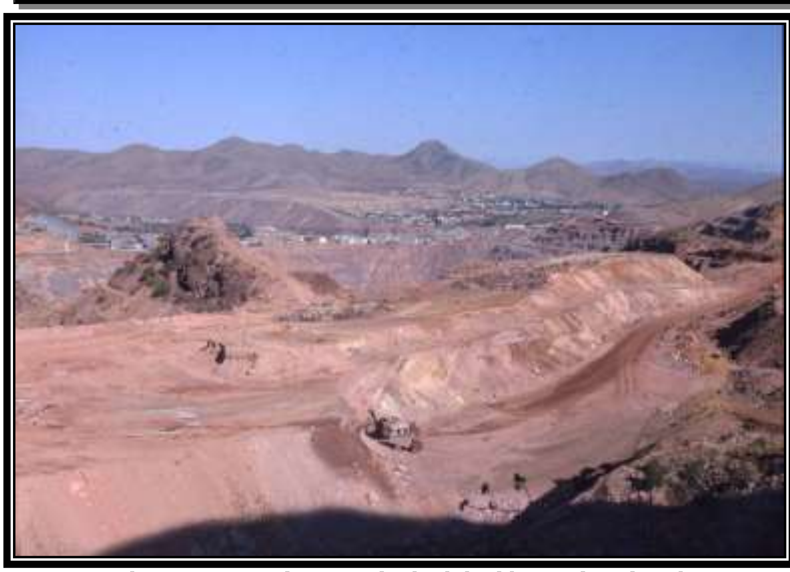
The pit support and maintenance facilities needed to be relocated as did some of the Junction Mine shops, but these costs were relatively minor and allowed for the needed changes to be made to the truck shop to accommodate the larger units. By 1963 the program was well advanced.

Preparing for the Holbrook Extension

Blasting near the Czar Mine for the relocation the Bisbee-Lowell Road – 1968
Graeme Larkin Collection

The Gardner Hoist house being dismantled for the Holbrook Extension – 1965
Graeme Larkin Collection

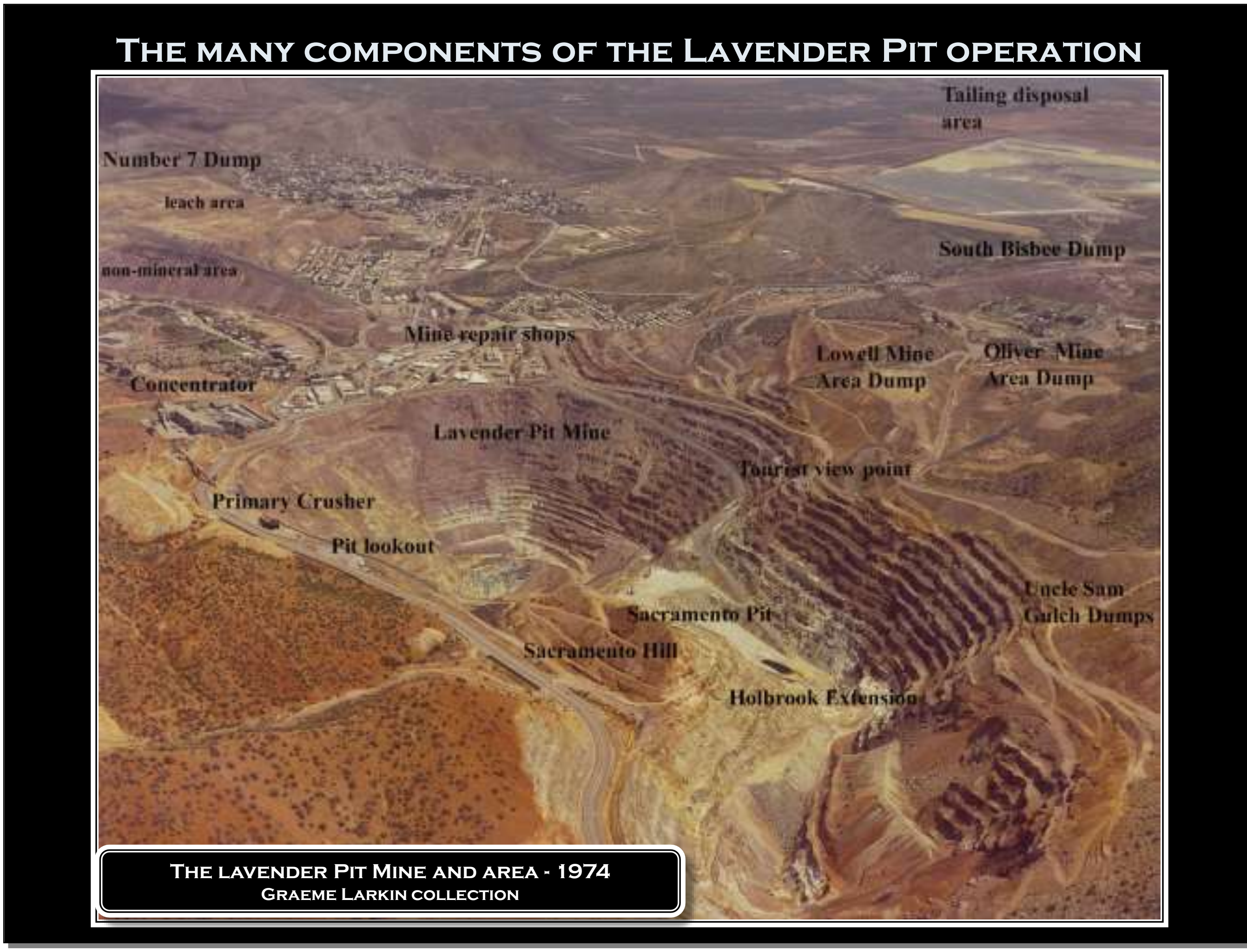
As with the Pit expansion to the east, substantial preparatory work was required. The Gardner and Oliver headframes removed, the old Sac Pit emptied of rock and the Bisbee-Lowell road relocated, among other tasks. However, it was worth the effort, as a bit more than two years were added to the pit life and, as a plus, numerous fine mineral specimens were recovered by PD when the pit remined areas exploited by the great Holbrook Mine in the 1890s and early 1900s. Most importantly, this vital resource, this additional copper was fully recovered for the benefit of all.



