**CONTACT INFORMATION**
Mining Records Curator
Arizona Geological Survey
1520 West Adams St.
Phoenix, AZ 85007
602-771-1601
http://www.azgs.az.gov
inquiries@azgs.az.gov

The following file is part of the

Arizona Department of Mines and Mineral Resources Mining Collection

**ACCESS STATEMENT**

These digitized collections are accessible for purposes of education and research. We have indicated what we know about copyright and rights of privacy, publicity, or trademark. Due to the nature of archival collections, we are not always able to identify this information. We are eager to hear from any rights owners, so that we may obtain accurate information. Upon request, we will remove material from public view while we address a rights issue.

**CONSTRAINTS STATEMENT**

The Arizona Geological Survey does not claim to control all rights for all materials in its collection. These rights include, but are not limited to: copyright, privacy rights, and cultural protection rights. The User hereby assumes all responsibility for obtaining any rights to use the material in excess of "fair use."

The Survey makes no intellectual property claims to the products created by individual authors in the manuscript collections, except when the author deeded those rights to the Survey or when those authors were employed by the State of Arizona and created intellectual products as a function of their official duties. The Survey does maintain property rights to the physical and digital representations of the works.

**QUALITY STATEMENT**

The Arizona Geological Survey is not responsible for the accuracy of the records, information, or opinions that may be contained in the files. The Survey collects, catalogs, and archives data on mineral properties regardless of its views of the veracity or accuracy of those data.

DUVAL

CORPORATION

METALS DIVISION

ESPERANZA PROPERTY

VISITORS

INFORMATION

DUVAL CORPORATION
ESPERANZA PROPERTY
ORGANIZATION

| | |
|---|---|
| Resident Manager | A. F. Lindstrom |
| Mine Superintendent | R. J. Arnold |
| Mine Engineer | E. L. Aurand |
| Mill Superintendent | G. S. Baker |
| Chief Accountant | J. H. Black |
| Chief Metallurgist | R. L. Brown |
| Safety Supervisor | F. E. Hatch, Jr. |
| Mine Geologist | C. D. Iles |
| Plant Maintenance Superintendent | D. P. McIntire |
| Chief Warehouseman | T. E. Pomroy |
| Purchasing Agent | W. T. Wilcox |
| Chief Chemist | H. L. Witte |

DUVAL CORPORATION

MINING AT THE ESPERANZA PROPERTY

History

The old New Years Eve underground mine, the first workings in the Esperanza area, was operated spasmodically, mining copper, from 1895 until the present Esperanza open pit property was developed.

The area was first visited by Duval personnel in the fall of 1954. In May 1955, exploration drilling was started on a 500-foot equilateral, triangular grid pattern. By May 1957, 88 churn and diamond drill holes were completed for a total footage of 30,724 feet. In addition, 2,100 feet of underground workings were excavated to gather more information concerning the ore body.

Pre-mining stripping of waste was started in November 1957, with Isbell Construction Company performing the mining under contract. By February 1959, when the mill was completed, sufficient ore was exposed to start actual production from the Esperanza Mine.

Exploratory drilling discovered ore in an adjacent area called West Esperanza in July 1960. Exploration and development drilling of this area, during 1961 and 1962, consisted of 141 rotary and diamond drill holes for a total footage of 26,139 feet. In March 1963, pre-mining stripping was started with the first ore being produced from the West Esperanza pit in August 1965.

In July 1965, Duval purchased the mining equipment at Esperanza from Isbell and took over the mining operations.

Pit Dimensions

Esperanza Pit: the highest original elevation along the west side of the pit was 4,314 feet. The lowest elevation to be mined under present mining

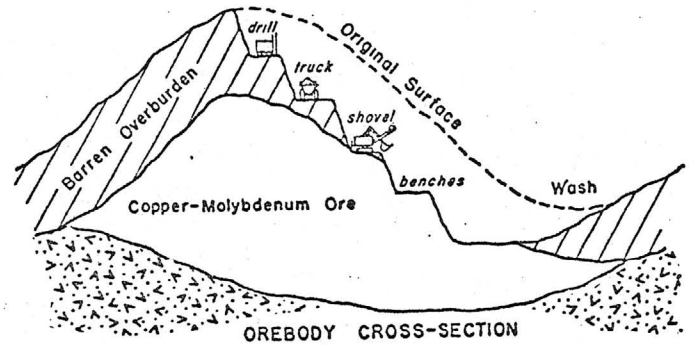
plans will be 3,515 feet for an elevation difference of 799 feet. Six benches, each 35 feet high, are presently being mined. The maximum dimensions of the pit are 4,000 feet east-west and 2,500 feet north-south.

West Esperanza Pit: the highest original elevation was 4,422 feet. The lowest elevation will be 3,600 feet for an elevation difference of 822 feet. Four benches, each 50 feet high, are presently being mined. The maximun dimensions of the pit are 2,100 feet east-west and 3,800 feet north-south.

Rock Types

The ore bodies are of the porphyry type with the main ore-bearing rocks being quartz-monzonite porphyry, quartz diorite, and andesite porphyry. Other types of rocks encountered are quartzite, welded tuff, quartz latite porphyry and dacite. The rocks are of Cretaceous and Tertiary age. The main copper minerals are chalcopyrite and chalcocite. Molybdenum mineralization occurs as molybdenite.

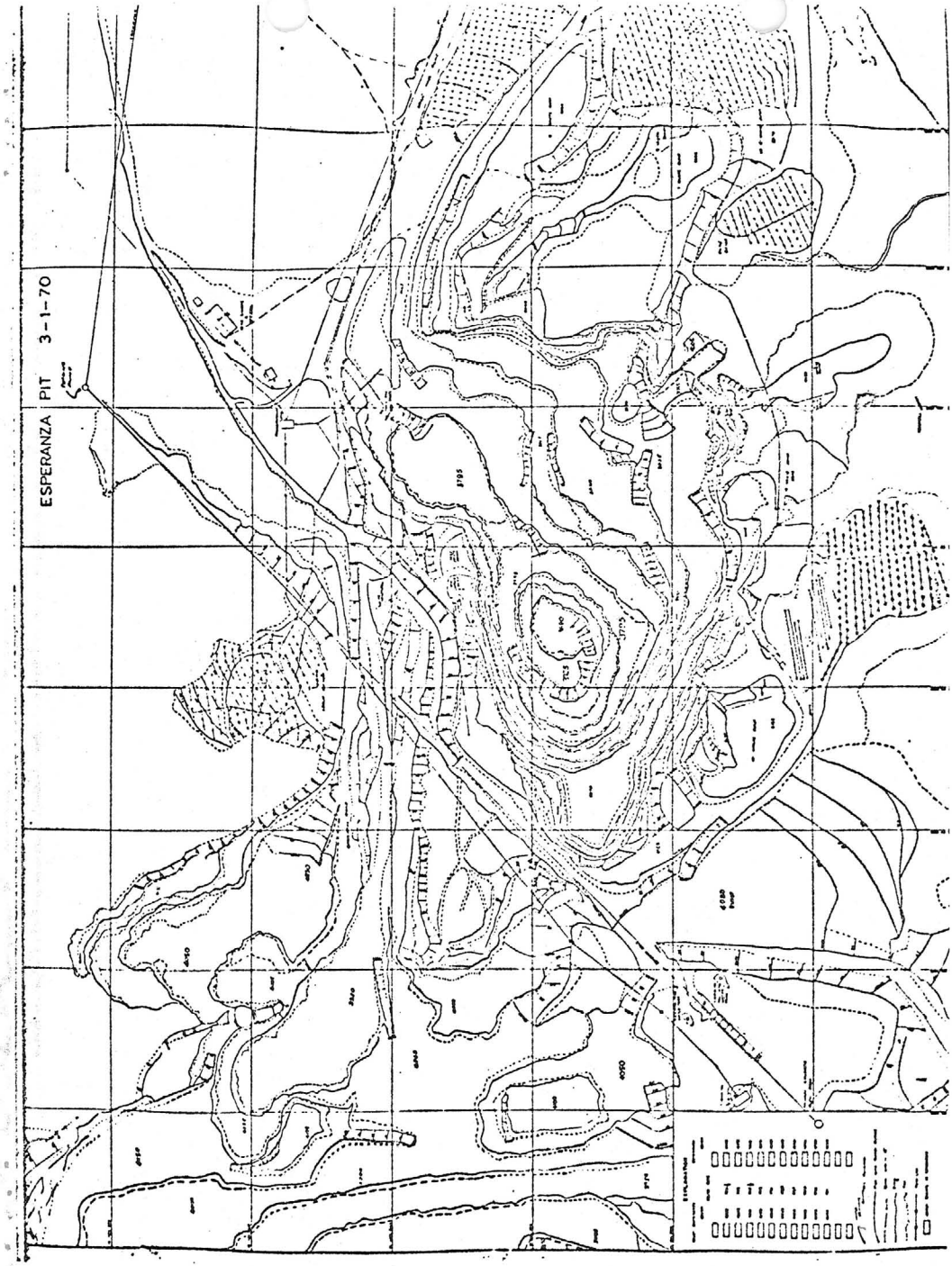
Blasting and Mining



OREBODY CROSS-SECTION

In blasting the rock, 9-inch or 9 7/8 inch diameter holes are drilled with a rotary drill. These holes are approximately 23 feet apart and are drilled to a depth of 7 feet below the next lower bench. The holes, when





Leach Dumps

Leach dumps are located between hills and over arroyos in order that the return water from the dumps can be collected. Leach solution, containing some acid, is sprayed on the surface of the dump. As the solution percolates down through the dump it dissolves the copper from the rock. The pregnant or copper-bearing solution is then collected below the dump and piped to the precipitation plant. Here the copper is removed from the pregnant solution by flowing it through beds of shredded iron scrap. The copper precipitates out in the form of a mud called cement copper or precipitate copper containing approximately 75% to 85% metallic copper.



dry, are loaded with ammonium nitrate mixed with diesel fuel and blasted. When the blast holes contain water, a gelatin type of blasting agent called slurry is used.

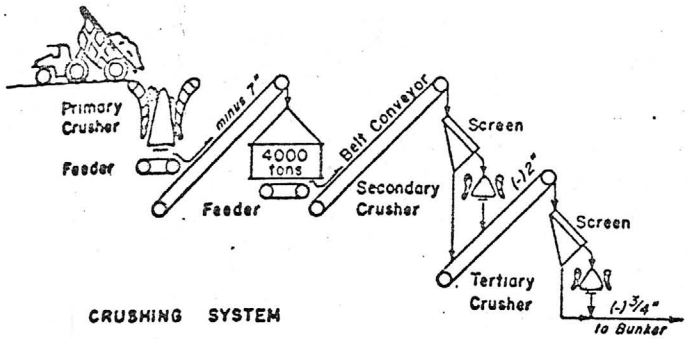
In order to determine whether the material to be mined is ore, leach, or waste, a sample is taken of the cuttings of each blast hole and assayed. The results determine whether the blasted material is to be designated as ore, leach, or waste. Material is considered ore if it contains copper and molybdenum equivalent to 0.4% copper or above. All material with a copper equivalent content between 0.15% and 0.4% is considered leach. Any material containing less than 0.15% copper equivalent is designated as waste.

Mine Tonnage

The total tonnage mined from the Esperanza and West Esperanza pits as of January 1, 1970 was 137.1 million tons. This represents 43.5 million tons of waste, 45.3 million tons of leach and 48.3 million tons of ore containing less than 1% copper and less than 1/10 of 1% molybdenum. At present, approximately 250,000 tons of material are mined per week.

Equipment

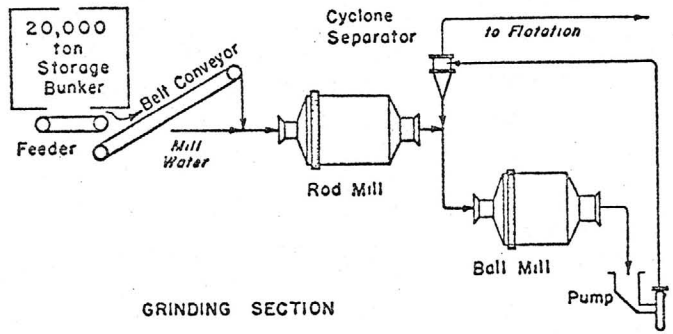
Electrically powered shovels and one front end loader are used for loading blasted rock. Shovels range from 5 to 12 cubic yard capacity and the loader has a 10 cubic yard capacity. The capacity refers to the size of the bucket on the shovel or loader. Haulage trucks have a capacity of 75 tons. The mine operates 3 shifts per day, 7 days per week during which period 35 shovel/loader shifts are worked. The majority of ore is hauled on the second and third shifts which enables maintenance work to be done on both the crushing and mining equipment on day shift.




CRUSHING SYSTEM

The Mill

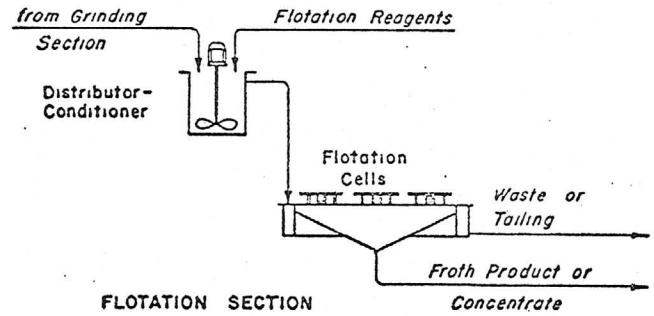
The mined ore is passed through three crushing stages during which it is reduced to less than one inch in size. It is then conveyed to the mill which, on an operating basis of 24 hours per day, 7 days per week, has a daily milling capacity of 15,000 tons. Here it is passed through rod and




GRINDING SECTION

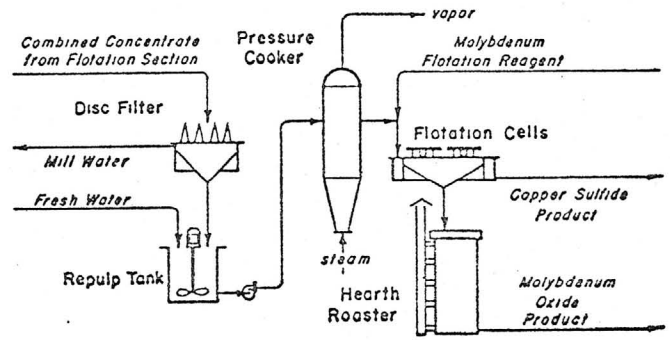
ball mills in which it is ground to a very fine, almost powder, size. It then goes through the flotation sections where the copper and molybdenum are separated from the ore pulp. Further processing through flotation






FLOTATION SECTION

separates the copper from the molybdenum. The copper concentrate, containing approximately 25% copper, is shipped to smelters. The molybdenum concentrate, containing approximately 58% molybdenum, is further refined and shipped direct to the consumer.




MOLYBDENUM RECOVERY SECTION

# *Esperanza*

COPPER DIVISION

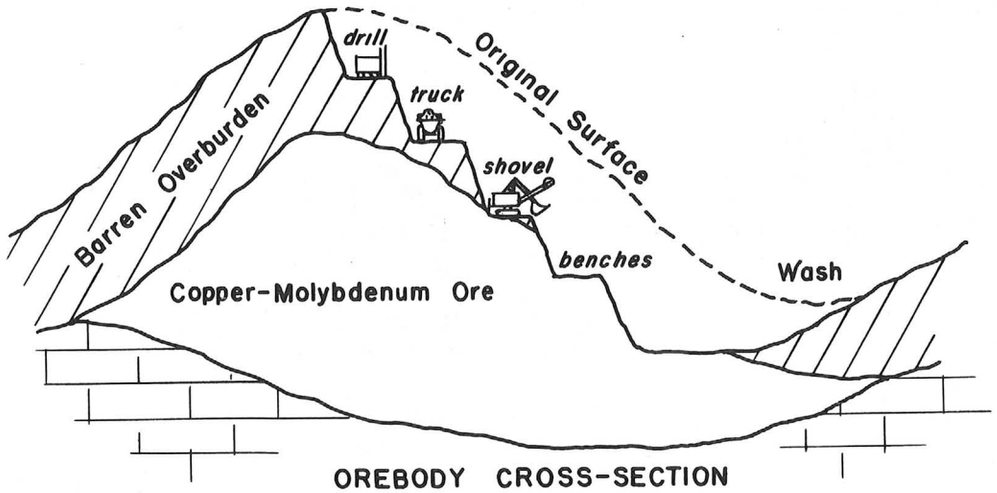
DUVAL SULPHUR & POTASH COMPANY

TUCSON, ARIZONA

of 1957 to remove 6 million tons of barren overburden to expose enough of the ore body so that routine bench mining could proceed. Both stripping and construction were completed by late February of 1959 and the first ore was fed into the process equipment.

## Mining Practice

The ore body as outlined by the drilling program is roughly contained in a Sierrita Mountain foothill which is some 350 feet high and 4,000 feet long. The mineralized section is covered by a blanket of barren overburden varying in thickness and averaging around 100 feet.




OREBODY CROSS-SECTION

The mining practice is the standard bench operation typical of open pit mines. Blast holes are drilled along the bench face and loaded with ammonium nitrate explosive. After detonation, the shot-down face is loaded with 5 cubic yard electric shovels into 40-ton diesel trucks.

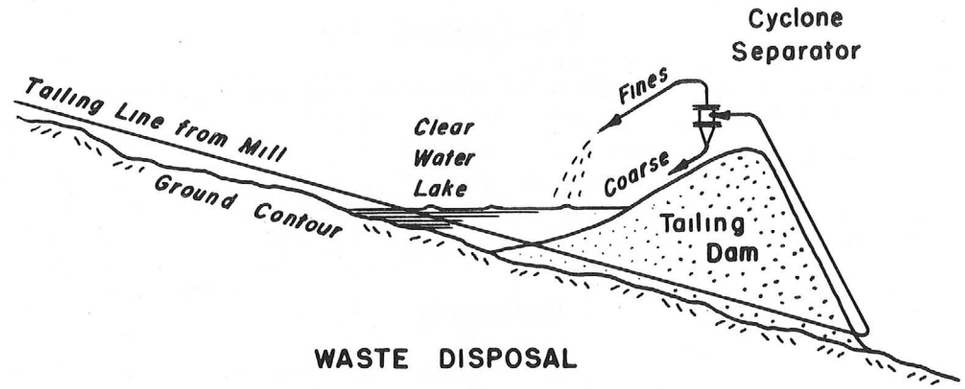
The nature of the deposit is such that waste rock must be continually removed to expose fresh ore for mining. The ratio of waste removed to ore mined, generally referred to as the stripping ratio, will average about 1 to 1 over the life of the ore body. Thus, for the daily 12,000 tons of ore hauled to the concentrator, a like tonnage of waste goes to the dump.

Careful assaying, mapping and mine planning are necessary to assure continuous daily production of ore, a low stripping ratio and a minimum loss of ore values to waste.

## Milling Practice

### A. Crushing

Mine run ore contains finely disseminated crystals of the black copper sulfide mineral chalcocite along with lesser percentages of the so-called




WASTE DISPOSAL

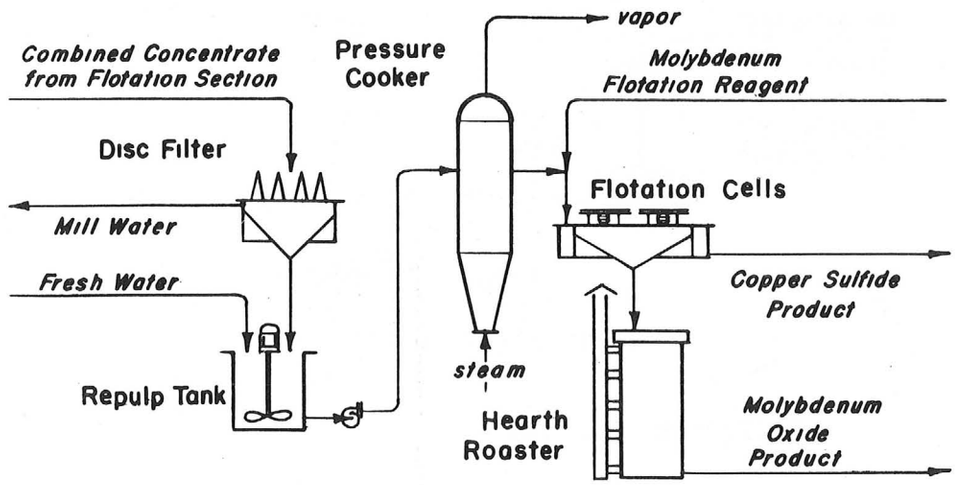
In essence, it takes advantage of a gravity flow tailing line to provide feed to the tailing cyclones. The cyclones discharge their relatively course underflow on the top of the growing dam and there compact. The relatively fine, clayey overflow discharges inside the dam. The fines settle out making a water tight seal against the dam and the clear water forms in a back lake for reuse in the milling process.

## Instrumentation

Various types of industrial instrumentation have been used throughout the entire processing facility. Where ever possible the tasks of operating personnel have been replaced by electronic-pneumatic recording and control devices. In addition to providing process records for metallurgical study, these controlling instruments sense process upsets imperceptible to human beings and constantly react to maintain desired equilibrium. In this manner the duties of the operating personnel have been largely reduced to that of an attendant. Each section of the plant has a central station where both power and process controls have been assembled in consoles and graphic panels. In this manner the scope of each operator is expanded without sacrifice of either efficiency or reliability.

One example of applied instrumentation is in the operation of the water field system. Water wells are located some six miles from the plant proper. Level control devices at the plant sense the process need for more or less fresh water. An automatic control signal is sent by radio to the water field where unattended pumps correct for the need.

Another example of the use of automatic control is in the molybdenum recovery section. Here a combination of flow, density, level, pressure and temperature measurements are integrated to maintain the desired metallurgical condition in the pressure cooker. The attendant operator functions only when process upsets and mechanical failures are beyond the range of the control devices. In such an event both light and sound alarms function to alert the operator.




MOLYBDENUM RECOVERY SECTION

The molybdenum sulfide concentrate is then fed to the ten-hearth roaster where it is oxidized to the oxide form for sale to the metals trade.

**E. Copper Concentrate Shipment**

The final copper concentrate, the unfloated mineral from the molybdenum flotation section, is filtered and conveyed by belt conveyor to the storage house adjacent to the mill building.

Each day the accumulated tonnage is weighed into trucks for transport to the railhead some eleven miles away from the plant. At the siding the trucks dump into open gondolas for shipment to the custom smelter.

This concentrate, sold as such to the smelter, contains between 25 and 35 percent copper and three to four ounces of recoverable silver per ton.

**F. Gangue Tailing Disposal**

The mother rock waste leaving the plant presents the dual problem of ultimate disposal and water reclamation.

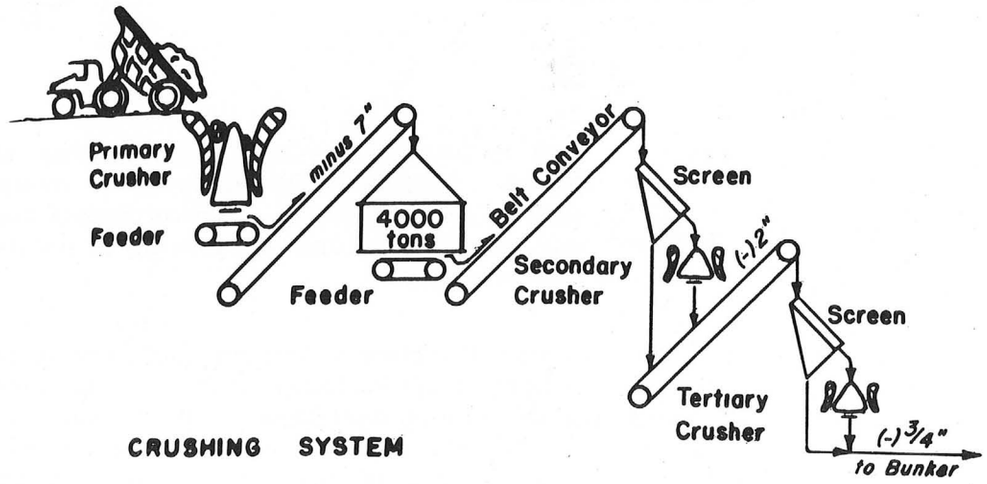
The magnitude of the disposal problem can be appreciated when one considers that nearly the entire 12,000 tons per day of finely ground plant feed must be disposed of every day for the life of the property. Obvious too, is the fact that if the water used to transport this waste away from the immediate vicinity could be salvaged for reuse, a tremendous saving in both money and a precious natural resource would result.

An adroit solution to these problems has evolved through the years.

oxide minerals of copper. Total copper concentration in the ore averages less than one percent. Also present in addition to the copper minerals, is a significant quantity of the molybdenum sulfide mineral called molybdenite. Molybdenum metal concentration is expected to average 0.022% throughout the ore body.

The first refining problem is size reduction to unlock the mineral crystals from the mother rock and to reduce such crystals to dimenions suitable for flotation.

The mining method produces broken rock up to 4 feet in size. Primary crushing of this material is done by the 48 inches gyratory crusher which is housed in its seven-story building.




CRUSHING SYSTEM

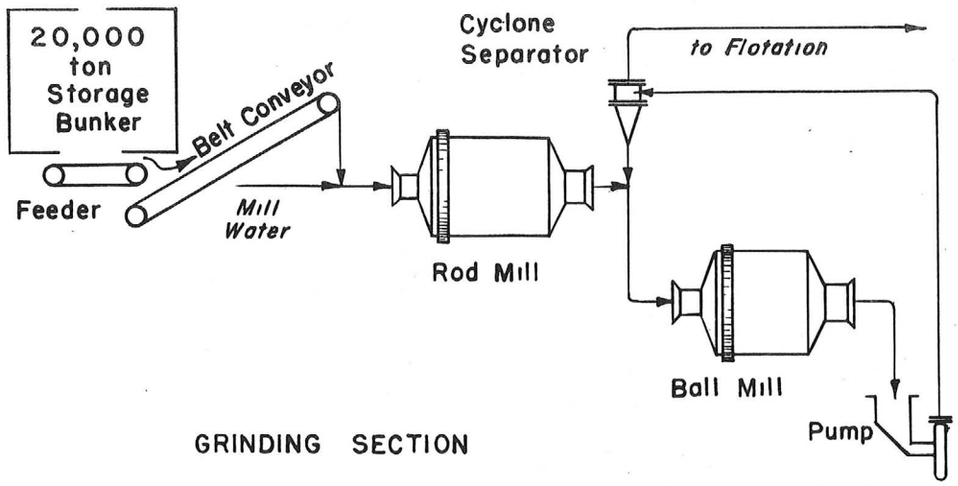
The primary crusher reduces the ore to a maximum size of 7 inches. Further size reduction is carried out in two stages by similar gyratory crushing machines of smaller size. Dry crushing ultimately reduces the particle size to less than 3/4 inch. This material is transferred by belt conveyors to the 20,000-ton storage bunker at the head of the concentrator.

Throughout the crushing system dust collectors are used at all crushing and transfer points to prevent loss of fines and eliminate a serious housekeeping problem.

Electronic instrumentation has been used throughout the system to provide maximum capacity without overload.

**B. Grinding**

Further size reduction to less than 1/100 of an inch is accomplished in large wet grinding mills. Crushed ore from the 20,000-ton storage bunker is fed to two of the worlds largest rod mills at the rate of 250 tons per hour each. Sufficient water is added with the feed to give the resulting pulp fluidity and the desired pulp density or percent solids.




GRINDING SECTION

The rod mill discharge is split to two ball mills wherein further and final size reduction is accomplished. The ball mill discharge is pumped with a slurry pump to the primary cyclone separators. These devices make a size classification and send the ore of desired fine size forward to flotation and return any oversize back to the ball mills.

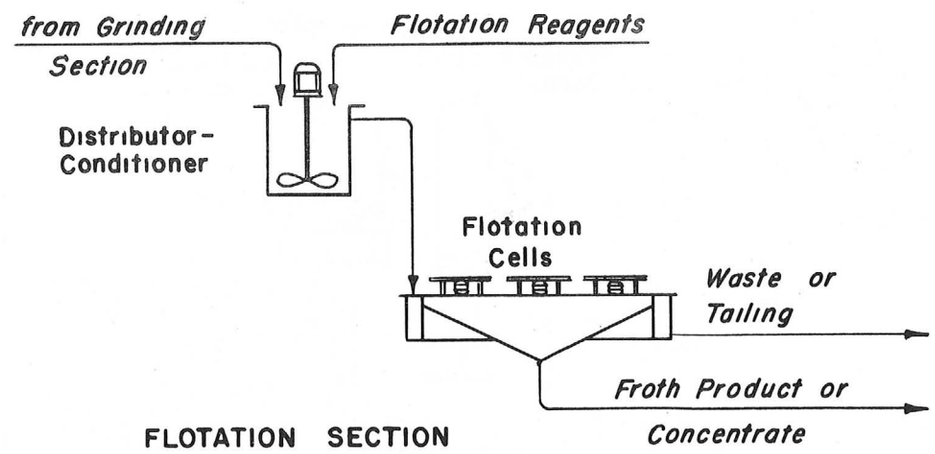
These grinding mills have outside diameters of thirteen feet three inches. The rod mills are sixteen feet long and each is charged with 130 tons of steel rods. The ball mills each carry 150 tons of steel balls. These tonnages of grinding media are maintained by periodic additions equal to the weight of metal which is worn away in the grinding of the ore. The recharging averages some eight tons of steel per day and is one of the major costs in the milling operation.

Here again in the grinding section the use of recording and control instrumentation is evident. These sensitive instruments keep a constant vigil on each phase of the section to assure maximum efficiency and reliability.

## C. Flotation

Having accomplished the desired size reduction, next begins the important task of separating the valuable minerals from the mother rock.

The primary cyclone discharge enters the distributor-conditioners where the flotation reagents are added. These reagents, ignoring the gangue rock, selectively seek out the valuable minerals and are adsorbed on their surfaces. Once adsorbed they effectively resurface the mineral and alter the surface characteristics to one having a water repellent, air-loving nature.




FLOTATION SECTION

From the conditioner-distributor the reagentized slurry enters the long trough-like flotation cells. The cells provide agitation such that the mineral particles are gently suspended in the water carrying medium. Air is introduced into each cell below the agitator resulting in a multitude of small bubbles rising through the suspended slurry. The reagentized minerals are attracted to the bubbles and floated to the surface of the cell. Additional reagents are added to provide a stable froth on the cell surface wherein the floated mineral collects and overflows the cell lip. Additional flotation steps are required to further refine the flotation product to the desired chemical purity.

The mother rock, unaffected by the action of flotation, moves from cell to cell down the series and ultimately discharges out the bottom of the last cell in the row.

## D. Molybdenum Recovery

Both of the principal products, copper and molybdenum, plus a trace of silver are concentrated in the flotation product. The problem of separating molybdenum is one of destroying the reagents used initially to make the copper-molybdenum minerals float and then reconditioning for specific molybdenum flotation.

This is accomplished by first filtering the reagent contaminated mill water from the combined concentrate and repulping with fresh water. The resulting slurry is fed to a giant pressure cooker wherein the reagents coating the minerals are distilled away. To the then sterile pulp is added a collector selective for molybdenum and flotation is again conducted. The froth product from this step is the molybdenum sulfide, while the tailing is the final copper product.

DUVAL

CORPORATION

*A Pennzoil Company*

4715 East Fort Lowell Road
Tucson, Arizona 85712

# DUVAL SIERRITA CORPORATION

Production from Duval Corporation's Sierrita-Esperanza copper/ molybdenum properties near Tucson, Arizona, has helped rank Duval as the second largest producer of molybdenum in the world and one of the five leading producers of copper in North America.

## How the Duval Sierrita Project Came About

In the Sierrita Mountains some 20 miles south of Tucson, Arizona, and about 40 miles north of Nogales, Sonora, Mexico, Duval Corporation, in July 1964, acquired a large low-grade copper-molybdenum ore body adjacent to its Esperanza Property. The purpose of the acquisition was to provide additional reserves for the Esperanza Property which began operations in 1959.

In May, 1966, the General Services Administration (GSA) announced a program to encourage additional domestic production of copper in the interest of national security. The program, which was authorized by President Johnson in March, 1966, was formulated under authority contained in the Defense Production Act of 1950, as amended. Upon learning of the copper production expansion program, Duval Corporation entered into negotiations with the GSA for development of the Sierrita copper-molybdenum property under the program.

After more than a year and a half of negotiations, Duval Sierrita Corporation, a wholly-owned subsidiary of Duval Corporation, and the GSA signed contracts in November, 1967, for development of the Sierrita Property. Out of the total of $100 million available to the program, Duval was assigned $83 million as advances against future delivery of copper to the government at a fixed price of 38 cents per pound. Total cost of the project exceeded $190 million. Additional financing beyond the $83 million was being provided to the extent of $48.75 million by government-guaranteed V-Loans, with the remainder provided by Duval.

The $83 million will be repaid by June 30, 1979, through deliveries to GSA of 218.4 million pounds of wirebar copper credited at the rate of 38 cents per pound. During this time, Duval Sierrita Corporation will sell on the open market its molybdenum and silver production plus such of its copper production as may be required to cover cash operating costs, interest and asset additions and replacements.

## History of Duval Corporation

Duval Corporation was chartered in Texas on August 18, 1926, under the name of Duval Texas Sulphur Company. The Company acquired its name from the location of its first sulphur property in Duval County, Texas. In 1935, Duval commenced production of sulphur on a portion of Boling Dome in Wharton County, Texas, and this property was successfully operated until 1940. Duval commenced production at its third sulphur property, Orchard Dome in Fort Bend County, Texas, in 1938, and operated the property until 1970.

Duval embarked upon a program of exploration for potash in New Mexico in 1947, and in November of 1951 began mining potash from its Saunders Mine located near Carlsbad. Since then Duval has brought two other potash mines in the Carlsbad area into operation—the Wills-Weaver Mine in 1961, and the Nash Draw Mine in 1964.

In March, 1959, the Company initiated production at its Esperanza copper-molybdenum property near Tucson, Arizona, and in 1964, brought its second copper-molybdenum property, Mineral Park, near Kingman, Arizona, into production. The Battle Mountain, Nevada, copper-gold-silver property was placed in operation in 1967.

Within a period of 24 months commencing in 1968, Duval brought four additional mining properties into production. These properties, representing an investment in excess of $300 million, were the Fort Stockton, Texas, sulphur property and the Saskatoon, Saskatchewan, Canada, potash property, both brought into production in 1968; the Culberson County, Texas, sulphur property brought into production in 1969; and the Sierrita copper-molybdenum property near Tucson, Arizona, where production commenced in the first quarter of 1970.

In 1950, the Company changed its name to Duval Sulphur & Potash Company and in 1963 to Duval Corporation. In 1930, United Gas Corporation acquired controlling interest in Duval Corporation.

In April of 1968, Pennzoil Company consolidated with United Gas Corporation to form Pennzoil United, Inc. The consolidated company name was changed to Pennzoil Company effective June 1, 1972.

Duval, now a wholly-owned Pennzoil Company subsidiary, continues to operate as a corporate entity.

Mining is accomplished by establishing a series of levels or benches, each being approximately 50 feet high. The first step in the mining cycle is the blasting of the various benches. To blast, rotary drills bore holes 59 feet in depth and nine to 12¼ inches in diameter. The holes are then loaded with explosives. A typical blast involving 40 holes breaks loose 200,000 tons of rock—enough material to keep one power shovel in production for approximately four days.

## Sierrita Property

The Sierrita Property consists of over 13,000 acres. Included in this acreage are 143 unpatented mining claims which were purchased by Duval. Approximately 58 percent of the Sierrita ore body was acquired in the purchase of these claims. The remaining 42 percent of the ore body was controlled by patented mining claims owned by Duval. Duval has transferred these patented claims to Sierrita.

## Exploration and Preliminary Development

A total of 178 test holes were drilled in order to delineate the Sierrita ore body and to test proposed waste dump areas. Some of the tests were drilled to check certain holes drilled by another mining company which had previously drilled 60 core tests in the area.

## Ore Reserves

The exploration and preliminary development program delineated an ore body of 414 million tons with an average copper content of 0.35 percent (seven pounds per ton) and an average molybdenum content of 0.036 percent (0.72 pounds per ton). Subsequent development continues to expand this reserve. Engineering pit design indicates that a total of 634 million tons of waste must be handled prior to and during the mining of the 414 million-ton ore reserve. This total of over a billion tons of ore and waste which will be mined, of which 131 million tons were removed during the pre-mine stripping operations, represents more than twice the tonnage excavated in the construction of the Panama Canal.

## Mining

It is anticipated that the eventual perimeter of the Sierrita open pit will encompass an area of approximately 460 acres. As presently designed, the pit will ultimately reach a depth of 1850 feet below the highest elevation of the pit area prior to mining. Such an ultimate depth will represent a distance of almost one and one-half times the height of the Empire State Building.

Mining is accomplished by establishing a series of levels or benches, each bench being approximately 50 feet high. The first step in the mining cycle is the blasting of the various benches. To blast a bench, rotary drills drill holes 59 feet in depth and from nine inches to 12¼ inches in diameter.

Blast holes which contain water are loaded with a gelatin explosive in slurry form. Holes which are dry are loaded with a mixture of ammonium nitrate and fuel oil.

A typical blast consisting of detonation of the explosives in 40 blast holes requires 75,000 pounds of explosives to break 200,000 tons of rock. A blast of this size provides enough broken material to keep one power shovel in production for approximately four days.

Giant haul trucks used to transport the ore from the benches to the crusher have a rated capacity of 120 and 150 tons. They weigh approximately 110-140 tons empty. Fuel tanks hold 450 to 500 gallons of diesel oil and the 48-ply tires stand nine to ten feet high and weigh some 3000 pounds.

## Mining Equipment and Facilities

The mining equipment features nine power shovels equipped with 15 cubic-yard buckets, 38 haul trucks of 120-ton capacity and 14 of 150-ton capacity. These shovels and trucks are among the largest presently used in the copper mining industry. In addition, six rotary blast-hole drills, 12 dozers and numerous other units such as motor patrols, fork lifts, cranes, water trucks, personnel busses and miscellaneous small trucks supplement the operation. Service facilities consist of two modern shops, steam cleaning pad, change room and offices.

Because the power shovels and haul trucks are among the largest used in the industry, some pertinent facts concerning these units are:

**Power Shovels**

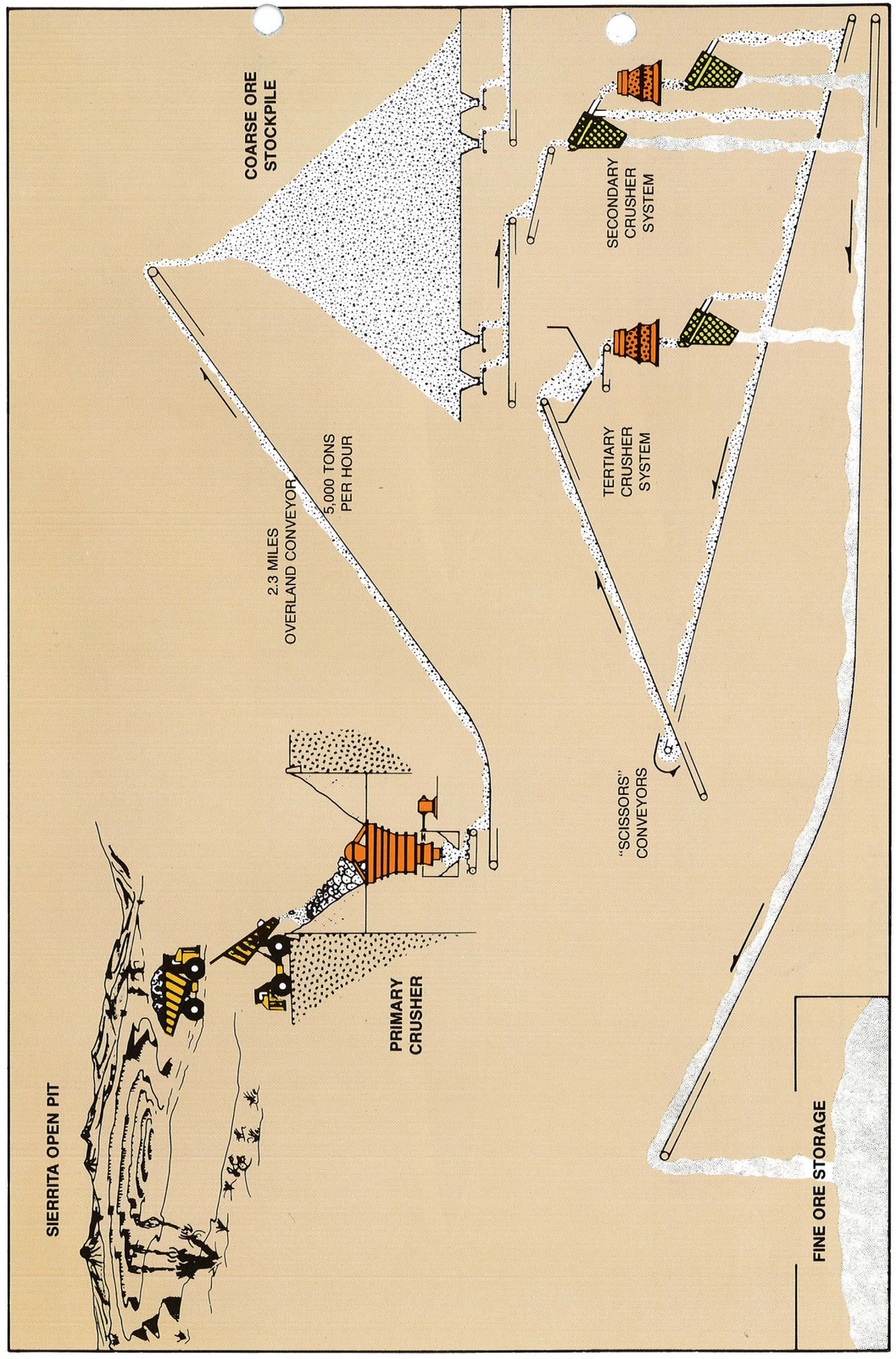
- The weight of each shovel is approximately 450 tons.
- Shovels are rated at 750 HP and are electrically powered by 4160-volt alternating current motors.
- The 15 cubic-yard bucket has a capacity of approximately 23 tons.

**Haul Trucks**

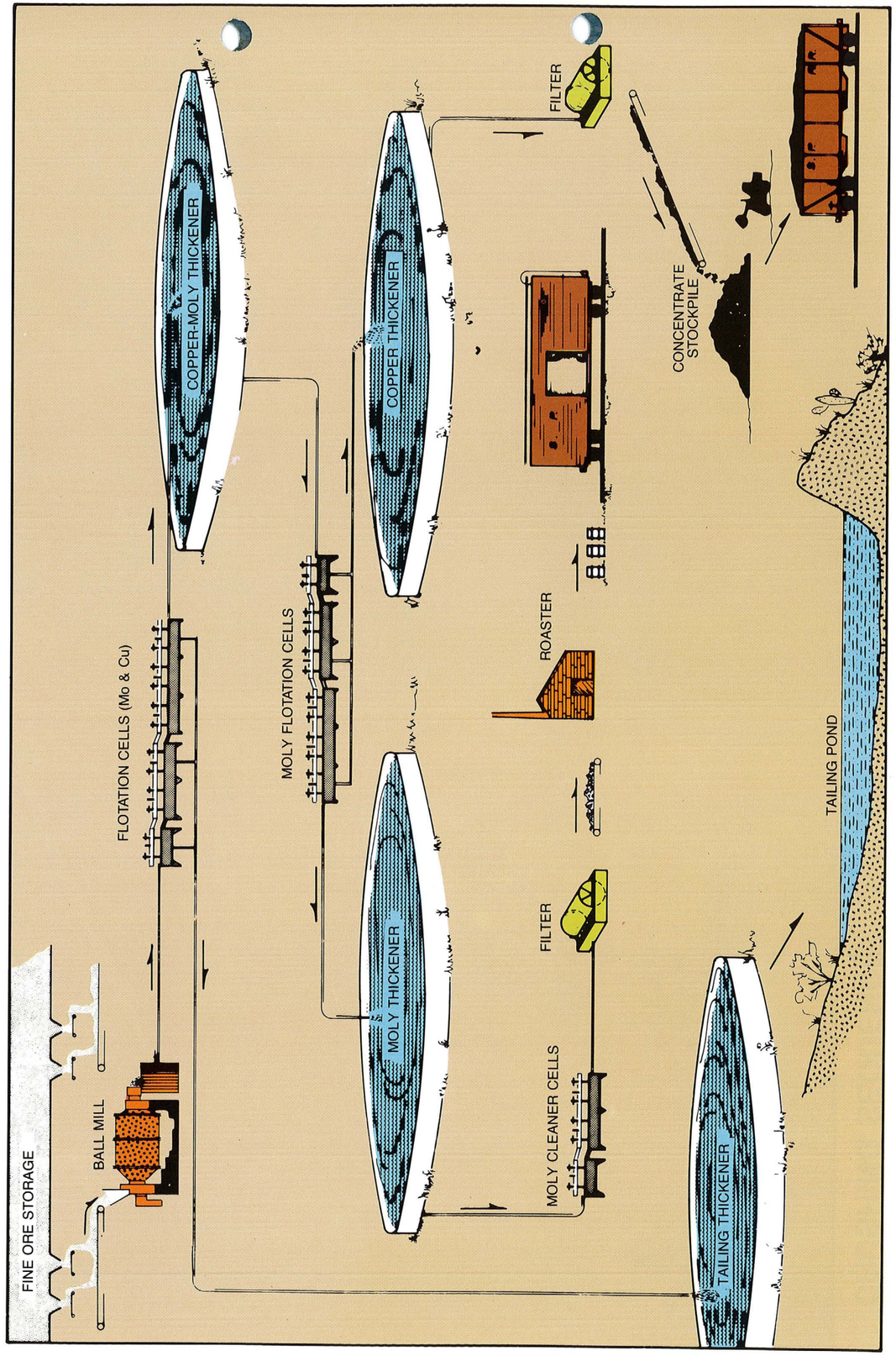
- The truck engines are 12 and 16 cylinder diesels rated at 1200 and 1600 HP.
- The truck engine drives a direct current generator, which supplies power to electric motor assemblies in the rear wheels.
- Trucks have a rated capacity of 120 and 150 tons. They weigh approximately 110 -140 tons empty.
- Fuel tanks hold 450 to 500 gallons of diesel oil and the engines use about one gallon per mile under full-load conditions and level haul.
- Tires are 48-ply, nine to ten feet in diameter and weigh approximately 3000 pounds, depending on truck size.
- The expected life of each truck is about seven to ten years, after which replacement is anticipated.