Re-mining the non-mineral material which had been placed in the Sacramento Pit some 25 years previously to prepare for the Holbrook extension of the Lavender Pit mine - 1968.
Graeme Larkin collection

As previously noted, the re-mining of the non-mineral material placed in the Sacramento Pit from 1951 to 1953 had to be undertaken to expose the ore grade material in the Holbrook Extension. This was relatively easy and cheap mining with short hauls into Uncle Sam gulch, where it remains to this day.

Slide 52



The lavender Pit Mine and area - 1974
Graeme Larkin collection

A large open pit operation consists of a number of ancillary and support facilities. Some of these are quite expansive in area. As can be seen in the above photo, the Lavender Pit mined two areas previously mined. Both the Sacramento Pit and the Holbrook underground mine were partially re-mined by the Lavender. This is the story of these types of copper systems.

As advances in technology allowed for larger, more efficient mining equipment, the cost to move rock drops. Improvements in copper recovery allow for enhanced metal recovery. Both of these changes make the waste or low-grade of yesterday ore today. I am certain that this trend will continue and that the day will come when the remaining mineralization in and around the Lavender Pit will be mined to further provide the necessary raw materials for a better life and good jobs for many. Excessive or poorly conceived reclamation, such as backfilling the pit could easily add costs that would render the remaining material uneconomic. I hope this temptation is resisted and that once more Bisbee is a copper camp.

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The end comes to a great mine

The Lavender Pit was closed in December 1974. All of the economic copper containing rock, for the time, had been mined and processed. However, the copper mineralization continues downward and to the east, but much barren material is on top of it.

And too, Arizona had become much less welcoming to mining, preferring to export these very good jobs To other countries

Lavender Pit Mine, looking west – February 1974
P. Kresan photo

Perhaps open pit mining may again return to Bisbee. The porphyry unit north of the Dividend Fault is mineralized and exploration drill has reviled that in excess of 350 million tons of potentially economic material remains. To be sure, this is a small deposit in the context of copper porphyry and permitting in the US is challenging – to say the least.

Nonetheless, copper will always be an important metal and the remaining material will almost sure be exploited as it becomes more and more difficult to economically or socially exploit the larger porphyry deposits abroad. In my mind it is just a matter of time before this happens.