## Plant Facilities

The concentrator was designed for a capacity of 60,000 tons of ore per day. Its associated facilities cost approximately $112 million. This capacity is greater than that of any single copper-molybdenum concentrator in North America. The construction of plant facilities, as originally designed, was completed by mid-1970. In May, 1970, an agreement was reached with the GSA for



## CONCENTRATING SEQUENCE




a $12 million expansion at the Sierrita Property. This expansion program, completed in 1971, increased the mining and milling capacity at the property to 72,000 tons per day. Subsequent changes and modifications have increased this capacity to 86,000 tons per day.

## Crushing

Primary size reduction of the mined ore is achieved by two 60-inch by 89-inch gyratory crushers located near the south perimeter of the Sierrita open pit. The crushers, which reduce the mine ore to about 85 per-cent minus six-inch, have a total operating capacity of 5000 tons-per-hour. The crushed ore is transported by a 54-inch wide belt conveyor to a 40,000-ton coarse ore open storage—an overland distance of about two and one-half miles.

Feeder belts under the coarse ore pile collect the ore to feed the fine-crushing plant. Ore is first fed to four vibrating double-deck scalping screens ahead of four 84-inch secondary crushers. The secondary crusher product is again screened, and the oversize material is further reduced by ten 84-inch tertiary crushers operating in a closed-circuit system consisting of a 2400-ton surge bin feeding the crushers and vibrating screens. The finished product, essentially all minus half-inch, is transported to a 60,000-ton live capacity fine-ore bin located in the concentrator building.

## Concentrating

The process of flotation is used to concentrate the copper and molybdenum minerals. To accomplish this, the crushed ore must be further reduced in size by grinding to achieve liberation of the mineral particles from the host rock.

The ore from the fine-ore storage is wet-ground in 16 ball mills each measuring 16½ feet in diameter by 19 feet long and driven by 3000 HP motors. The ball mills operate in a closed circuit with cyclone classifiers. The ground ore in an ore-water slurry, after being conditioned with reagents, is introduced into flotation machines which produce a low-grade (rougher) concentrate of copper and molybdenum minerals. The rougher concentrate is then re-ground in two 11-foot diameter by 15-foot-long regrind ball mills that are operated in a closed circuit with cyclone classifiers. The rougher concentrate is floated and re-floated to a final concentrate. A total of 662 flotation machines are used in the copper-molybdenum concentration. The tailing from the flotation process is thickened before disposal in four 350-foot diameter rake thickeners; the water, which is recovered from the slurry, is re-used in the process. The concentrate is thickened in 100-foot diameter thickeners.

The combined copper-molybdenum concentrate is then subjected to flotation to separate the two products. The concentrate is steamed and conditioned with reagents before flotation. In the first flotation, the copper minerals are depressed and the molybdenum floated. The copper concentrate is the tailing from this flotation and, after thickening in a 125-foot diameter thickener, is de-watered in four drum filters and loaded in open gondola railroad cars for transporting to the smelter. The molybdenum is further concentrated by cleaning and re-cleaning stages of flotation. The final molybdenum concentrate is filtered, dried and stored for packaging for marketing as molybdenum sulfide or for roasting in two 23½-foot diameter multiple-hearth roasters. The roasted product, molybdenum trioxide, is packaged and marketed as technical molybdic oxide.

## Production

Annual metal production from the Sierrita Property amounts to 180 million pounds of copper, 14 million pounds of molybdenum and 850,000 ounces of silver. Duval Corporation ranks fifth among United States copper producers and is the second largest producer of molybdenum in the world.

## Landscaping Program

Duval landscapes spoil banks and tailing dams from its copper operations. Utilizing a drip irrigation system, liquid fertilizers are injected into soil devoid of mineral value. Native plants and trees are then planted into the revitalized soil, blending the tailing dams with the adjacent countryside.

## Employment

Peak employment during development of the Sierrita Property was 2400. Average employment during production is 1750.

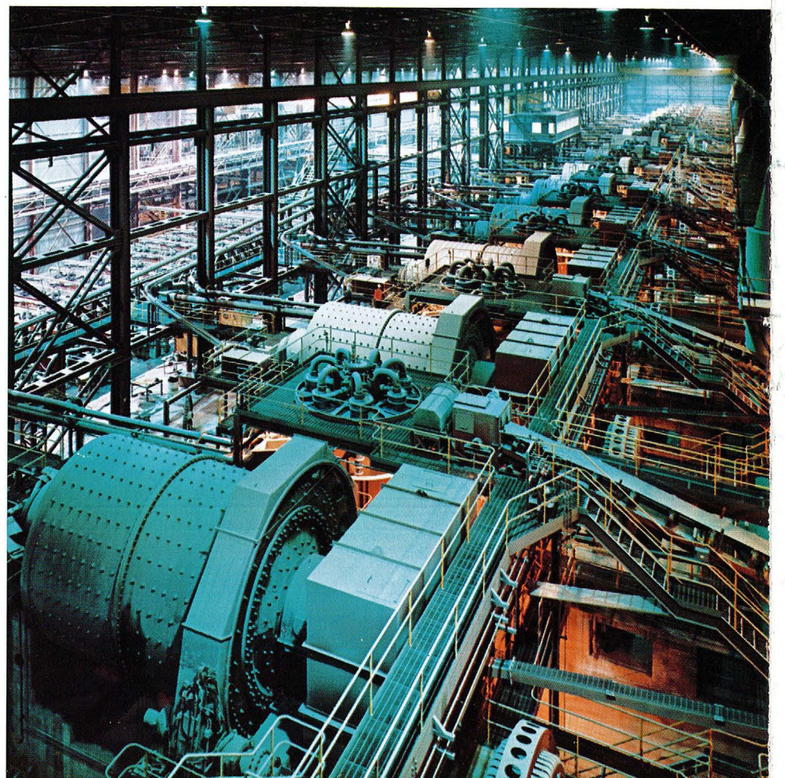
## Utilities

Electric power and natural gas is supplied by a local utility company. Power requirements are approximately 70,000 kilowatts or 50 million kilowatt-hours per month. This amount of power would supply a city of 100,000 population.

Natural gas requirements are 50 million cubic feet per month with most of the gas used to process the molybdenum minerals.

The ground ore in an ore-water slurry, after being conditioned with reagents, is introduced into flotation machines which produce a low-grade (rougher) concentrate of copper and molybdenum materials. Further grinding and flotation is then carried out before the final concentrate is produced.

The process of flotation is used to concentrate the copper and molybdenum minerals. To accomplish this, the crushed ore must be further reduced in size by grinding. The ore from the fine-ore storage is wet-ground in 16 ball mills each measuring 16½ feet in diameter by 19 feet long and driven by 3000 HP motors.



## Glossary

**Ball Mill:** a rotating, horizontal cylinder partially filled with steel balls and water that grinds the ore stored in the fine ore bin to free the valuable minerals from the waste rock.

**Coarse Ore Pile:** where the product from the primary crusher is stockpiled prior to being fed into the secondary crushers.

**Concentrator:** a plant where ore or metal is freed and separated from its containing rock or earth. The concentration of ores always proceeds in steps or stages, e.g.: crushing, sizing, and flotation to produce a concentrate.

**Cyclone Classifier:** a device for classification by centrifugal means of fine particles suspended in water, whereby the coarser grinds collect at and are discharged from the lower apex of the apparatus and the fine particles along with the water are discharged from a top opening.

**Fine Ore Bin:** a place of temporary storage for the product from the tertiary crushers (½″ sized ore) that will be fed into the ball mills in the concentrator.

**Flotation:** the process of separating valuable minerals from waste rock with the use of chemicals, reagents and air. (Reagents coating the ore particles are attracted to air bubbles which then float to the pulp surface and are skimmed off as concentrate.) Waste particles are not coated and are, therefore, not floated. Accordingly, a separation is accomplished.

**Molybdenite:** a black platy disulfide of molybdenum ($MoS_2$) which is processed to molybdenum trioxide and is used in steel alloys and electrodes of mercury vapor lamps.

**Ore:** a natural occurring mineral or mineral compound that can be mined at a profit.

**Primary Crusher:** a heavy duty dry crushing machine capable of accepting mine run ore (blocks of rock up to 4′ in size) and reducing it to less than 6″ pieces.

**Reagent:** a chemical or solution used to produce a desired chemical reaction or conditioning of the slurry prior to flotation.

**Scalping Screen:** a vibrating screen designed to separate coarse and fine ore so that the coarse fraction can be further crushed.

**Secondary Crusher:** the second stage of crushing (by machine) in which the product from the primary crusher is further reduced in size as part of the process to free the valuable minerals from the rock.

**Slurry:** a liquid mixture of finely ground particles of rock and minerals in water.

**Slurry Blasting Agents:** a dense, insensitive high velocity explosive of very high water resistance.

**Spoil Bank:** a pile or bank of waste rock or dirt.

**Surge Bin:** a compartment for temporary storage of ore which will assure a constant rate of supply to the crushers or grinding mills.

**Tailing Pond:** an impoundment or storage area for the waste rock and water from the concentrator that no longer contains mineral values of any significance.

**Tailings:** the finely crushed rock that no longer contains any mineral values. (Residue from the flotation process.)

**Tertiary Crusher:** the third stage of grinding by a machine in which the product from the secondary crusher is further reduced in size (to about ¾″) as part of the process of freeing the valuable minerals from the rock.

**Thickener:** a circular pond or impoundment that is used to reduce the amount of liquids from a liquid-solid mixture and permit the recovery of clear overflowing water for reuse in the process.

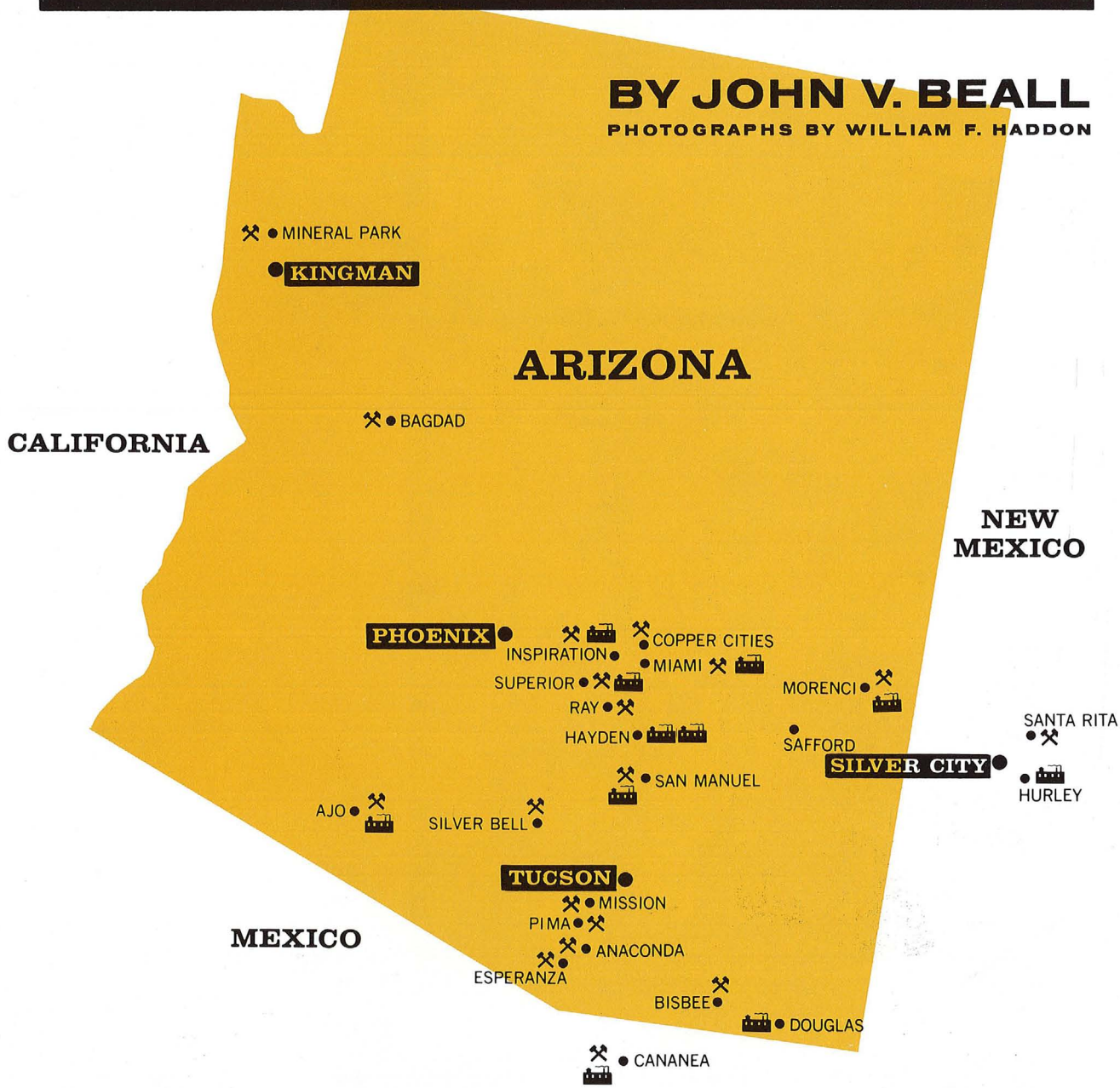
**Wirebar Copper:** a cast shape of copper which has a cross section approximately square with tapered ends designed for hot rolling to rod for subsequent drawing into wire and is approximately 99.99% pure copper.

Duval Corp.

# SOUTHWEST COPPER
## A POSITION SURVEY

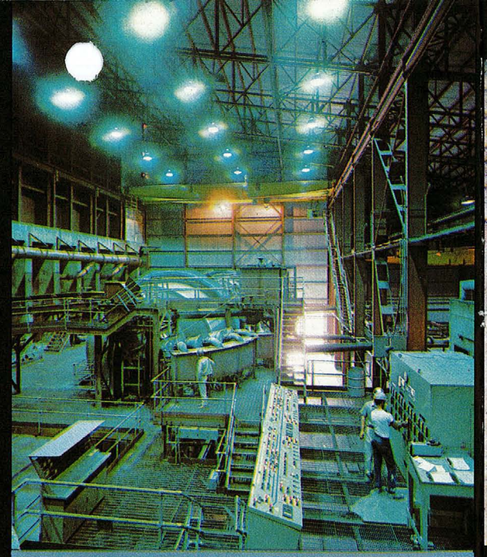

**BY JOHN V. BEALL**

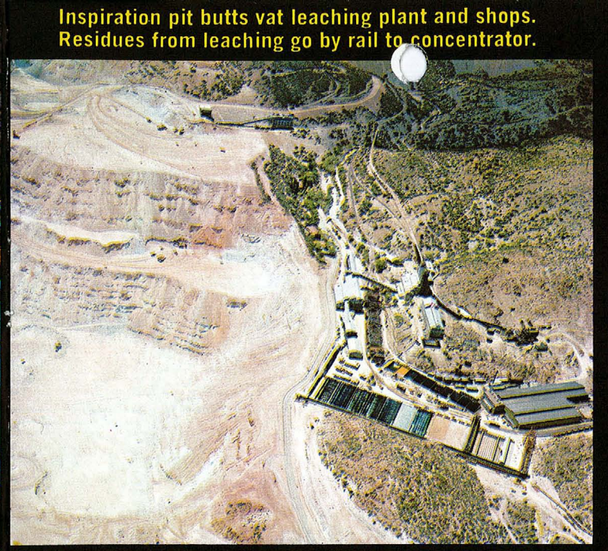
PHOTOGRAPHS BY WILLIAM F. HADDON

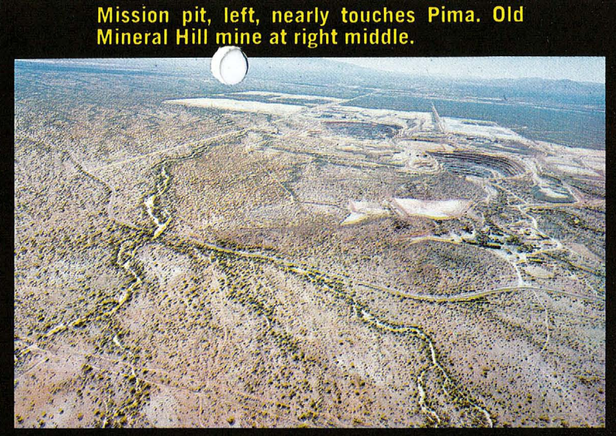

When the mineral seekers came, they brought romance, excitement and, too often, transitory riches. It has been so for uncounted centuries. While the rich ore lasted, living was high and money flowed—mostly out of town. The whole creation was like a circus. The headframe went up like the center pole of the big top. The reduction works was an ingenious affair; an opportunity for self-expression by the mining engineer on the job. When the high grade gave out or the bottom dropped out of the market, the whole show folded. Machinery was scavenged for the next location. About all that was left were the raw footings, like giantsteps on the hillside; and the headframe above the silent diggings. Mostly, the people went away too.

Arizona Territory was like that at the turn of the century. It can still happen. But, in copper, the age-old pattern has been disrupted. From Mineral Park in the northwest to Chino in the east and Cananea in the South, a growing number of companies have emerged—large, stable, productive. Southwest copper is truly a mighty industry, accounting for one fifth of world new copper production. In this period of scientific development, changes are fast, often dramatic. But even mining engineers, or possibly more so because they have an intimate knowledge of

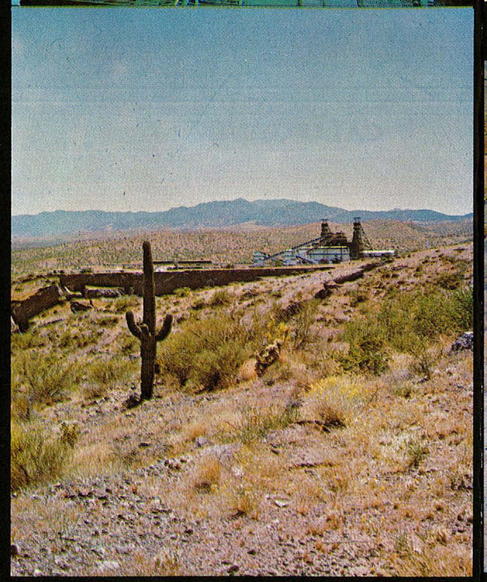




Inspiration pit butts vat leaching plant and shops. Residues from leaching go by rail to concentrator.



Mission pit, left, nearly touches Pima. Old Mineral Hill mine at right middle.



Lavender pit at Bisbee supplies bulk of ore to plant.

Phelps Dodge's Morenci concentrator and smelter.

Cananea pit in Mexico, is 1 of 2 operating.

Top: Bagdad's concentrator receives ore from open pit via enclosed conveyor at left. Headframe is relic of former underground mining.

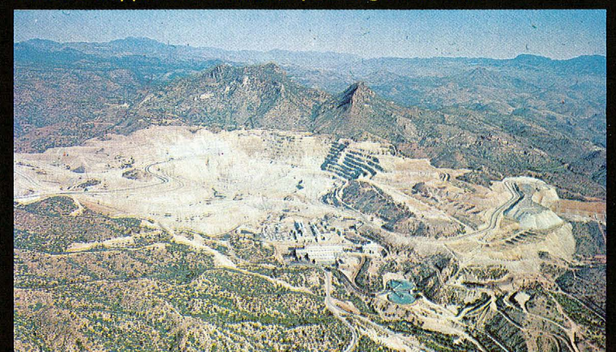
Bottom: Airborne view of Christmas mine shows headframe, 4000 tpd concentrator, tailing area and offices set in rugged Arizona terrain.

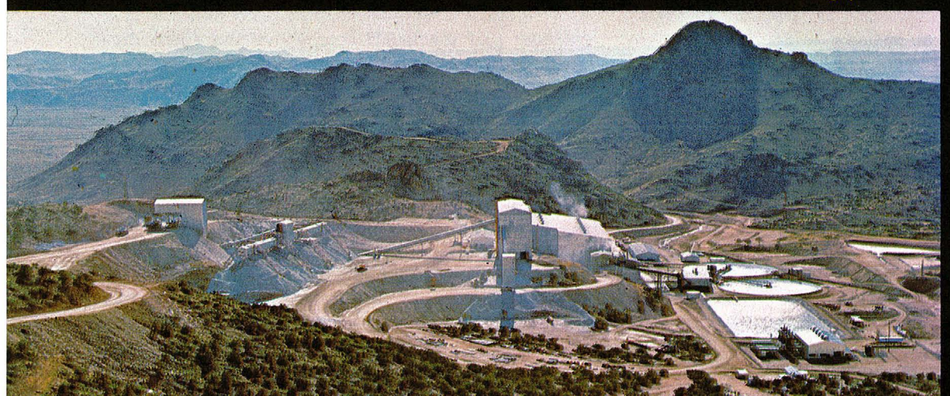
Top: Grinding bay at Mineral Park shows autogenous mills, cyclone arrangement and control panel.

Bottom: San Manuel twin ore shafts and crushing plant are beyond subsidence area.

Ray pit sends ore 23 miles to Hayden reduction works.

Miami's Copper Cities mine, operating since 1954.





Duval's Mineral Park concentrator went on steam in late 1964. See interior view above.

the industry, fail to appreciate the evolutionary changes that have shaped Southwest copper into what it is today.

Southwest copper growth seems to divide into two periods; one from shortly after 1900 until 1930 and a second beginning in 1940 and continuing into the present. The early period was embued by the idea of large scale mining and sparked by development of blockcaving, rail haulage pits and flotation; the second by an equipment revolution that lowered costs in mine and plant and cut sharply into the lead time for plant construction when large amounts of capital would be tied up without financial return. Other important factors have been the recovery of by-product molybdenum and improvements in exploration techniques such as those which permitted the discovery of the Pima district by Walter Heinrichs, Jr. and Robert Thurmond.

In 1900 there was no concentrator bigger than 500 tpd in the region. In this survey the smallest now is 4000 tpd, there are eleven 12,000 tpd or greater and the biggest is 58,000 tpd at Morenci. The old makeshift plants have been superceded by packaged sections that can be expanded at will. Leaching of soluble copper minerals was developed early and has been greatly extended. But it was replacement of vanners and tables by flotation that gave the great boost to copper recoveries thereby bringing in the large low grade porphyries.

Selective mining has all but ceased to be a copper source of consequence in the Southwest. Magma, at Superior, is still mining high grade ore from dwindling reserves. Cananea ceased underground mining a month or two ago. Christmas strives to lower the cut-off by mechanization and is therefore somewhere between a high grade selective mine and the mass producting method of blockcaving. Bisbee is still producing from underground to sweeten the mill heads as well as high grade, direct-smelting oxides. From a tonnage standpoint, the only big underground producer is San Manuel which carries on the great blockcaving methods developed at Inspiration, Miami and Ray. However, if underground mining were in search of a champion, there is none better than San Manuel weighing at 39,000 tpd from underground!

The great source of copper now is from the expanding number of open pit mines. As one engineer described them; "the great waste mines." Since the amount of waste produced is greater than the ore and the planning of waste removal determines the available ore, the expression is quite accurate. Such great pits as Morenci, Chino and New Cornelia started early with open cut methods because of large dimensions that were amenable to rail haulage, then the most feasible system for mass movement of bulk materials. Many of the other mines that are operating today on smaller deposits were made possible by the development of truck haulage. Strides in heavy equipment manufacture have also brought in deposits that suffered from the double handicap of low tenor in copper and the necessity of deep stripping before mining.

Growth of the mines and present status is given in the table accompanying this article. The numerous plant additions described in the status reports on each property which follow bespeak the healthy growth position of Southwest copper.

At the last count, made last summer, there were 45 companies doing exploration work in Arizona. The march of progress goes on. Off by Safford, there are vast reserves of low grade copper in which Bear Creek, Phelps Dodge and United Nuclear have or are performing exploration. But down just south of Pima, a new giant is being exposed for productivity. Now the great difference from the old days can be seen. Southwest copper employs 18,000 men who have founded stable communities in support of an enduring industry.

## Anaconda

South of Pima in the Twin Buttes area, The Anaconda Co. began a giant stripping operation two months ago. It will take 4 years to complete, in which 165 million tons of alluvial overburden will be removed. Anaconda has been testing areas leased from Banner Mining Co. for about 2 years and the Twin Buttes project has been the major outcome.

A 900 ft shaft was sunk and drifts and cross-cuts driven into the orebody to take bulk samples now being tested in a 200-ton pilot plant situated at the old Mineral Hill mine near Pima. Anaconda cannot tell about the flowsheet or size of the plant that will be constructed until tests are complete.

In the meantime, the Company moved swiftly and surely into what may be the world's biggest premine stripping job. Removal of 165 million tons will take the surface down 460 ft to bedrock. The first units of a $4 million fleet of heavy equipment are in operation. Scrapers of 80 ton capacity are being used for the initial cut down to 150 ft. After that a 60-in. slope belt will be added in sections. It will travel at 960 fpm to carry overburden material delivered by scraper and discharged to a truck loading hopper at the rate of 6000 tph. Bottom dump trucks of 100 ton capacity will carry the overburden to the tailing area where it will be used to form the retaining dam. When fully installed the conveyor will be 11,000 ft overall with the main section, a single conveyor 8300 ft long. This is said to be the longest known single overland belt conveyor used in open pit mining in the U.S.

By 1970, Anaconda's Twin Buttes mine is scheduled to be in production.

## Cananea

After 65 years of underground mining, Cananea discontinued subsurface mining this year. Operations are now centered on open pit methods. The Company has some experience at this having already exhausted two pits. Ore is presently being extracted from the Sonora Hill deposit and La Cananea pit has been

(*Continued on page 84*)



A new and expanded cement copper plant is scheduled for completion next year as Morenci resumes heap leaching on a larger scale.

## Copper Queen

Bisbee is the home of the Copper Queen Branch of Phelps Dodge. Underground mining has been in progress continuously in this hill country just north of the Mexican border since 1871 and last year accounted for 44% of the copper produced in the district. However, mine production at Bisbee today comes from the Lavender pit, 6 million tons of ore in 1964, and the underground mines, 749,000 tons. Part of the ore from underground is direct smelting and is sent to Douglas where the Company smelter is situated. An important amount of copper is recovered by heap leaching low grade rock from the mine and making cement copper.

The underground mines practice selective mining of high grade ore. In 1964, sand filling of stopes in conjunction with square setting was introduced using tailing from the concentrator. For the geologist, the underground offers a fascinating game of detection of the discrete, irregular replacement deposits in limestone. Fifteen diamond drills are busy all the time probing for ore. Through three shafts, the Campbell, Cole and Dallas, approximately 750 miners are engaged in working 103 stopes at depths of up to 3233 ft.

Open pit mining is not new at the Copper Queen. From 1923 to 1928, the Sacramento Hill deposit was worked by open pit with rail haulage. In 1954, the Lavender pit was brought in working a lower grade ore but with the advantage of flexible modern truck haulage, high speed drills and electric shovels. The Lavender orebody is a true porphyry copper; the ore being disseminated in a brecciated porphyry intrusive. From high on the crest of the pit, the operation is directed by a dispatcher who, with two radio channels, directs trucks to the proper loading station and maintenance vehicles to where they are needed.

Sitting above the red and gray 50-ft bench walls, is the Copper Queen concentrator. The concentrator was assembled at the pit from several other dismantled units in order to avoid a long uphill haul to the old plant. Like Morenci and New Cornelia, single stage ball milling with spiral classifiers is employed. The ore contains practically no molybdenum and there are no other by-products. The pyrite-chalcocite ratio is 16 to 1 in the plant feed which accounts for the copper concentrate grade being a low 11% to 12% Cu.

The concentrates are roasted prior to smelting in the Company's plant at Douglas. Sponge iron is also made at Douglas for use in precipitating copper from heap leach solutions at the Copper Queen.

## New Cornelia

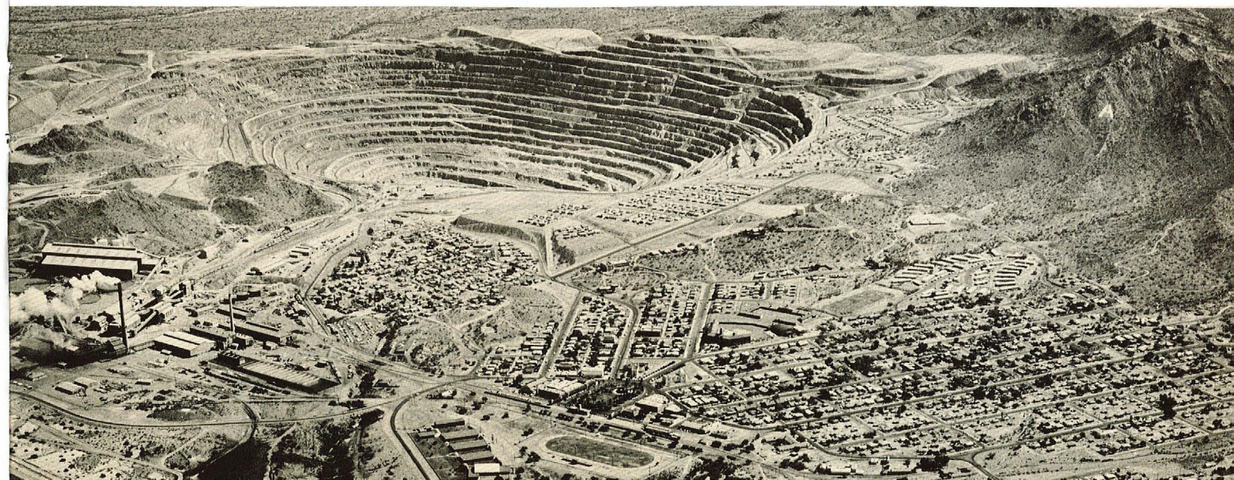
Tucked away in the southwest corner of Arizona, Phelps Dodge's New Cornelia Branch efficiently extracts ore from a circular pit that delineates an orebody 4000 x 5000 ft in cross section and at least 1000 ft thick. Oxide capping on the protore, which baffled the first owners, had long since been extracted and yielded up its copper. Since then, few complications have interfered with uniform development and expansion. There are no side operations or by-products to distract from the primary objective of mining, concentrating and smelting copper sulfides into anode copper.

Ore extraction is controlled to provide a uniform feed to the mill. Drillholes are 12 in. diam and blasting is with ANFO, both being common features in Arizona open pit mining. Shovels are 6- to 9-cu yd capacity loading into railroad cars.

The concentrator was originally designed for two stages of grinding but has been converted to single stage ball milling in closed circuit with spiral classifiers. The rougher concentrate is routed to the regrinding mills prior to further flotation.

A smelter was completed in 1950 eliminating the necessity of shipping 300 miles to Douglas a product that was two-thirds waste. Green concentrate is

*Photograph of Phelps Dodge's New Cornelia Branch at Ajo shows the open pit mine, concentrator and smelter.*



charged direct into the bath, as distinct from the sidewall, of the single reverberatory furnace. Few companies practice bath smelting although practitioners claim advantageous heat transfer by the method.

In 1964, a number of improvements in the concentrator permitted milling at a daily rate of 32,248 tons, a record.

## Miami

Miami Copper Co. came on the scene in the early days of large-scale development of copper in the Southwest, and began producing copper in 1911. In 1960, the Company was merged into Tennessee Corp. However, Miami's well deserved fame rests in the tremendous achievement of mass mining of low grade ores by blockcaving for 49 years.

From 1943 to 1953, the Company mined the Castle Dome orebody by open cut methods. In 1954 it began open pit mining of the Copper Cities deposit. This operation is still in progress.

Leaching was begun in 1939 on underground gob at the Miami mine. After the mine was shut down in 1959, leaching was continued. Dump leaching was also begun in 1951. Today the scope of operations is open pit mining and concentrating at Copper Cities and leaching of the caved area in place at Miami, and dumps at Castle Dome and Copper Cities. About 40% of the copper production is from cement copper.

At Castle Dome and Copper Cities the orebodies are in monzonite porphyry and at Miami they are in schist. At Miami it is necessary to add acid for leaching while at the former two properties there is sufficient pyrite in the rock to make the addition of acid unnecessary. Acid is added to the solution going to the caved area in amounts to allow ½ lb of free acid per ton of final copper bearing solution which keeps the pipes from plugging up with iron salts. The underground drifts and cross cuts are used as solution sumps and weirs set in them permit measuring flow and sampling of solution from various blocks being leached. Although these devices are useful for control of operations, the efficiency of leaching will never be determined because there is no data on the copper content of the gob being leached. At Copper Cities on the other hand, records have been kept of the assays of rock placed on the dumps and could ultimately permit quantitative evaluation of productivity. Nevertheless Miami has contributed a great deal to the techniques of leaching.

The Copper Cities concentrator, which is a straight sulfide circuit without molybdenum by-product plant, was moved from Castle Dome to its present location.

Miami sends its precipitates to Douglas and its concentrates to Inspiration; the copper is returned to the Company for marketing.

## Inspiration

Any mining engineer will enjoy the colorful march of engineering changes that have taken place at Inspiration. A pioneer in blockcaving when mining began in 1915, the Company converted to open pit mining in 1948. Two pits are now being mined, the Thornton and Live Oak; the west extension of the Thornton is being stripped and the Red Hill is in reserve.

When the concentrator was built, it was the first copper concentrator to be designed for flotation as the principal means of copper recovery. In fact, construction was held up a year while the process was tested. Then a few years later a change came; increasing amounts of silicates and oxides in the ore. A new recovery method was needed. When the new method was achieved, not without considerable sweat, it involved vat leaching of the ore with sulfuric acid and ferric sulfate. Later copper was even removed from water used to wash the residues by precipitating it on tin cans. The extraction process was by electrowinning. This was the method adopted in 1926 and it put the flotation concentrator in moth balls. In the book "The Porphyry Coppers," published in 1933, A. B. Parsons speculated as to when, if ever, this mill might be reactivated.

It was 30 years later that the ore character began changing again; nonsoluble sulfides appeared in increasing amounts. In 1957, the old concentrator, after rehabilitation, was back in business only this time it treated residues from leaching for the valuable sulfides. This is the process now being used; leach first, then flotation concentration. Nearly all the ore from the two pits goes through both plants. With less copper solution going to electrowinning, electrolytic cells became available for refining. To this capacity an 80-tank refinery was added permitting the Company to refine all its copper production. Inspiration operates a copper smelter so that copper concentrates from the reactivated mill are treated on the property. Custom ores are also smelted.

A new round of expansion is currently on foot to be completed this year. Mine production is to be upped from 16,500 to 20,000 tpd. To handle the additional tonnage, a new traveling bucket excavator will speed removing residues from leach tanks. It will discharge to a new belt conveyor system, instead of rail cars, that will transfer the residues 1.4 miles to the concentrator. These new facilities are to maintain copper production at its present rate in the face of lower grade ores.

## Christmas

Inspiration looked beyond the Globe-Miami area in 1954 and took options on the Christmas and New Year properties some 37 miles away. The complex sulfide orebody is a replacement deposit in limestone in which the principal ore minerals are chalcopyrite and bornite.

Development of the property was a major operation involving the sinking of shafts to nearly the 1800-ft level and construction of a concentrator and some housing. Production began in 1962 and has been increased each year although the design capacity of the mill, 4000 tpd, has not been attained. Difficulties in mining due to heavy ground, water and a shortage of skilled miners have slowed production. The metallurgy, however, has worked out according to expectations.

Mining at Christmas has "the new look" with mobile drill jumbos and combination loader-haulage units. Sand fill is the major form of ground support. It has been found that stopes must be filled shortly after extraction. Ore is collected and transported to the shaft by rail. The automatic ore hoist is controlled from underground by the skip tender.

The single-section concentrator reduces ore in two stages of crushing followed by rod milling to two ball mills in closed circuit with cyclones. Recovery is by rougher flotation succeeded by two stages of cleaning. Only one concentrate is made which is trucked to Inspiration for smelting.

## Ray

Ray Mines Div. of Kennecott Copper Corp. came into production in the early days of the rise of porphyry coppers. The deposit has stood the test of more than 50 years of large scale mining but not without the climatic readjustments that have distinguished the evolution of porphyry coppers. Mining by blockcaving was practiced for over 40 years; then, beginning in 1955, it was displaced by open pit mining. Today mine production is supplemented by the leaching of underground workings and mine dumps, adding about 20% to copper output. Mining operations are now tapping ores with sufficient molybdenite in them for economic recovery. A plant, similar to the one at Chino, is under construction to begin making a molybdenum concentrate in 1966. Silicate zones containing 0.8% Cu in chrysocolla are now being removed from over sulfide ores. The silicates are stockpiled while leaching methods are investigated. Sulfide ore mined at Ray is separated into two categories, high nonsulfides and low nonsulfides, for milling purposes. The high ore contains 0.08% or more nonsulfides and is treated by LPF; above 25% of the concentrator feed is treated in this manner.

The original concentrator was constructed at Hayden, 23 miles away, near a source of water in 1910. The old section of the mill has a capacity today of 14,000 tpd. In 1960, a major expansion of the concentrator added two sections of 5000 tons each. The plant is well instrumented for operation from control centers. An operational on-stream X-ray spectroscopic analyzer is processing samples from five tailing locations. The Norelco instrument has four channels and 15 sample stations. Although use has been restricted so far to one channel and 5 stations, operators believe that information from the analyzer has assisted in increasing recovery about ½%. About 40 tons of pyrite concentrates made each day are converted to sponge iron for use in copper precipitation in LPF.

The smelter completed in 1958, has a new gas-fired, rotary dryer for concentrates. The smelter makes anodes that are sent to the company-owned refinery in Anne Arundel County, Md.

## Chino

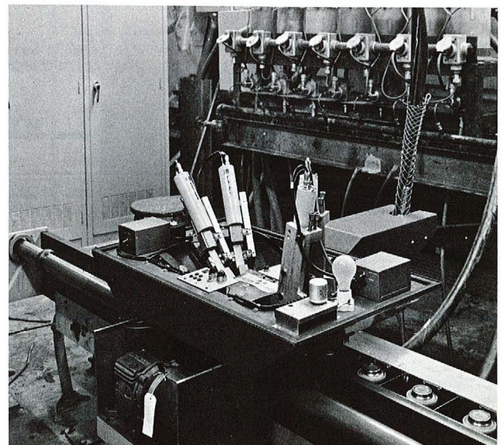
Chino Mines Division, headquartered at Hurley, N. M., is in a district where mining has gone on for centuries and Chino is the granddaddy of the porphyry coppers. Operations moved into the "porphyry copper" scale in 1912 when first production came from the open pit. The only older operating open pit copper mine is Bingham.

Last year was the first full year of all truck haulage at Chino. Although rail haulage has been phased out, the skip inclined hoist removes ore and waste from levels below 5800 ft. At Chino the trend is also to larger haulage units, a dozen of the 85-ton electric wheel trucks are in service. Ore is trucked to a surge pile for blending and transferred to rail cars for shipment to the concentrator at Hurley. Blending is for grade and metallurgical control and such physical characteristics as moisture and hardness. Stripping is currently at an increased rate, and production of cement copper is being expanded to increase overall production of copper by 25%.

Dump leaching, begun in the 20's, has been with water but now experiments are underway with acid. The expansion, requiring an $8 million investment, has been in stages. Solution circulation rate has been stepped up from 8000 gpm in 1964 to reach 15,000 gpm in 1965.

The concentrator reduces ore in four stages of crushing and two stages of ball mill grinding with ball mills in closed circuit with rake and cyclone classifiers. Rougher concentrates are classified and the oversize is reground while undersize is cleaned twice. In the moly plant, copper concentrates are steamed to drive off flotation reagents, and then conditioned with burner oil to float the molly and alcohol frother. Moly rougher concentrates are cleaned, filtered, roasted and then repulped for a further flotation cleaning.

*X-ray analyzer with cover off shows 4 channel counters.*



# 1964 MINE STATISTICS

| | INITIAL PRODUCTION | MINING METHOD | REDUCTION PLANT | ORE & WASTE, *tpd* | ORE, *tpd* | AVG. Cu CONTENT, % | AVG. $MoS_2$ CONTENT, % | ORE MINERALS |
|---|---|---|---|---|---|---|---|---|
| **CIA MINERA DE CANANEA** | 1900 | | | 65,000 | 16,000 | 0.80 | | CHALCOCITE |
| PHELPS DODGE CORP. *MORENCI* | | | | 150,000 to 155,000 | 57,000 to 58,000 | 0.90 | 0.012 | CHALCOCITE |
| *COPPER QUEEN* | | | | OP 78,000 | OP 18,000[3] UG 2500[3] | OP 0.81 | | CHALCOCITE CHALCOPYRITE BORNITE |
| *NEW CORNELIA* | | | | 91,000 | 32,000 | 0.776 | | CHALCOCITE CHALCOPYRITE BORNITE |
| **MIAMI COPPER CO.** | 1911 | [7] | [8] | 40,000 | 12,000 | 0.66 | | CHALCOCITE CHALCOPYRITE |
| KENNECOTT COPPER CORP. *RAY* | 1911 | | | 74,000 | 24,000 | 0.85 | | CHALCOCITE CHALCOPYRITE |
| *CHINO* | 1912 | | | 74,000 | 22,000 | 0.975 | | CHALCOCITE CHALCOPYRITE MOLYBDENITE |
| INSPIRATION CONSOLIDATED COPPER CO. *INSPIRATION* | 1915 | | | 42,700 | 16,500 | 0.898[9] | 0.0124 | CHALCOCITE CHALCOPYRITE |
| *CHRISTMAS* | 1962 | | | 3000 | 3000 | 1.493 | | CHALCOPYRITE BORNITE MAGNETITE PYRITE |
| MAGMA COPPER CO. *SUPERIOR* | | | | 1600 | 1500 | 4.78 | | CHALCOCITE CHALCOPYRITE BORNITE |
| *SAN MANUEL* | 1956 | | | 35,000 | 35,000 | 0.83 | 0.025 | CHALCOCITE CHALCOPYRITE MOLYBDENITE |
| **BAGDAD COPPER CORP.** | 1937 | | | 43,200 | 7000 | 0.76 | 0.03 to 0.05 | CHALCOCITE CHALCOPYRITE MOLYBDENITE |
| AMERICAN SMELTING & REFINING CO. *SILVER BELL* | 1954 | | | 29,000 | 9000 | | | CHALCOCITE CHALCOPYRITE MOLYBDENITE |
| *MISSION* | 1961 | | | 90,000 | 15,000[1] | n.a. | n.a. | CHALCOPYRITE MOLYBDENITE |
| **PIMA MINING CO.** | 1957 | | | 48,000 | 8000 | 1.0 | | CHALCOPYRITE |
| THE DUVAL CORP. *ESPERANZA* | 1959 | | | 30,000 | 12,000 | 0.55 | 0.021 | CHALCOCITE CHALCOPYRITE MOLYBDENITE |
| *MINERAL PARK* | 1965 | | | 30,000 | 14,000 | 0.5 | 0.03 | CHALCOCITE MOLYBDENITE |

| | GANGUE ROCK | MILLING CAPACITY, *tpd* | TOTAL Cu PRODUCTION, *tpy* | Cu IN CONCENTRATES, *tpy* | % Cu IN CONCENTRATES | TOTAL Cu RECOVERY, % | CEMENT Cu, *tpy* | $MoS_2$ PRODUCTION, *tpy* | Cu PRODUCT | PRODUCT SHIPPED TO | EMPLOYEES, WAGES | EMPLOYEES, SALARIED | EXPANDED PRODUCTION, *tpy* | EXPANSION COMPLETION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CIA MINERA DE CANANEA** | QUARTZ SERICITE KAOLIN | 16,000 | 32,900 | 30,000 | 30.0 | 78.0 | 3300 | | BLISTER CAKE | MEXICO CITY | 1450 | 220 | 46,000 | 1966 |
| PHELPS DODGE CORP. *MORENCI* | QUARTZ MONZONITE | 58,000 | 129,406 | 128,600 | 22 or 23 | n.a. | 800 | 350 | ANODES | EL PASO | 1890[5] | n.a. | 139,000 | 1965 |
| *COPPER QUEEN* | QUARTZ PORPHYRY LIMESTONE | 20,000 | 74,033 | 58,200[4] | 11 or 12 | n. a. | 5400 | | ANODES | EL PASO | 2350[5,6] | n.a. | | |
| *NEW CORNELIA* | MONZONITE DIORITE RHYOLITE | 31,000 | 70,818 | 70,689 | 32.76 | n.a. | | | ANODES | EL PASO | 1380[6] | n.a. | | |
| **MIAMI COPPER CO.** | QUARTZ MONZONITE GRANITE PORPHYRY | 12,000 | 32,150 | 19,000 | 32. | 86.6 | 13,000[8] | | CONCENTRATES PRECIPITATES | INSPIRATION DOUGLAS | 468[5] | 122 | | |
| KENNECOTT COPPER CORP. *RAY* | SCHIST DIABASE PORPHYRY | 24,000 | 58,235 | 50,200 | 20 to 22 | 84% | 9040 | | ANODES | MARYLAND | 1003 | 393 | | |
| *CHINO* | QUARTZ DIORITE METAMORPHOSED SEDIMENTS | 22,000 | 81,372 | 56,388 | 22.25 | 82 | 27,421 | 598 | FIRE REFINED BLISTER | MARKET MARYLAND | 1140 | 320 | 100,000 | 1965 |
| INSPIRATION CONSOLIDATED COPPER CO. *INSPIRATION* | SCHIST GRANITE | 16,500 | 48,908 | 19,697 | 37.5 | 86. | 3807 | 490 | CATHODES BLISTER | MARKET | 1305 | 194 | SAME[10] | 1965 |
| *CHRISTMAS* | METAMORPHIC LIMESTONE | 4000 | 12,476 | 12,476 | 27.13 | 89.86 | | | CONCENTRATES | INSPIRATION | 362 | 34 | 18,000 | |
| MAGMA COPPER CO. *SUPERIOR* | SCHIST DIABASE LIMESTONE | 1600 | 17,064 | 17,356 | 23.14 | 96.73 | | | BLISTER | LAUREL HILL, N. Y. EL PASO | 984 | 108 | | |
| *SAN MANUEL* | MONZONITE PORPHYRY QUARTZ MONZONITE | 36,000 | 92,588 | 94,895 | 29.91 | 88.22 | | 2485 | ANODES | LAUREL HILL, N. Y. EL PASO | 1823 | 239 | 100,000 | 1965 |
| **BAGDAD COPPER CORP.** | MONZONITE PORPHYRY | 6000 | 19,631 | 11,878 | 28.0 | 75.0 | 7753 | 267 | CONCENTRATES PRECIPITATES | HAYDEN EL PASO | 345 | 36 | | |
| AMERICAN SMELTING & REFINING CO. *SILVER BELL* | IGNEOUS SEDIMENTARIES | 8400 | 23,600 | 21,200 | 31.0 | n.a. | 2400 | 400 | CONCENTRATES PRECIPITATES | HAYDEN EL PASO | 256 | 50 | | |
| *MISSION* | HORNFELS ARGILLITES TACTITES | 15,000[1] | 52,400 | 52,400 | 28.6 | n.a. | | 14[2] | CONCENTRATES | HAYDEN EL PASO | 479 | 73 | | |
| **PIMA MINING CO.** | HORNFELS ARKOSITES | 8000 | 30,000 | 30,000 | 25.0 | 91.0 | | | CONCENTRATES | EL PASO | 300 | 45 | 35,000 | 1966 |
| THE DUVAL CORP. *ESPERANZA* | QUARTZ MONZONITE WELDED TUFFS LATITE | 12,000 | 21,000 | 19,000 | 25.0 | 86.0 | 2000 | 550 | CONCENTRATES PRECIPITATES | HAYDEN EL PASO | 250 | 95 | | |
| *MINERAL PARK* | QUARTZ PORPHYRY QUARTZ MONZONITE SCHIST | 14,000 | 20,000 | 19,000 | 22 to 25 | 85 | | | CONCENTRATES PRECIPITATES | TACOMA EL PASO | 230 | 79 | | |

OPEN PIT MINE — SMELTER

UNDERGROUND MINE — CEMENT COPPER PLANT

COPPER CONCENTRATOR — ELECTROLYTIC REFINERY

MOLYBDENUM PLANT — VAT LEACHING PLANT

1 CURRENTLY 20,000 TPD

2 MOLY PLANT STARTED LATE 1964, 600-700 TPY POTENTIAL

3 40% UNDERGROUND ORE IS DIRECT SMELTING

4 INCLUDES CONCENTRATES FROM UNDERGROUND ORE

5 INCLUDES DOUGLAS

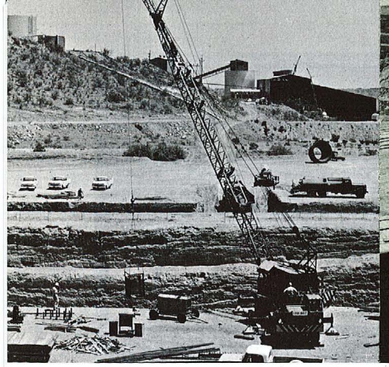
6 WAGES & SALARIED

7 COPPER CITIES

8 INCLUDES MIAMI, CASTLE DOME, COPPER CITIES

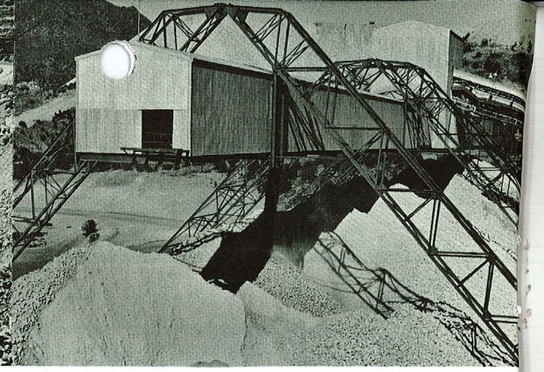
9 0.422% CU OXIDE, 0.476% CU SULFIDE

10 TO TREAT LOWER GRADE ORE—NO INCREASE



*Expanding at Pima*

*Digging at Mission*



*On stream at Mineral Park*

Of interest at the mill are the on-stream X-ray analyzer, a computer being tested, and a test of rubber liners, lifters and grates in a ball mill going into nine months continuous operation.

The smelter produces blister and fire refined copper. There is little gold or silver in the ore to be lost by going the fire refined route to market. A new concentrate-precipitate drier is to be installed at the smelter to reduce moisture in charge to reverberatory.

## San Manuel

Historically San Manuel goes down in the ranks with Inspiration, Miami and Ray as a great underground blockcaving mine. In present day terms it is a phenomenon which exchanges honors with Climax as world premiere blockcaving mine in rock caved and hoisted, although Climax does not have to hoist ore. In our Southwest copper story, San Manuel is second only to Morenci in copper production but it employs the greatest number of people in a mine-by-mine count. Where Inspiration, Miami and Ray were venturing into the unknown to a larger degree, San Manuel had its neck stuck out somewhat considering the lower grade of ore to be extracted.

Development began in 1948 although the property was optioned in 1944 and the presence of the orebody had been known for a good many years before. It came on stream in 1955. It was a large undertaking involving the development of underground mine plant, building of a reduction works, 30-mile railroad and permanent townsite. But after all the orebody boasted a half billion tons of reserves.

Production based on underground personnel averages 61 tons per man-shift, overall it is rated at 38 tons per man-shift.

San Manuel completed an expansion this year that increases ore production from 35,000 tpd to 40,000 tpd. Two sections have been added to the mill to step up milling capacity from 35,000 tpd to 39,000 tpd. A primary crusher was added at each of the two ore shafts. A new reverberatory furnace has been constructed at the smelter.

Besides blister copper, the Company has several valuable by-products; molybdenum gold and silver. Blister copper is sent to Laurel Hill, N. Y., and El Paso, Texas, for refining.

## Magma

Magma's Superior Div. may be reaching the end at the old Magma mine. Begun in 1912, the property has been a substantial high grade mine producing copper and by-product gold and silver. Square set mining has been supplemented with sand fill in recent years. Extreme temperatures in underground workings necessitated the construction of a system for cooling the air. A large refrigeration plant was built about 20 years ago and was added to later. Engineers come from all over the world to study this operation. Vein mining at depths of 3000 to 4900 ft, naturally high temperature gradient abetted by heat from mineral oxidation and the warm temperatures of desert air at the surface created severe conditions for providing adequate control of humidity and temperature at the working faces. The underground plant is in need of modernization but the Company reports that at present there are insufficient ore reserves to justify this expense.

The reduction works are composed of concentrator and smelter. Blister copper is the end product.

## Silver Bell

Interests of the American Smelting and Refining Co. in this area consist of open pit mining and concentrating of copper ores at Silver Bell and Mission near Tucson and a custom smelter at Hayden. The Company has built a new building in Tucson to house its U.S. mining and southwestern administrative offices.

In 1952, stripping was begun on a copper deposit at Silver Bell. Mining was not new to the area, small underground mines having been worked for many years until 1927 when a hiatus began.

Two pits are benched out of the mountain side about four miles apart, the Oxide and El Tiro. The concentrator is adjacent to the Oxide mine. Two types of ore are being extracted, relatively clean disseminated sulfides in igneous rocks with sedimentary inclusions and sulfides in sediments with overlying oxides. The mixed and oxidized material encountered in stripping, containing about 1% Cu or less, is being segregated, pending results of ammonia leaching tests in a 10-ton pilot plant. Content of this material prohibits acid leaching.



The concentrator is being expanded from 9000 tpd to 10,000 tpd by the addition of a sixth ball mill and some new crushing and screening plant.

A well developed dump leaching system has been in operation since 1960, irrigating dumps with water and precipitating on iron scrap. This operation is to be expanded from circulating 1000 gpm to 2000 gpm.

## Mission

Mission open pit mine, now four years old, lies in the afternoon shadow of the waste dump of the Pima mine started some 4 years earlier. The two new mines, Mission and Pima, 15 miles south of the center of Tucson, are within sight of older underground mines of Banner Mining Co., now among the groups leased to The Anaconda Co.

The open pit mines in this immediate vicinity are found in alkaline sedimentary rocks, easy grinding hornfels and tougher argillites and tactites. To develop these deposits, it has been necessary to remove about 200 ft of desert alluvium.

Moving 100,000 tons of ore and waste each day puts Mission among the biggest mines in the country. In this Southwest group, it is topped only by Morenci, although Mission is seventh in total copper production. In mining, Mission uses the biggest shovels, having five with 9-cu yd and one with 10-cu yd buckets. Trucks are 55-, 60- and 65-ton load capacity with one 85-ton truck leased for testing. Automatic lubrication is being installed on all shovels. Samples, posted on maps within 24 hr, permit convenient mine control.

When the modern concentrator was constructed, certain automatic controls were not provided but the design was compatible for incorporating additional such devices. The latest addition installed in January and still experimental, is an on-stream X-ray spectroscopic analyzer complex. It consists of a VXQ 25000 six-channel X-ray made by Applied Research Laboratory of Bausch & Lomb to measure copper and molybdenum concentrations and pulp densities. All measurements are made simultaneously. Samples are analyzed from eight locations taken every 15 or 20 minutes. Points sampled are final concentrates, final tailing and scavenger tailing, two locations each and one each of flotation feed and combined scavenger concentrate. Data are programmed to an LPG 21 General Precision computer with a print-out unit. An oscilloscope is used for programming and trouble shooting.

After exhaustive research, a molybdenite by-product plant was put on stream toward the end of 1964. To feed this plant, copper concentrates are combined with a scavenger concentrate which contains Cu, Ag, Zn and $MoS_2$ values. In the process, concentrates are roasted prior to final flotation. A small tonnage of zinc concentrate is also made as a by-product.

Mission has been operating at slightly better than design capacity since start-up and is currently treating about 20,000 tpd.

## Bagdad

Bagdad is no exception to the rule of being the surviving operating company in an old mining district. In 1941 underground blockcaving was expanded and in 1946 underground work was abandoned in favor of open pit mining. The pit today is 800 ft vertically from crest to floor. Shortly after the pit was developed, a system of crushing the ore with a crusher in the pit floor was devised. Feeders removed the reduced rock from a bin to a 1000-ft belt conveyor which travels in a 17½° incline tunnel to surface and lifts the ore a vertical distance of 300 ft to discharge it to the fine crushing plant. As pits go, Bagdad's is a small one but operates with large dimensions; 50-ft benches are carried and loading buckets are up to 9 cu yd.

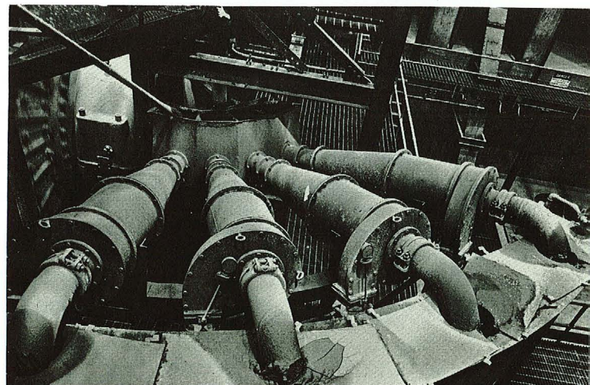
The concentrator mills 6000 tpd and floats the coarsest ore in the Southwest; it is unique in not having a regrind section.

Molybdenite grade, which fluctuates from 0.03% to 0.05% in the ore, is recovered by flotation. A steaming unit has been recently installed to clean copper concentrates of reagents prior to moly flotation. This reduced reagent consumption in the moly plant.

Oxide ores are recovered by heap leaching on dumps. A 200-ton acid plant makes acid from imported sulfur for use in leaching. A long-held ambition of the Bagdad Copper Corp., to produce refined copper at the property is about to be realized. A chemical refining process developed by Chemetals Corp. will be used to convert cement copper to high purity copper metal. The plant, costing $4 million and owned jointly by Bagdad and Chemetals is under construction and is to be completed in 1966. Cement copper will be redisolved in sulfuric acid and precipitated with hydrogen under temperature and pressure. Precipitates will be filtered, sintered and sized. The powder metal is expected to be equivalent to electrolytic copper.

The fact that Bagdad is tucked off by itself in some tough country with poor road connections to the outside would seem to be cause for depression. But quite the opposite appears to be true judging by the jaunty and cheerful appearance of the workers and the camp. There could be several explanations. The nonunion labor force enjoys a 10% par-

*Primary cyclones lie low at Mineral Park.*



ticipation in the profits. The unique chemical refining plant will bring with it the aura of the Space Age. Then, next to most dwellings is a camper, power boat or both ready to roll when the weekend arrives to more salubrious locals such as nearby Lake Mead.

## Pima

Expansion is a way of life at Pima. The Company is in the course of its third since starting operations in 1957. The mill began life at a capacity of 3000 tpd, was increased to 7500 tpd in 1963 and, by mid-1966, will be milling at the rate of 18,000 tpd. The Company is owned 50% by Cyprus Mines Corp. and 25% each by Utah Construction and Mining Co. and Union Oil Co.

A northeast extension of the pit is being prepared that will nearly connect with the Mission pit of American Smelting & Refining Co. The present mine is now 600 ft below the rim and will reach a depth of 720 ft when it is phased out in 1967. The Company is going to larger haulage units, up to 85-ton capacity, with the acquisition of nine electric-wheel trucks.

New crushing facilities and 4 mill sections similar to 2 existing sections and 2 thickeners are to be added to the concentrator. Portions of the old crushing plant will be incorporated into the new crushing plant which includes a new 54-in. gyratory crusher. Crushing is in three stages. A mill section is composed of 1 rod mill in open circuit with 2 ball mills, each in closed circuit with cyclones. Two stage grinding reflects the harder ores found in the Pima district. At some other mines only one stage of ball milling is needed before rougher flotation. Nearly all plants regrind the pulp before cleaner flotation steps. Each rougher flotation section has 6 banks of 10 cells and the cleaning section has 3 banks of 10 cells which services two rougher sections. Scavenger concentrates from the rougher sections and cleaner tails are reground. At present there is no by-product molybdenite plant although research is in progress.

## Esperanza

Duval first entered the copper mining industry when it began production at the Esperanza mine in the Twin Buttes District in 1959. It is now readying its second pit at this location to start production by January 1966. Further west, the Company is doing exploration on a new low grade deposit, the Sierrita, which could also be tributary to the Esperanza mill.

The Esperanza deposit is in quartz monzonite porphyry, welded tuffs and latite; ore minerals are chalcopyrite and chalcocite. Mining was contracted to Isbell Construction Co., but on August 1 the equipment was purchased and Duval began conducting its own mining operations. The first drop cut was made recently but prior to this the loaded haul was downhill.

Waste from the pit is stocked for dump leaching. No acid is added to the water irrigating the dumps. An attempt is made to spray the least amount of solution possible and still wet the surface on the theory of minimum flow maximizing concentration in the pregnant solution. Dumps are leached continuously.

The two section concentrator has one rod mill for two ball mills in closed circuit with cyclones in each section. Overflow from the cyclones goes to rougher flotation, regrind, cleaner and recleaner banks. In the moly plant, copper concentrates are steamed and treated in three stages of flotation after which the molybdenite concentrates are roasted to molybdenum trioxide for shipment to market.

## Mineral Park

Newest star in the Arizona showcase of copper mines is the Mineral Park property of Duval. Exploratory work begun in 1959 led to the conclusion that a deposit containing upwards of 60 million tons of 0.54 Cu and 0.045 Mo could be mined by open pit methods at an overall stripping ratio of approximately 1.5 to 1. During the exploration period, drillholes were checked by underground bulk sampling. Airborne work not only speeded mapping but helicopters were used in locating some drill equipment. The precipitous terrain posed many problems in addition to those for drilling; in particular location of access roads and adequate sites for waste disposal. These dispositions were made before the commencement of stripping. Two years of pre-mine stripping, about 18 million tons, were completed to coincide with concentrator construction and mine production began in November 1964.

Cut-off grade for mining is 0.4% Cu equivalent. All rock having a minimum to 0.4% Cu assay is placed on heap leaching locations. The fact that assay records are being kept on leach dumps as they are formed will provide much valuable information on efficiency of leaching not available at many of the older mines. Advantage was taken of mining on the face of Ithaca Peak to provide a downhill haul to the primary crusher throughout the mining of 70% of the orebody.

The 12,000 tpd concentrator is designed for copper and molybdenum recovery. It is the first one in the Southwest to use single stage wet autogenous grinding. Of the four mills in operation, two were operated autogeneously and two were using balls for grinding. While the autogenous mills were performing at rated capacity, the two using balls were at excess capacity. The cyclone classifiers are placed close to the mills in a position approaching horizontal in order to minimize pump head.

The plant is equipped with centralized electrical control and instrument panels. The instrument panels were delivered as complete units to the plant during construction with marked leads for connections accessible from outside the units.

The moly plant is similar to the one at Esperanza. Copper concentrates are sold to Asarco at Hayden. •



SOCIETY OF

# DUMP LEACHING—AN EXPANDING SOURCE OF COPPER

On this page and the succeeding two pages of photographs attention is focused on the leaching of low-grade copper ore on mine dumps. This practice is expanding rapidly and may ultimately lead to large scale "chemical mining."

Leaching is still in the "art" stage because there is little precise knowledge of the chemistry. Although the practice is not new, it is only recently that intensive experimentation has begun with a view to lifting the process out of the category of a minor sideline and elevating it to an integral part of copper producing operations. For example, at Chino leaching has been dovetailed into overall mining plans by expanding the leaching operation, putting higher grade material on the leaching dumps, and raising the cut-off grade of ore that is sent to the concentrator.

It is quite possible that as experimental work progresses, dumps will be shattered by explosive charges for controlled percolation of solutions that may be injected under pressure and fortified with catalysts and solvents to achieve greater production in a shorter period of time. It is probable that the future will see more leaching in place than at present.

Current leaching practice is an approximation of natural processes, in which old dumps or low grade ore, considered waste, is irrigated with water, in some cases souped up with acid. The water percolates through the dump dissolving copper as it descends until the solution is trapped at the bottom where it drains to catchment reservoirs and is then delivered to tanks where it replaces iron placed there to precipitate the copper. Operating data given in table below show variations in different orebodies.

For all practical purposes, leaching is performed by sulfuric acid and ferric sulfate by oxidizing copper minerals to soluble copper sulfate. Where there is sufficient pyrite in the waste dump, leaching may be performed with natural water, the acid being formed by reaction with pyrite. The general equations given below approximate the reactions which are thought to take place for the minerals that are amenable to the process. Chalcopyrite, an important ore mineral, is not significantly leached by the solutions. Certain bacteria, utilizing iron and copper in their metabolism, are oxidizing agents which catalyze the leaching process. Other catalysts and solvents are coming on the market which may economically increase the efficiency of leaching. Precipitation of copper from the pregnant solution may see a change in method due to the high cost of iron scrap.

Azurite

$$Cu_3(OH)_2 \cdot (CO_3)_2 + 3H_2SO_4 = 3CuSO_4 + 2CO_2 + 4H_2O$$

Chalcocite

$$Cu_2S + 2Fe_2(SO_4)_3 = 2CuSO_4 + 4FeSO_4 + S$$

Covellite

$$CuS + Fe_2(SO_4)_3 = CuSO_4 + 2FeSO_4 + S$$

Cuprite

$$Cu_2O + H_2SO_4 + Fe_2(SO_4)_3 = 2CuSO_4 + H_2O + 2FeSO_4$$

Chrysocolla

$$CuSiO_3 \cdot 2H_2O + H_2SO_4 = CuSO_4 + SiO_2 + 3H_2O$$

Malachite

$$Cu_2(OH)_2 \cdot CO_3 + 2H_2SO_4 = 2CuSO_4 + CO_2 + 3H_2O$$

Pyrite

$$2FeS_2 + 2H_2O + 7O_2 = 2FeSO_4 + 2H_2SO_4$$

| DUMP LEACHING DATA | CANANEA | COPPER QUEEN | RAY | CHINO | INSPIRATION | BAGDAD | ESPERANZA |
|---|---|---|---|---|---|---|---|
| Qty. of sol. circulating, gpm | 1200 | 2100 | 5000 | 11,000 | n.a. | 3300 | 1000 |
| % Cu in dump (range) | 0.2-0.4 | 0.3 | n.a. | 0-0.5 | n.a. | 0.25-0.75 | 0.15-0.4 |
| pH of sol. to dump | 2.75 | 3.5 | 2.1-3.5 | 3.5 | 2.64 | 2.00 | 4.5 |
| $Fe^{++}$ in sol. to dump, gpl | 20.0 | 10 | 1.2-2.4 | 3.6 | 4.96 | 3.80-4.20 | 1.44 |
| $Fe^{+++}$ in sol. to dump, gpl | 2.2 | nil | 0.06 | .1 | 0.50 | .10-.20 | trace |
| Cu in sol. to dump, gpl | 0.15 | nil | trace | .1 | 0.24 | 0.02 | trace |
| pH of pregnant sol. | 2.0 | 2.0 | 2.0-2.5 | 2.5 | 1.88 | 2.3-2.5 | 2.5 |
| $Fe^{++}$ in pregnant sol., gpl | 6.0 | 3.5 | 0-0.96 | 1.0 | 3.34 | .02-.05 | trace |
| $Fe^{+++}$ in pregnant sol., gpl | 12.0 | 3.0 | 0.24-1.80 | 1.0 | 2.73 | 1.80-2.00 | 0.24 |
| Cu in pregnant sol., gpl | 1.50 | 1.4 | 0.24-3.60 | 1.8 | 1.877 | 1.10-1.30 | 1.2 |
| Quantity of acid additions, lb/ton of sol. | none | none | n.a. | 3.3* | 9.82 | 14-16 | none |
| Operng. range of Cu in preg. sol., gpl | 1.30-2.50 | 1.1-2.4 | 0.60 | 1.2-2.4 | n.a. | 1.3-1.10 | n.a. |
| Solution loss, % | 5.0 | 1 | n.a. | 5-6 | 6.65 | 7 | 25-30 |
| Iron consumption, tons/ton Cu ppt | 4 | 2.5 | n.a. | 1.5 | 2.52 | 1.8 | 1.35 |
| Length of dump rest, months | 6 | 12 | n.a. | 4 | n.a. | 2½ | none |

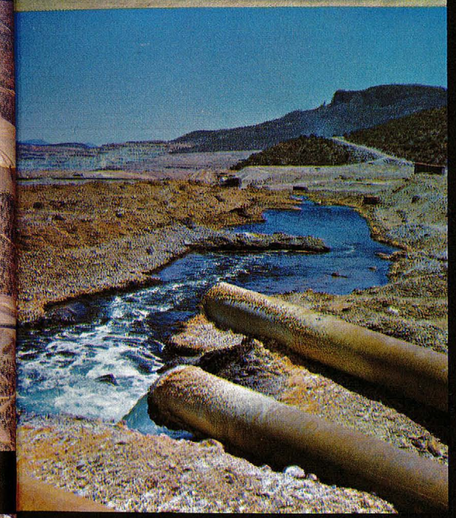
*Testing

Iron stains show up Miami's leach areas.

Copper-bearing solu s collect below Castle Dome terraces

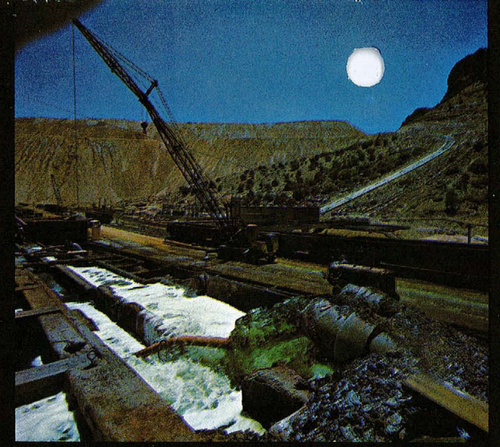
Silver Bell leaching ponds with El Tiro pit behind.

Ponds atop Bisbee dumps in rest p d.

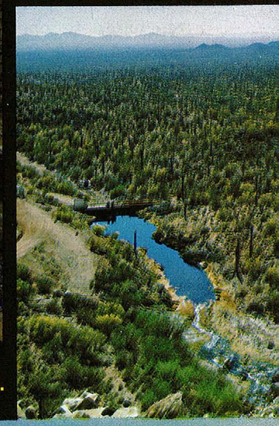


Gravity flow can reduce pumping costs.

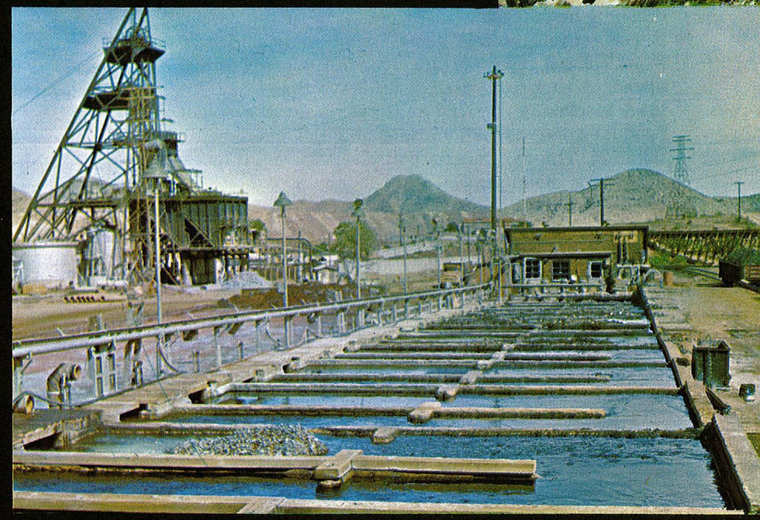
Shredded can supply ahead of ppt/tanks.



Chino's precipitation and piping to leach areas.



Gathering pond for solutions from dumps.



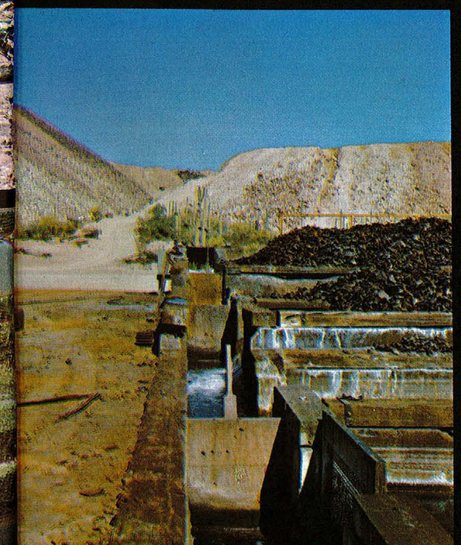
Circulating solutions deposit their copper on iron at Bisbee.

Heavy scrap supplements shredded cans in Bisbee's precipitation.

Top: Esperanza ponds show iron salts accumulations.

Right: Solution distribution lines feed sprays.

Below: Iron, eventually sealing dumps, must be ripped.



stripped and is ready for mining. Another deposit amenable to open pit exploitation is in reserve. Each of the deposits is a distinct porphyry-volcanic contact zone of disseminated secondary copper mineralization.

The Company is in the throws of a 40% expansion. One feature of the expansion is a new ore pass placed in the bottom of La Cananea pit to eliminate the necessity of an adverse ore haul in a pit that will reach a depth of 700 ft. It was necessary to drive a 2500 ft inclined tunnel under the pit, excavate a station to accommodate a 66- x 84-in. jaw crusher and drive a 600-ft raise to the bottom of the pit. Ore will be removed by belt conveyor. Since the portal of the tunnel is at a lower elevation than the existing crushing plant, the tunnel conveyor discharges to another inclined belt that carries the ore 2500 ft to the secondary and tertiary crushing installations.

The concentrator is being expanded from 16,000 to 22,000 tpd capacity. One rod mill is being added ahead of each pair of ball mills. Cyclones will be used to classify the rod mill discharge, the spigot product going to ball milling and the overflow to flotation. The ball mills are also served by cyclones. Scavenger flotation cells are being added. These plant additions, representing a nominal 40% increase in milling rate are hoped to increase copper production in practice by one half.

There is a well developed dump leaching set-up at Cananea. Ferric sulfate which is naturally present is used for dissolving copper and no acid is added. The concentration of ferric sulfate reaching the precipitation plant must be controlled because it consumes iron. Some solution bleeding is done in an attempt to reduce build-up of iron salts. To more completely prepare the dumps for solution, they are alternately leached and rested.

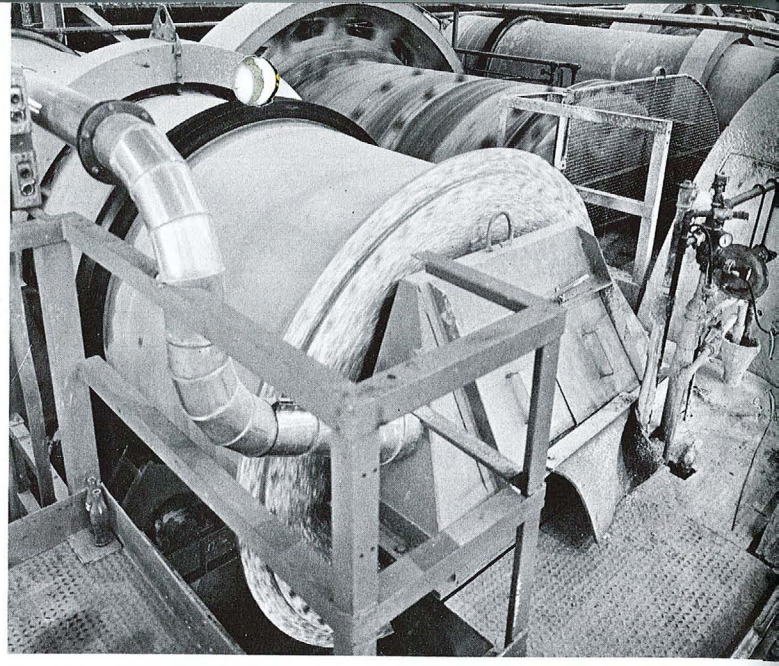
The Cananea product is blister copper cakes that are sent to Mexico City.

As is true at most foreign camps, the Company must operate extensive maintenance shops for rebuilding equipment. Maintenance and motor-pool employees total 360 of the 1670 payroll. Power is generated in the Company's gas-fired steam power plant which has a generating capacity of 38,000 kw.

## Morenci

In the exciting period of copper development that surged in Arizona after the turn of the century, Morenci was the first copper producing district of consequence. Until 1932, production was from underground mining operations and at this time all underground mining was discontinued. Stripping operations on the now famous pit began in 1937 and the new copper concentrator was ready for production in 1942.

Morenci and New Cornelia are the only remaining rail-haulage pits in the Southwest copper industry. At Morenci a double entry ramp system is used with approximately two trains serving each operating shovel. Trains are dispatched according to shovel requirements rather than by assignment to shovels.



*New leach-precipitation drum in operation at Morenci.*

Ore cars are 80-ton nominal capacity drawn by 1750-hp and 1850-hp locomotives. Some older 1200-hp engines are also in service. Truck haulage is utilized as the need arises for stripping operations above operating rail haulage levels and for making drop cuts. Through 1963, 917 million tons of ore and waste have been removed from the pit of which 607 million tons were ore.

The original concentrator was 25,000 tpd milling capacity, increased to 45,000 tpd two years later or in 1944. Nominal milling capacity today is 58,000 tpd, achieved by 30 parallel ball mills of approximately 2000 tons capacity each operating in closed circuit with a spiral classifier.

During the 30's, when a method for concentration of the projected open pit orebody was being considered, leaching was in the running because of the rapid oxidation characteristics of the chalcocite ore. The decision was made to follow the uncomplicated sulfide-flotation route. Presently, an LPF adjunct to the mill went on stream and is expected to recover an additional 1.25 lb of copper per ton of feed from the oxide copper previously going out in the tailing. As a result, total copper production will be increased from 7% to 10%.

In the process, crushed concentrator feed is leached with sulfuric acid to dissolve copper and then precipitated with a unique sulfide precipitant to convert it to a mixture of cupric sulfide and sulfidized metallic copper particles. Both these reactions proceed almost simultaneously in a revolving drum, one, placed beside each of the 30 ball mills. The precipitated copper continues with the sulfide copper through grinding circuit to flotation where it is recovered. As the total ore emerges from the leaching drum it is neutralized with lime to alkaline flotation range.

The LPF addition necessitated the construction of an acid plant, additional capacity for the lime plant and a precipitant manufacturing plant, which consumes pyrite, lime and coal as raw materials.

A concentrate roasting plant has also been installed at the smelter.

# STORIES

# OF

# DUVAL'S ESPERANZA MINE

# ASARCO'S MISSION UNIT

ARIZONA DEPARTMENT OF MINERAL RESOURCES

Frank P. Knight, Director Frank J. Tuck, Statistical Engineer

Mineral Building, Fairgrounds, Phoenix 7, Arizona

December, 1961

December, 1961

# INTRODUCTION

The "Stories of Arizona Copper Mines", published by this Department in 1957, covered the "Big Low-Grades and Bonanzas" developed up to that time. Since then, Duval Sulphur and Potash Company's "Esperanza Mine" came into production in March of 1959, and the American Smelting & Refining Company's "Mission Unit" in August, 1961.

This Department has therefore taken this means to record the story of these two new mines, which may serve as a continuation of the "Stories of Arizona Copper Mines".

Arizona Department of Mineral Resources

# STORY OF DUVAL'S ESPERANZA MINE IN PIMA COUNTY, ARIZONA *

Until 1959, the name of the Duval Sulphur and Potash Company was associated with the production of sulphur in Fort Bend County, Texas, and of potash at Carlsbad, New Mexico, but in March, 1959 the Company became a large producer of low grade copper ore in Arizona, and since that time its Esperanza Mine, some 33 miles southwest of Tucson, has joined the ranks of the "Arizona Porphyries".

Test drilling at the Esperanza property began in May, 1955, and during the following two years 88 churn drill holes, 34 diamond drill holes and 2,100 feet of tunnels and raises were completed.

The old New Year's Eve mine made the first actual penetration into what is now Duval's Esperanza property. The original workings were reactivated briefly during the years of World War II. This recent effort failed to develop sufficient high grade ore for profitable small mine operation, even though traces of molybdenum mineralization were found.

By late summer of 1954, local mine interests had accumulated the 150 mining claims which cover the present ore body and adjacent areas.

Dr. Harrison A. Schmitt, consulting mining geologist, accompanied by the head of Duval's exploration team, first set foot on the Esperanza in the fall of 1954. Dr. Schmitt immediately recognized the potential of the property and contract discussions with the claim holders were begun at once.

Test hole No. 1 was started on May 8, 1955. Two years of intensive work in drilling, mapping, sampling and assaying were required before final appraisal and the decision to proceed could be reached.

Detailed metallurgical studies were conducted concurrently. Process development proceeded from the laboratory to a pilot plant. Basic flowsheet

---

* The source of most of the material for this story was a brochure issued by the company in May of 1959.

drawings were prepared for the recovery of both copper and molybdenum.

A construction contract was awarded to Stearns-Roger Manufacturing Company on June 29, 1957 for the concentrator and related facilities. Pre-mining stripping operations began in November of 1957 by the Isbel Construction Company to remove 6 million tons of barren overburden to expose enough of the ore body so that routine bench mining could proceed. Both stripping and construction were completed by late February of 1959 and the first ore was fed into the process equipment.

## Mining Practice

The ore body as outlined by the drilling program is roughly contained in a Sierrita Mountain foothill which is some 350 feet high and 4000 feet long. The ore body lies chiefly in three types of rocks: (1) a series composed largely of graywacke, arkose and conglomerate-breccia, (2) an intrusive andesite, and (3) a quartz monzonite porphyry. The known ore is an enriched blanket averaging about 130 feet in thickness covered by an average of 95 feet of overburden.

The mining practice is the standard bench operation typical of open pit mines. 9-inch blast holes are drilled along the bench face and loaded with ammonium nitrate explosive-with fuel oil mixture. After detonation, the shotdown face is loaded with 5 cubic yard electric shovels into 40-ton diesel trucks.

The nature of the deposit is such that waste rock must be continually removed to expose fresh ore for mining. The ratio of waste removed to ore mined, generally referred to as stripping ratio, will average about 1 to 1 over the life of the ore body. Thus, for the daily 12,000 tons of ore hauled to the concentrator, a like tonnage of waste goes to the dump. Bench heights are 35 feet with 0.5 to 1 slopes.

Careful assaying, mapping and mine planning are necessary to assure continuous daily production of ore, a low stripping ratio and a minimum loss of ore values to waste.

## Milling Practice

### Crushing

Mine run ore contains finely disseminated crystals of the black copper sulphide mineral called chalcocite along with lesser percentages of the so-called oxide minerals of copper. The ore itself varies in grade from 0.65 to 0.85 percent copper. Also present in addition to the copper minerals is a significant quantity of the molybdenum sulphide mineral called molybdenite. Molybdenum metal concentration is expected to average 0.022% throughout the ore body.

The first concentration problem is size reduction to unlock the mineral crystals from the mother rock and to reduce such crystals to dimensions suitable for flotation.

The mining method produces broken rock up to 4 feet in size. Primary crushing of this material is done by the 48 inches gyratory crusher which is housed in its seven-story building.

The primary crusher reduces the ore to a maximum size of 7 inches. Further size reduction is carried out in two stages by similar gyratory crushing machines of smaller sizes. Dry crushing ultimately reduces the particle size to less than 3/4 inch. This material is transferred by belt conveyors to the 20,000-ton storage bunker at the head of the concentrator. Throughout the crushing system dust collectors are used at all crushing and transfer points to prevent loss of fines and eliminate a serious house-keeping problem. Electronic instrumentation has been used throughout the system to provide maximum capacity overload.

### Grinding

Further size reduction to less than 1/100 of an inch is accomplished in large wet grinding mills. Crushed ore from the 20,000-ton storage bunker is fed to two of the world's largest rod mills at the rate of 250 tons per hour each. Sufficient water is added with the feed to give the resulting pulp fluidity and the desired pulp density or percent solids.

The rod mill discharge is split to two ball mills wherein further and final size reduction is accomplished. The ball mill discharge is pumped with a slurry pump to the primary cyclone separators. These devices make a size classification and send the ore of desired fine size forward to flotation and return any oversize back to the ball mills.

These grinding mills have outside diameters of thirteen feet three inches. The rod mills are sixteen feet long and each is charged with 130 tons of steel rods. The ball mills each carry 150 tons of steel balls. These tonnages of grinding media are maintained by periodic additions equal to the weight of metal which is worn away in the grinding of the ore. The re-charging averages some eight tons of steel per day and is one of the major costs in the milling operation.

Here again in the grinding section the use of recording and control instrumentation is evident. These sensitive instruments keep a constant vigil on each phase of the section to assure maximum efficiency and reliability.

## Flotation

Having accomplished the desired size reduction, next begins the important task of separating the valuable minerals from the mother rock.

The primary cyclone discharge enters the distributor-conditioners where the flotation reagents are added. These reagents, ignoring the gangue rock, selectively seek out the valuable minerals and are adsorbed on their surfaces. Once adsorbed they effectively resurface the mineral and alter the surface characteristics to one having a water repellent, air-loving nature.

From the conditioner-distributor the reagentized slurry enters the long trough-like flotation cells. The cells provide agitation such that the mineral particles are gently suspended in the water carrying medium. Air is introduced into each cell below the agitator resulting in a multitude of small bubbles rising through the suspended slurry. The reagentized minerals are attracted to

the bubbles and floated to the surface of the cell. Additional reagents are added to provide a stable froth on the cell surface wherein the floated mineral collects and overflows the cell lip. Additional flotation steps are required to further concentrate the flotation product to the desired concentration - usually from 25 percent to 35 percent copper. The mother rock, unaffected by the action of flotation, moves from cell to cell down the series and ultimately discharges out the bottom of the last cell in the row.

## Molybdenum Recovery

Both of the principal products, copper and molybdenum, plus a small amount of silver, are concentrated in the flotation product. The problem of separating molybdenum is one of destroying the reagents used initially to make the copper molybdenum minerals float and then reconditioning for specific molybdenum flotation.

This is accomplished by first filtering the reagent contaminated mill water from the combined concentrate and repulping with fresh water. The resulting slurry is fed to a giant pressure cooker wherein the reagents coating the minerals are distilled away. To the then sterile pulp is added a collecting reagent selective for molybdenum and flotation is again conducted. The froth product from this step is the molybdenum sulphide, while the tailing is the final copper product.

The molybdenum sulphide concentrate is then fed to the ten-hearth roaster where it is oxidized to the oxide form for sale to the metals trade.

## Copper Concentrate Shipment

The final copper concentrate, the unfloated mineral from the molybdenum flotation section, is filtered and conveyed by belt conveyor to the storage house adjacent to the mill building.

Each day the accumulated tonnage is weighed into trucks for transport to the railhead some eleven miles away from the plant. At the siding the trucks dump into open gondolas for shipment to the custom smelter.

This concentrate, sold as such to the smelter, contains between 25 and 35 percent copper and three to four ounces of recoverable silver per ton.

## Tailing Disposal

The mother rock waste leaving the plant presents the dual problem of ultimate disposal and water reclamation.

The magnitude of the disposal problem can be appreciated when one considers that nearly the entire 12,000 tons per day of finely ground plant feed must be disposed of every day for the life of the property. Obvious too, is the fact that if the water used to transport this waste away from the immediate vicinity could be salvaged for reuse, a tremendous saving in both money and a precious natural resourse would result.

An adroit solution to these problems has evolved through the years. In essence, it takes advantage of a gravity flow tailing line to provide feed to the tailing cyclones. The cyclones discharge their relatively coarse underflow on the top of the growing dam, and there compact. The relatively fine, clayey overflow discharges inside the dam. The fines settle out making a water tight seal against the dam and the clear water forms in a back lake for reuse in the milling process.

## Instrumentation

Various types of industrial instrumentation have been used throughout the entire processing facility. Wherever possible the tasks of operating personnel have been replaced by electronic-pneumatic recording and control devices. In addition to providing process records for metallurgical study, these controlling instruments sense process upsets imperceptible to human beings and constantly

react to maintain desired equilibrium. In this manner the duties of the operating personnel have been largely reduced to that of an attendant. Each section of the plant has a central station where both power and process controls have been assembled in consoles and graphic panels. The scope of each operator is expanded without sacrifice of either efficiency or reliability.

One example of applied instrumentation is in the operation of the water system:

## Water System

A water supply for the Esperanza property was developed on the western edge of the Santa Cruz River Valley about 6 miles east of the mill site. Three 16 inch wells, located about 1,500 feet apart, were sunk to depths ranging from 650 feet to 900 feet. Water is pumped from these from a depth of 350 feet to a gathering tank, thence through a 16 inch steel pipe line for 30,000 feet to the mill system. The total lift from water table to the mill storage tanks is about 1,150 feet. Level control devices at the plant sense the process need for more or less fresh water. An automatic control signal is sent by radio to the water field where unattended pumps correct for the need.

Another example of the use of automatic control is in the molybdenum recovery section. Here a combination of flow, density, level, pressure and temperature measurements are integrated to maintain the desired metallurgical condition in the pressure cooker. The attendant operator functions only when process upsets and mechanical failures are beyond the range of the control devices. In such an event both light and sound alarms function to alert the operator.

## TYPICAL METALLURGICAL DATA *

| | |
|---|---|
| Tons milled per operating day ..... | 12,000 |
| Operating time, % of possible ..... | 95.0 |
| Copper Recovery: | |
| % of sulphide copper ..... | 92.0 |
| % of acid-soluble copper ..... | 60.0 |
| % of total copper ..... | 83.0 |
| Molybdenum Recovery: | |
| Primary recovery from ore ..... | 80.0 |
| Secondary recovery from Cu-Mo concentrates ... | 90.0 |
| Overall recovery ..... | 72.0 |
| Grade copper concentrate: | |
| % Cu ..... | 25.0 |
| % Fe ..... | 25.0 |
| % Insol. ..... | 14.0 |
| Grade Molybdenum Trioxide Calcine: | |
| % Mo ..... | 58.6 |
| % $M_oO_3$ ..... | 88.0 |
| % Cu ..... | 0.25 |
| % Fe ..... | 2.5 |
| % Insol. ..... | 8.0 |
| % S ..... | 0.25 |

* Reported in "Mining Engineering", November, 1961 by C. H. Curtis, Asst. Resident Manager, Duval Sulphur & Potash Co., Tucson, Arizona.

## OPERATING STATISTICS *

| | |
|---|---|
| Power Consumption ..... | KWH/Ton |
| Crushing ..... | 1.4 |
| Wet Grinding ..... | 12.8 |
| Flotation ..... | 4.2 |
| Water ..... | 0.9 |
| Molybdenum Recovery ..... | 0.9 |
| Total ..... | 20.2 |
| Reagent Consumption ..... | Lbs./Ton Ore |
| Lime ..... | 3.5 |
| Potassium ethyl xanthate ..... | 0.025 |
| Potassium amyl xanthate ..... | 0.005 |
| Methyl amyl alcohol ..... | 0.10 |
| Stove oil ..... | 0.03 |
| Sodium ferrocyanide ..... | 0.05 |

* Reported in "Mining Engineering", November, 1961 by C. H. Curtis, Asst. Resident Manager, Duval Sulphur & Potash Co., Tucson, Arizona.

## Employment

Mining is done under contract by Isbell Construction Company of Reno, Nevada. About 100 men are employed by Isbell on ore and waste.

About 235 men are employed at the present time by Duval Sulphur and Potash Company. Of these about 80 men work in the mill, and 155 men in the shops, warehouse and offices.

The Company spent about $20 million for exploration, development, stripping, and plant construction. The mine was named Esperanza, which is Spanish for Hope, by the Company's late President, Mr. George F. Zoffman.

The president of the Company is Mr. W. P. Morris, and the Company's office is in the Mellie Esperson Building at Houston, Texas. The Resident Manager is Mr. George E. Atwood, the Administrative Assistant is Mr. Ben G. Messer. There are excellent colored photos of the Company's Arizona property in the 1959 Report to Stockholders.

Production of the Esperanza Mine since inception in March of 1959 was as follows:

| | Tons Copper Ore Mined | Pounds Copper Recovered |
|---|---|---|
| 1959 | 3,104,530 | 34,106,798 |
| 1960 | 4,245,762 | 50,735,060 |

# THE STORY OF ASARCO'S MISSION UNIT *

The new Mission Unit of American Smelting and Refining Company, which commenced operations on August 1, 1961, is now producing at its rated capacity of 45,000 tons of copper a year. This open-pit copper mine is located 15 miles southwest of Tucson, Arizona.

The Mission property was first optioned by Asarco in 1953 and exploration work undertaken. Pre-mine stripping and construction of a concentrating mill were commenced in August of 1959. This work was completed in less than two years at a cost of approximately $34,000,000, representing a substantial saving in time and money over original estimates.

During the stripping period, a total of 45,215,000 tons of waste over-burden was removed and 1,178,000 tons of ore were produced and stockpiled. The mill was designed to treat an average of 15,000 tons of ore per day, or 5,400,000 tons per year, from which approximately 165,000 tons of copper concentrates containing 45,000 tons of copper will be recovered.

These concentrates will be smelted at Asarco's Hayden, Arizona, and El Paso, Texas, plants. The resultant blister copper will be refined at its Baltimore and Perth Amboy refineries.

## Geology

The Mission Unit of American Smelting and Refining Company lies in Pima County, Arizona, about fifteen miles southwest of Tucson. The area to be mined by open pit methods will cover about 250 acres, the maximum pit dimensions being approximately 2500 x 5000 feet.

The deposit lies within an extensive zone of porphyry copper type alternation-mineralization in sedimentary rocks which have been folded, faulted and intruded by monzonite porphyry. Disseminated pyrite and chalcopyrite pervade all rocks within the zone, but ore-grade copper mineralization occurs principally along certain of the sedimentary horizons, forming gentle to moderately steep-dipping tabular bodies ranging from a few feet to over 200 feet in thickness.

In the mineralized area, bedrock is overlain by approximately 200 feet of gravel wash. All but the lower 20 to 30 feet of this gravel is loosely consolidated and amenable to low-cost mining methods. In contrast, the lower portion is tightly cemented forming a hard tough layer immediately over the mineralized bedrock.

From the standpoint of structure as well as mineralization, the ore body may be divided into three parts: east, central and west. On the east, where the grade is somewhat higher than the average, the ore-bearing beds are bounded in part by a series of northerly striking faults on which considerable movement has taken place, resulting in a horst-graben or vertically displaced structure. These faults are pre-mineral in age and have served to some extent to localize stronger copper mineralization. They also represent sharp ore-waste contacts, as, for example,

---

* The source of the information in this story is a brochure published by the American Smelting and Refining Company in November, 1961.

the east fault which forms the near-vertical ore limit on the east. In the north central part of the deposit, barren limestone lies at relatively shallow depths and ore grade mineralization is confined for the most part to a thin, irregular layer just above the limestone. On the west, the structure is less complex and ore mineralization is much more continuous along the bedding, but the grade is generally lower than the average for the deposit.

Although there is little variation in the ore minerals (essentially chalcopyrite with minor bornite in the primary zone, and chalcocite with some oxide copper in a thin, discontinuous secondary zone), the gangue is variable in mineralogical composition, depending on where it is found in the several sedimentary formations. Tactite (composed mainly of garnet) and hornfels (composed of various lime-silicates) comprise two of the three major ore types. The third type, argillite or siltstone is generally lower in copper content than the first two.

## Development

In September, 1954, drilling was begun in part of the area. Three years later, drilling was begun in the remainder of the area. In all, 346 holes were drilled; their total length being about 200,000 feet. In February of 1958, work was started on a shaft, drifts, crosscuts and raises in the ore zone. Approximately 2300 feet of underground work was done to check interpretation of diamond drilling and obtain bulk samples for pilot mill tests. Pilot plant testing of samples were carried out at the University of Arizona to obtain metallurgical data for mill design.

## Mining

It was necessary to remove about 200 feet of gravel. Several possible methods for removing this gravel overburden were studied. These included shovels and trucks, belt conveyors with drag lines, German-type excavating wheels and scrapers. The first was finally considered best because it offered maximum flexibility for placing waste in disposal areas and promised full life use of all major equipment.

The pit was designed with 50-foot benches in gravel and 40-foot benches in rock with main haulage road grades of 7%. The working slope of the pit averages 23 degrees. The ultimate slope will be 37 degrees or 1.33 to 1 in alluvial material and 45 degrees in rock, plus allowance for haul roads. Pit plans were laid out to keep at least 3000 lineal feet of ore exposed on working benches which makes the daily production rate five tons per foot of ore bench. Pre-mine stripping was planned in excess of 46,000,000 tons.

## Principal Mine Equipment

5 - Electric shovels - 9 yard. 1-10-yard.
29 - Ore trucks - 55 ton.
3 - Rotary drills - 2-12¼ inch; 1-9 inch.
Main blasting agent, ammonium nitrate.

## Milling

The Company's engineers planned a mill for treatment of 15,000 net tons of ore of average hardness per day, after allowing for down-time. The annual rate of 5,400,000 tons is based on 360 days at normal capacity.

Western Knapp Engineering Company was awarded the contract for construction of the crushing and milling facilities.

The primary crusher is a 54-inch gyratory with a grizzly for each of two truck dumping points. Further crushing is done in two stages with two 7-foot Symons standard cone crushers and two 7-foot shorthead Symons crushers. The final stage is in open circuit, but the plant is designed so that this can be closed merely by adding two screens.

The grinding circuit consists of four rod mills followed by eight ball mills. Because the ore varies greatly in hardness it was impossible to design grinding circuits to meet extremes at the rated tonnage so the over-all design was based on average hardness.

The rougher flotation time of ten minutes gives a good metallurgical recovery of the copper values of the ore, which are mostly in the form of chalcopyrite. Water is returned from the tailing pond and from two 275-foot tailing thickeners to keep the use of fresh water to a minimum.

## Principal Milling Equipment

1 Primary crusher - 54" gyratory
Intermediate ore storage pile - live capacity, 20,000 tons
2 Secondary crushers - 7' standard Symons cone
2 Tertiary crushers - 7' short head Symons cone
Fine ore bins - live storage capacity, 15,700 tons
4 Rod mills - $10\frac{1}{2}$' x 15'
8 Ball mills - $10\frac{1}{2}$' x 15'
320 Flotation cells - Fagergren
2 Regrind ball mills 7'7" x 13'
2 Disc filters - 8'10" diameter
2 Tailings thickeners - 275' diameter
Mill water tank - 600,000 gallons capacity
2 Middlings thickeners - 125' diameter
1 Concentrate thickener - 90' diameter

## Water Supply

Water is supplied from wells located near the Santa Cruz River about three miles east of the mill. The estimated consumption after return water from the tailings area is available, is 2,500 gallons per minute. Maximum requirements prior to that time are approximately 3,500 gallons per minute. Three wells 20 inches in diameter were drilled and each equipped with a 1600 gpm submersible pump. A 100,000 gal. gathering tank at wells, and 17,000 feet 18" pipe line discharges into a 600,000 gal. receiving tank at the mill.

## Power Supply

Electric power for the operation is supplied by the Tucson Gas, Electric Light and Power Company over a 138,000 volt transmission line constructed from their Tucson facilities, stepped down to 4,160 volts at the mill substation.

## Transportation

A six mile branch of the Southern Pacific Railroad was constructed to the property from its Tucson-Nogales line to handle shipment of concentrates and incoming freight.

## Conclusion

From the first clearing of the desert's scrubby brush to the first flow of production required less than two years, bettering the estimated time by more than six months.

The Chairman and President of Asarco is J. D. MacKenzie with general offices at 120 Broadway, New York 5, N. Y. The manager of Asarco's Southwestern Mining Department is T. A. Snedden, with offices at 813 Valley National Building, Tucson, Arizona.

Arizona Department of Mineral Resources December, 1961

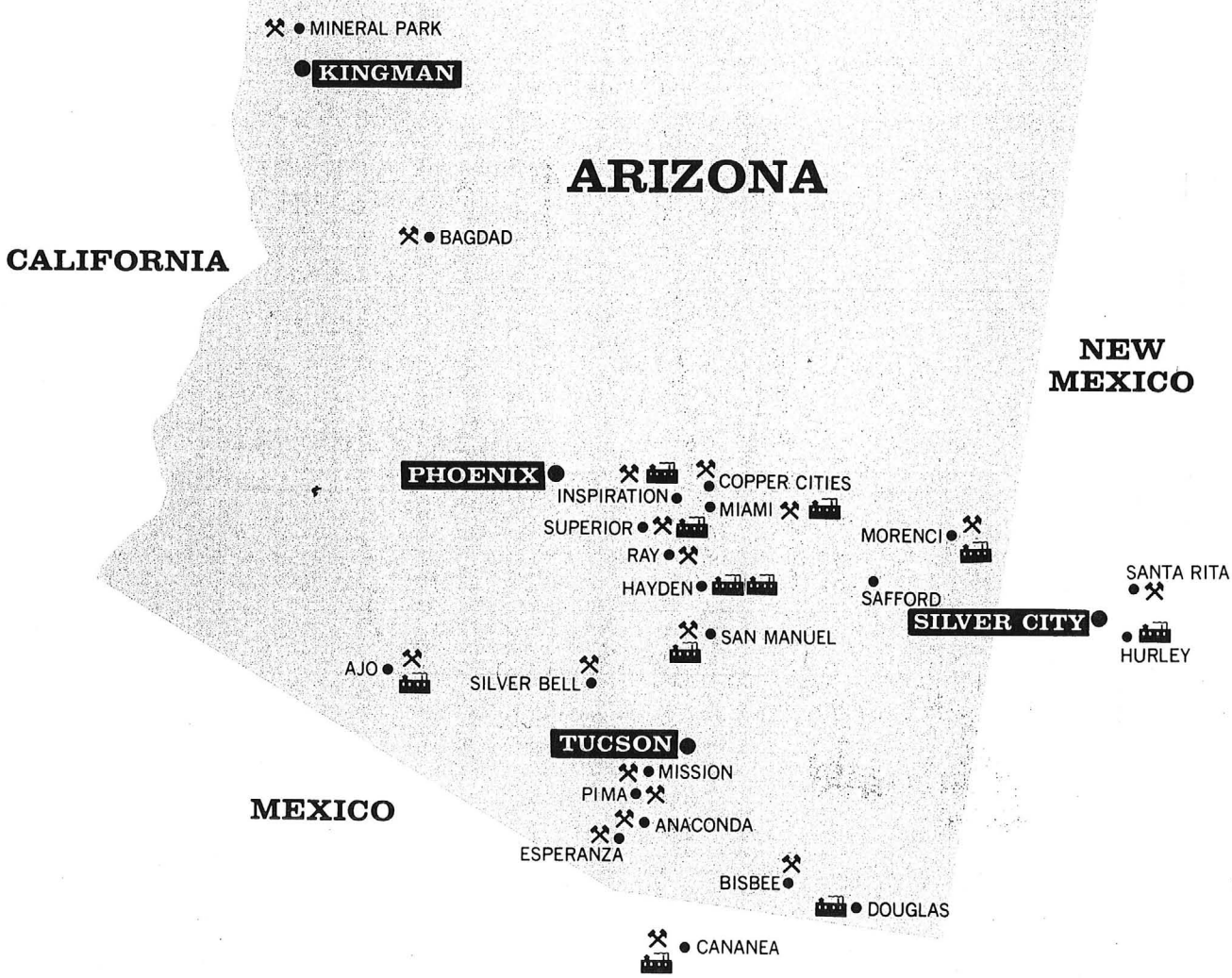
Newmont Corp.

# SOUTHWEST COPPER

# A POSITION SURVEY

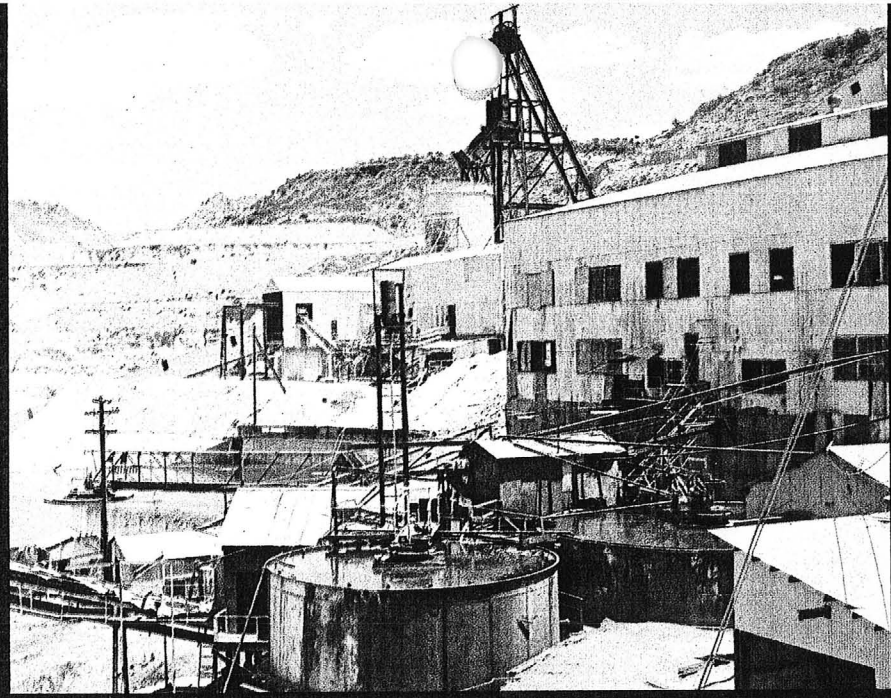

## BY JOHN V. BEALL

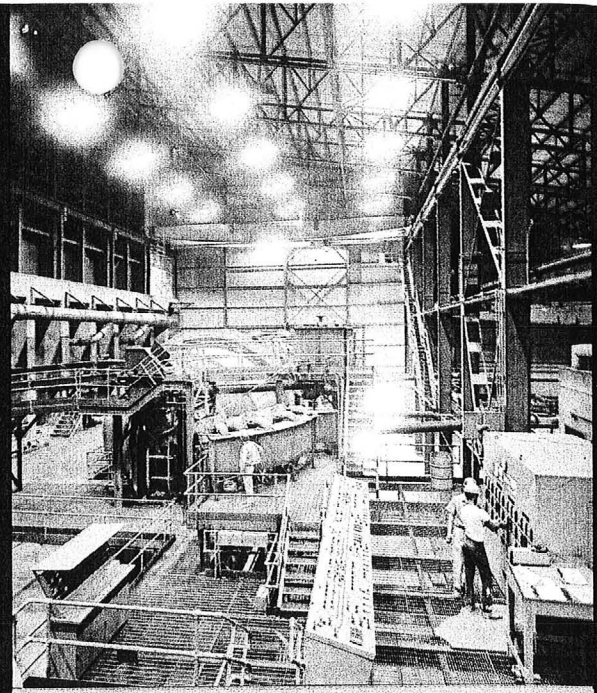
PHOTOGRAPHS BY WILLIAM F. HADDON

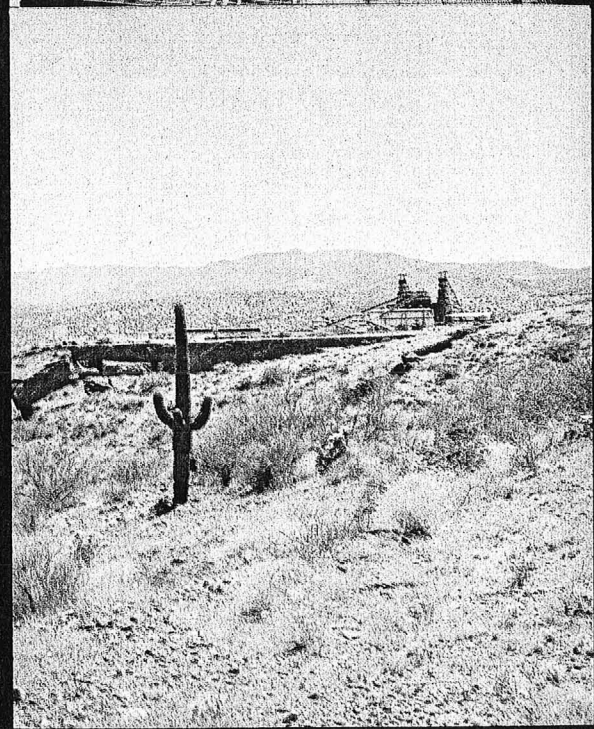




When the mineral seekers came, they brought romance, excitement and, too often, transitory riches. It has been so for uncounted centuries. While the rich ore lasted, living was high and money flowed—mostly out of town. The whole creation was like a circus. The headframe went up like the center pole of the big top. The reduction works was an ingenious affair; an opportunity for self-expression by the mining engineer on the job. When the high grade gave out or the bottom dropped out of the market, the whole show folded. Machinery was scavenged for the next location. About all that was left were the raw footings, like giantsteps on the hillside; and the headframe above the silent diggings. Mostly, the people went away too.

Arizona Territory was like that at the turn of the century. It can still happen. But, in copper, the age-old pattern has been disrupted. From Mineral Park in the northwest to Chino in the east and Cananea in the South, a growing number of companies have emerged—large, stable, productive. Southwest copper is truly a mighty industry, accounting for one fifth of world new copper production. In this period of scientific development, changes are fast, often dramatic. But even mining engineers, or possibly more so because they have an intimate knowledge of





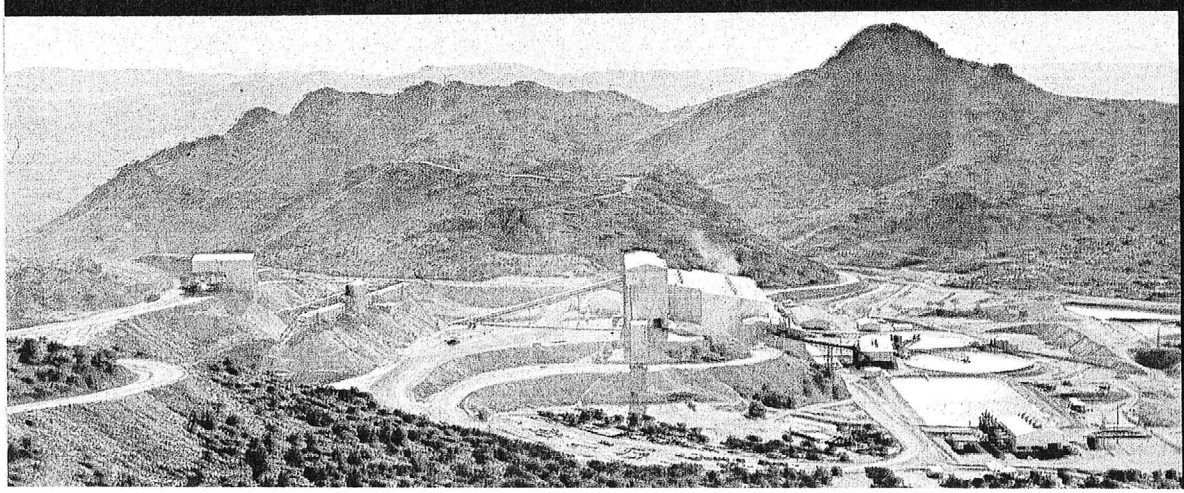


Top: Bagdad's concentrator receives ore from open pit via enclosed conveyor at left. Headframe is relic of former underground mining.

Bottom: Airborne view of Christmas mine shows headframe, 4000 tpd concentrator, tailing area and offices set in rugged Arizona terrain.

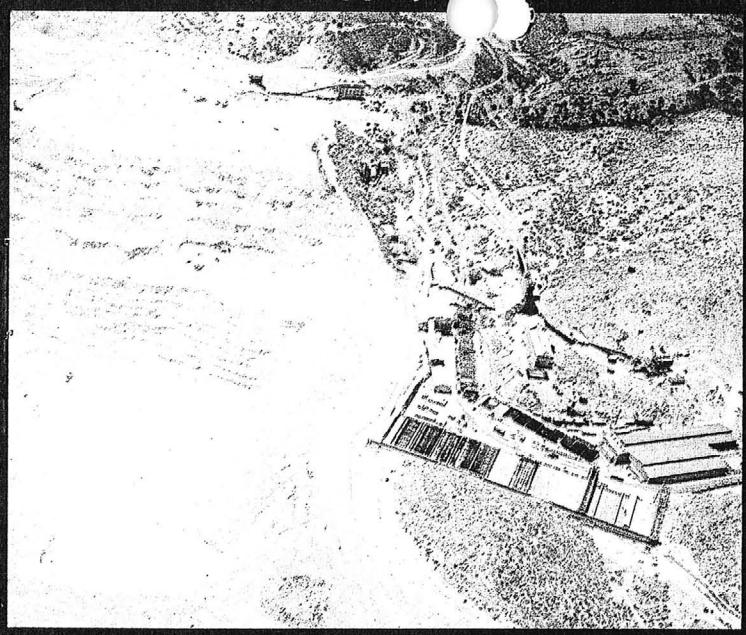
Top: Grinding bay at Mineral Park shows autogenous mills, cyclone arrangement and control panel.

Bottom: San Manuel twin ore shafts and crushing plant are beyond subsidence area.



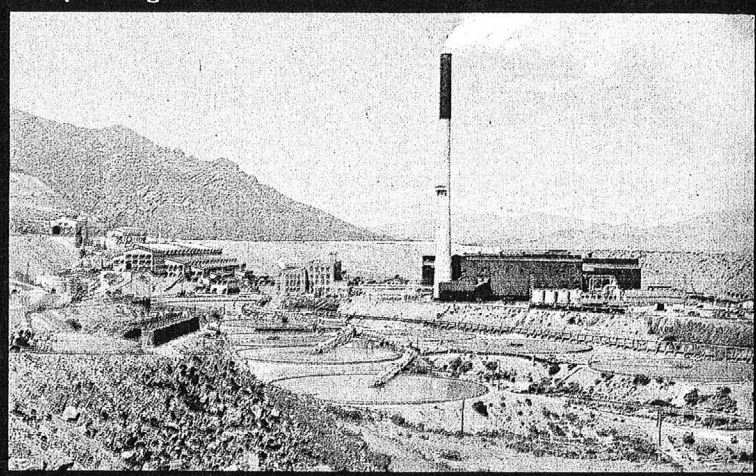
Duval's Mineral Park concentrator went on steam in late 1964. See interior view above.

Inspiration pit butts vat leaching plant and shops. Residues from leaching go by rail to concentrator.

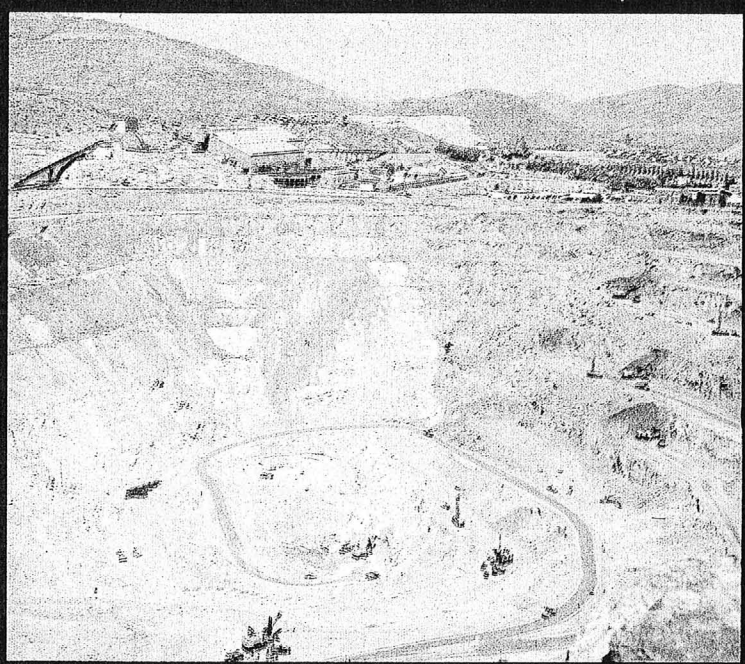


Mission pit, left, nearly touches Pima. Old Mineral Hill mine at right middle.

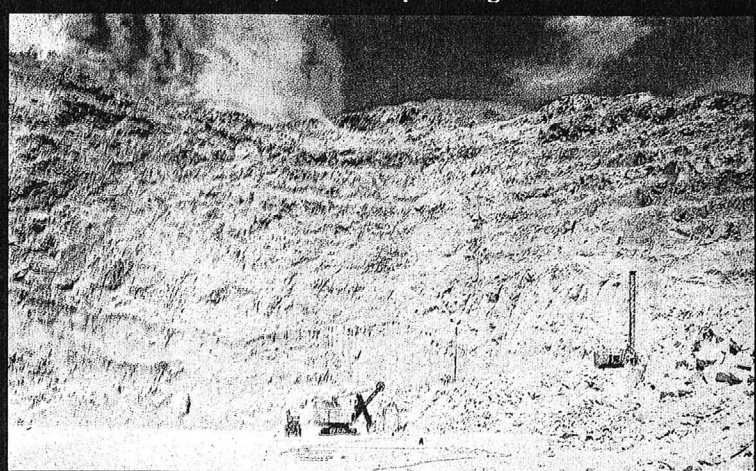
Phelps Dodge's Morenci concentrator and smelter.



Lavender pit at Bisbee supplies bulk of ore to plant.

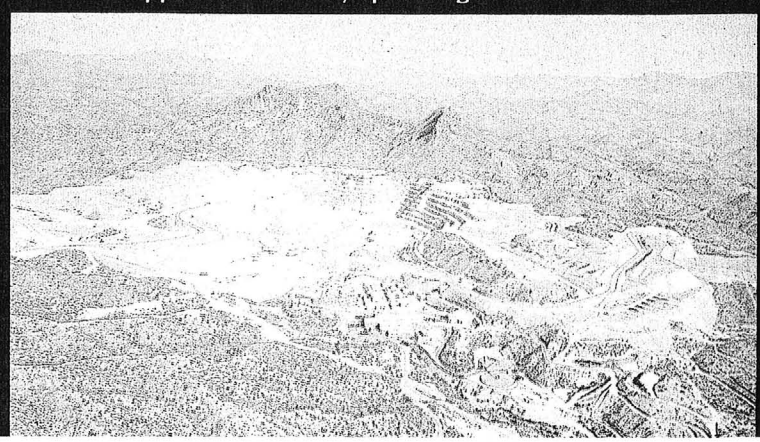


Cananea pit in Mexico, is 1 of 2 operating.



Ray pit sends ore 23 miles to Hayden reduction works.

Miami's Copper Cities mine, operating since 1954.



the industry, fail to appreciate the evolutionary changes that have shaped Southwest copper into what it is today.

Southwest copper growth seems to divide into two periods; one from shortly after 1900 until 1930 and a second beginning in 1940 and continuing into the present. The early period was embued by the idea of large scale mining and sparked by development of blockcaving, rail haulage pits and flotation; the second by an equipment revolution that lowered costs in mine and plant and cut sharply into the lead time for plant construction when large amounts of capital would be tied up without financial return. Other important factors have been the recovery of by-product molybdenum and improvements in exploration techniques such as those which permitted the discovery of the Pima district by Walter Heinrichs, Jr. and Robert Thurmond.

In 1900 there was no concentrator bigger than 500 tpd in the region. In this survey the smallest now is 4000 tpd, there are eleven 12,000 tpd or greater and the biggest is 58,000 tpd at Morenci. The old makeshift plants have been superceded by packaged sections that can be expanded at will. Leaching of soluble copper minerals was developed early and has been greatly extended. But it was replacement of vanners and tables by flotation that gave the great boost to copper recoveries thereby bringing in the large low grade porphyries.

Selective mining has all but ceased to be a copper source of consequence in the Southwest. Magma, at Superior, is still mining high grade ore from dwindling reserves. Cananea ceased underground mining a month or two ago. Christmas strives to lower the cut-off by mechanization and is therefore somewhere between a high grade selective mine and the mass producting method of blockcaving. Bisbee is still producing from underground to sweeten the mill heads as well as high grade, direct-smelting oxides. From a tonnage standpoint, the only big underground producer is San Manuel which carries on the great blockcaving methods developed at Inspiration, Miami and Ray. However, if underground mining were in search of a champion, there is none better than San Manuel weighing at 39,000 tpd from underground!

The great source of copper now is from the expanding number of open pit mines. As one engineer described them; "the great waste mines." Since the amount of waste produced is greater than the ore and the planning of waste removal determines the available ore, the expression is quite accurate. Such great pits as Morenci, Chino and New Cornelia started early with open cut methods because of large dimensions that were amenable to rail haulage, then the most feasible system for mass movement of bulk materials. Many of the other mines that are operating today on smaller deposits were made possible by the development of truck haulage. Strides in heavy equipment manufacture have also brought in deposits that suffered from the double handicap of low tenor in copper and the necessity of deep stripping before mining.

Growth of the mines and present status is given in the table accompanying this article. The numerous plant additions described in the status reports on each property which follow bespeak the healthy growth position of Southwest copper.

At the last count, made last summer, there were 45 companies doing exploration work in Arizona. The march of progress goes on. Off by Safford, there are vast reserves of low grade copper in which Bear Creek, Phelps Dodge and United Nuclear have or are performing exploration. But down just south of Pima, a new giant is being exposed for productivity. Now the great difference from the old days can be seen. Southwest copper employs 18,000 men who have founded stable communities in support of an enduring industry.

## ANACONDA

South of Pima in the Twin Buttes area, The Anaconda Co. began a giant stripping operation two months ago. It will take 4 years to complete, in which 165 million tons of alluvial overburden will be removed. Anaconda has been testing areas leased from Banner Mining Co. for about 2 years and the Twin Buttes project has been the major outcome.

A 900 ft shaft was sunk and drifts and cross-cuts driven into the orebody to take bulk samples now being tested in a 200-ton pilot plant situated at the old Mineral Hill mine near Pima. Anaconda cannot tell about the flowsheet or size of the plant that will be constructed until tests are complete.

In the meantime, the Company moved swiftly and surely into what may be the world's biggest premine stripping job. Removal of 165 million tons will take the surface down 460 ft to bedrock. The first units of a $4 million fleet of heavy equipment are in operation. Scrapers of 80 ton capacity are being used for the initial cut down to 150 ft. After that a 60-in. slope belt will be added in sections. It will travel at 960 fpm to carry overburden material delivered by scraper and discharged to a truck loading hopper at the rate of 6000 tph. Bottom dump trucks of 100 ton capacity will carry the overburden to the tailing area where it will be used to form the retaining dam. When fully installed the conveyor will be 11,000 ft overall with the main section, a single conveyor 8300 ft long. This is said to be the longest known single overland belt conveyor used in open pit mining in the U.S.

By 1970, Anaconda's Twin Buttes mine is scheduled to be in production.

## CANANEA

After 65 years of underground mining, Cananea discontinued subsurface mining this year. Operations are now centered on open pit methods. The Company has some experience at this having already exhausted two pits. Ore is presently being extracted from the Sonora Hill deposit and La Cananea pit has been

(*Continued on page 84*)

A new and expanded cement copper plant is scheduled for completion next year as Morenci resumes heap leaching on a larger scale.

## COPPER QUEEN

Bisbee is the home of the Copper Queen Branch of Phelps Dodge. Underground mining has been in progress continuously in this hill country just north of the Mexican border since 1871 and last year accounted for 44% of the copper produced in the district. However, mine production at Bisbee today comes from the Lavender pit, 6 million tons of ore in 1964, and the underground mines, 749,000 tons. Part of the ore from underground is direct smelting and is sent to Douglas where the Company smelter is situated. An important amount of copper is recovered by heap leaching low grade rock from the mine and making cement copper.

The underground mines practice selective mining of high grade ore. In 1964, sand filling of stopes in conjunction with square setting was introduced using tailing from the concentrator. For the geologist, the underground offers a fascinating game of detection of the discrete, irregular replacement deposits in limestone. Fifteen diamond drills are busy all the time probing for ore. Through three shafts, the Campbell, Cole and Dallas, approximately 750 miners are engaged in working 103 stopes at depths of up to 3233 ft.

Open pit mining is not new at the Copper Queen. From 1923 to 1928, the Sacramento Hill deposit was worked by open pit with rail haulage. In 1954, the Lavender pit was brought in working a lower grade ore but with the advantage of flexible modern truck haulage, high speed drills and electric shovels. The Lavender orebody is a true porphyry copper; the ore being disseminated in a brecciated porphyry intrusive. From high on the crest of the pit, the operation is directed by a dispatcher who, with two radio channels, directs trucks to the proper loading station and maintenance vehicles to where they are needed.

Sitting above the red and gray 50-ft bench walls, is the Copper Queen concentrator. The concentrator was assembled at the pit from several other dismantled units in order to avoid a long uphill haul to the old plant. Like Morenci and New Cornelia, single stage ball milling with spiral classifiers is employed. The ore contains practically no molybdenum and there are no other by-products. The pyrite-chalcocite ratio is 16 to 1 in the plant feed which accounts for the copper concentrate grade being a low 11% to 12% Cu.

The concentrates are roasted prior to smelting in the Company's plant at Douglas. Sponge iron is also made at Douglas for use in precipitating copper from heap leach solutions at the Copper Queen.

## NEW CORNELIA

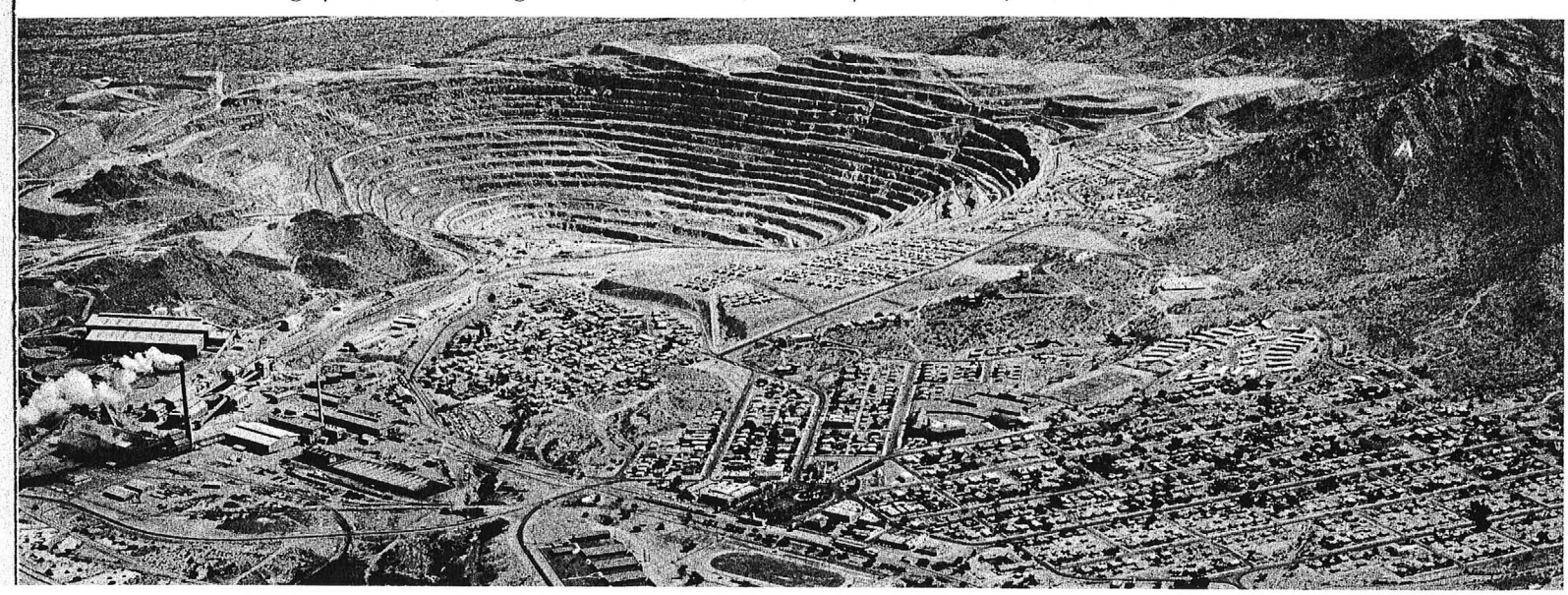
Tucked away in the southwest corner of Arizona, Phelps Dodge's New Cornelia Branch efficiently extracts ore from a circular pit that delineates an orebody 4000 x 5000 ft in cross section and at least 1000 ft thick. Oxide capping on the protore, which baffled the first owners, had long since been extracted and yielded up its copper. Since then, few complications have interfered with uniform development and expansion. There are no side operations or by-products to distract from the primary objective of mining, concentrating and smelting copper sulfides into anode copper.

Ore extraction is controlled to provide a uniform feed to the mill. Drillholes are 12 in. diam and blasting is with ANFO, both being common features in Arizona open pit mining. Shovels are 6- to 9-cu yd capacity loading into railroad cars.

The concentrator was originally designed for two stages of grinding but has been converted to single stage ball milling in closed circuit with spiral classifiers. The rougher concentrate is routed to the regrinding mills prior to further flotation.

A smelter was completed in 1950 eliminating the necessity of shipping 300 miles to Douglas a product that was two-thirds waste. Green concentrate is

*Photograph of Phelps Dodge's New Cornelia Branch at Ajo shows the open pit mine, concentrator and smelter.*



charged direct into the bath, as distinct from the sidewall, of the single reverberatory furnace. Few companies practice bath smelting although practitioners claim advantageous heat transfer by the method.

In 1964, a number of improvements in the concentrator permitted milling at a daily rate of 32,248 tons, a record.

## Miami

Miami Copper Co. came on the scene in the early days of large-scale development of copper in the Southwest, and began producing copper in 1911. In 1960, the Company was merged into Tennessee Corp. However, Miami's well deserved fame rests in the tremendous achievement of mass mining of low grade ores by blockcaving for 49 years.

From 1943 to 1953, the Company mined the Castle Dome orebody by open cut methods. In 1954 it began open pit mining of the Copper Cities deposit. This operation is still in progress.

Leaching was begun in 1939 on underground gob at the Miami mine. After the mine was shut down in 1959, leaching was continued. Dump leaching was also begun in 1951. Today the scope of operations is open pit mining and concentrating at Copper Cities and leaching of the caved area in place at Miami, and dumps at Castle Dome and Copper Cities. About 40% of the copper production is from cement copper.

At Castle Dome and Copper Cities the orebodies are in monzonite porphyry and at Miami they are in schist. At Miami it is necessary to add acid for leaching while at the former two properties there is sufficient pyrite in the rock to make the addition of acid unnecessary. Acid is added to the solution going to the caved area in amounts to allow ½ lb of free acid per ton of final copper bearing solution which keeps the pipes from plugging up with iron salts. The underground drifts and cross cuts are used as solution sumps and weirs set in them permit measuring flow and sampling of solution from various blocks being leached. Although these devices are useful for control of operations, the efficiency of leaching will never be determined because there is no data on the copper content of the gob being leached. At Copper Cities on the other hand, records have been kept of the assays of rock placed on the dumps and could ultimately permit quantitative evaluation of productivity. Nevertheless Miami has contributed a great deal to the techniques of leaching.

The Copper Cities concentrator, which is a straight sulfide circuit without molybdenum by-product plant, was moved from Castle Dome to its present location.

Miami sends its precipitates to Douglas and its concentrates to Inspiration; the copper is returned to the Company for marketing.

## Inspiration

Any mining engineer will enjoy the colorful march of engineering changes that have taken place at Inspiration. A pioneer in blockcaving when mining began in 1915, the Company converted to open pit mining in 1948. Two pits are now being mined, the Thornton and Live Oak; the west extension of the Thornton is being stripped and the Red Hill is in reserve.

When the concentrator was built, it was the first copper concentrator to be designed for flotation as the principal means of copper recovery. In fact, construction was held up a year while the process was tested. Then a few years later a change came; increasing amounts of silicates and oxides in the ore. A new recovery method was needed. When the new method was achieved, not without considerable sweat, it involved vat leaching of the ore with sulfuric acid and ferric sulfate. Later copper was even removed from water used to wash the residues by precipitating it on tin cans. The extraction process was by electrowinning. This was the method adopted in 1926 and it put the flotation concentrator in moth balls. In the book "The Porphyry Coppers," published in 1933, A. B. Parsons speculated as to when, if ever, this mill might be reactivated.

It was 30 years later that the ore character began changing again; nonsoluble sulfides appeared in increasing amounts. In 1957, the old concentrator, after rehabilitation, was back in business only this time it treated residues from leaching for the valuable sulfides. This is the process now being used; leach first, then flotation concentration. Nearly all the ore from the two pits goes through both plants. With less copper solution going to electrowinning, electrolytic cells became available for refining. To this capacity an 80-tank refinery was added permitting the Company to refine all its copper production. Inspiration operates a copper smelter so that copper concentrates from the reactivated mill are treated on the property. Custom ores are also smelted.

A new round of expansion is currently on foot to be completed this year. Mine production is to be upped from 16,500 to 20,000 tpd. To handle the additional tonnage, a new traveling bucket excavator will speed removing residues from leach tanks. It will discharge to a new belt conveyor system, instead of rail cars, that will transfer the residues 1.4 miles to the concentrator. These new facilities are to maintain copper production at its present rate in the face of lower grade ores.

## Christmas

Inspiration looked beyond the Globe-Miami area in 1954 and took options on the Christmas and New Year properties some 37 miles away. The complex sulfide orebody is a replacement deposit in limestone in which the principal ore minerals are chalcopyrite and bornite.

Development of the property was a major operation involving the sinking of shafts to nearly the 1800-ft level and construction of a concentrator

and some housing. Production began in 1962 and has been increased each year although the design capacity of the mill, 4000 tpd, has not been attained. Difficulties in mining due to heavy ground, water and a shortage of skilled miners have slowed production. The metallurgy, however, has worked out according to expectations.

Mining at Christmas has "the new look" with mobile drill jumbos and combination loader-haulage units. Sand fill is the major form of ground support. It has been found that stopes must be filled shortly after extraction. Ore is collected and transported to the shaft by rail. The automatic ore hoist is controlled from underground by the skip tender.

The single-section concentrator reduces ore in two stages of crushing followed by rod milling to two ball mills in closed circuit with cyclones. Recovery is by rougher flotation succeeded by two stages of cleaning. Only one concentrate is made which is trucked to Inspiration for smelting.

## Ray

Ray Mines Div. of Kennecott Copper Corp. came into production in the early days of the rise of porphyry coppers. The deposit has stood the test of more than 50 years of large scale mining but not without the climatic readjustments that have distinguished the evolution of porphyry coppers. Mining by block-caving was practiced for over 40 years; then, beginning in 1955, it was displaced by open pit mining. Today mine production is supplemented by the leaching of underground workings and mine dumps, adding about 20% to copper output. Mining operations are now tapping ores with sufficient molybdenite in them for economic recovery. A plant, similar to the one at Chino, is under construction to begin making a molybdenum concentrate in 1966. Silicate zones containing 0.8% Cu in chrysocolla are now being removed from over sulfide ores. The silicates are stockpiled while leaching methods are investigated. Sulfide ore mined at Ray is separated into two categories, high nonsulfides and low nonsulfides, for milling purposes. The high ore contains 0.08% or more nonsulfides and is treated by LPF; above 25% of the concentrator feed is treated in this manner.

The original concentrator was constructed at Hayden, 23 miles away, near a source of water in 1910. The old section of the mill has a capacity today of 14,000 tpd. In 1960, a major expansion of the concentrator added two sections of 5000 tons each. The plant is well instrumented for operation from control centers. An operational on-stream X-ray spectroscopic analyzer is processing samples from five tailing locations. The Norelco instrument has four channels and 15 sample stations. Although use has been restricted so far to one channel and 5 stations, operators believe that information from the analyzer has assisted in increasing recovery about ½%. About 40 tons of pyrite concentrates made each day are converted to sponge iron for use in copper precipitation in LPF.

The smelter completed in 1958, has a new gas-fired, rotary dryer for concentrates. The smelter makes anodes that are sent to the company-owned refinery in Anne Arundel County, Md.

## Chino

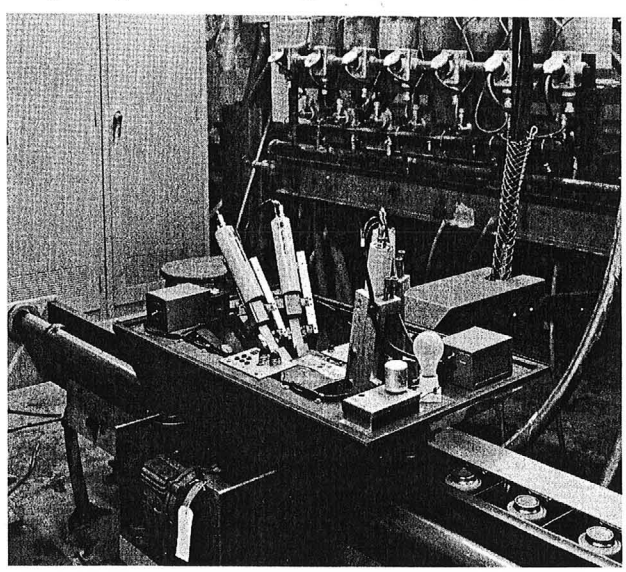
Chino Mines Division, headquartered at Hurley, N. M., is in a district where mining has gone on for centuries and Chino is the granddaddy of the porphyry coppers. Operations moved into the "porphyry copper" scale in 1912 when first production came from the open pit. The only older operating open pit copper mine is Bingham.

Last year was the first full year of all truck haulage at Chino. Although rail haulage has been phased out, the skip inclined hoist removes ore and waste from levels below 5800 ft. At Chino the trend is also to larger haulage units, a dozen of the 85-ton electric wheel trucks are in service. Ore is trucked to a surge pile for blending and transferred to rail cars for shipment to the concentrator at Hurley. Blending is for grade and metallurgical control and such physical characteristics as moisture and hardness. Stripping is currently at an increased rate, and production of cement copper is being expanded to increase overall production of copper by 25%.

Dump leaching, begun in the 20's, has been with water but now experiments are underway with acid. The expansion, requiring an $8 million investment, has been in stages. Solution circulation rate has been stepped up from 8000 gpm in 1964 to reach 15,000 gpm in 1965.

The concentrator reduces ore in four stages of crushing and two stages of ball mill grinding with ball mills in closed circuit with rake and cyclone classifiers. Rougher concentrates are classified and the oversize is reground while undersize is cleaned twice. In the moly plant, copper concentrates are steamed to drive off flotation reagents, and then conditioned with burner oil to float the molly and alcohol frother. Moly rougher concentrates are cleaned, filtered, roasted and then repulped for a further flotation cleaning.

*X-ray analyzer with cover off shows 4 channel counters.*



# 1964 MINE STATISTICS

| | INITIAL PRODUCTION | MINING METHOD | REDUCTION PLANT | ORE & WASTE, *tpd* | ORE, *tpd* | AVG. Cu CONTENT, % | AVG. $MoS_2$ CONTENT, % | ORE MINERALS |
|---|---|---|---|---|---|---|---|---|
| **CIA MINERA DE CANANEA** | 1900 | | | 65,000 | 16,000 | 0.80 | | CHALCOCITE |
| PHELPS DODGE CORP. **MORENCI** | | | | 150,000 to 155,000 | 57,000 to 58,000 | 0.90 | 0.012 | CHALCOCITE |
| **COPPER QUEEN** | | | | OP 78,000 | OP 18,000[3] UG 2500[3] | OP 0.81 | | CHALCOCITE CHALCOPYRITE BORNITE |
| **NEW CORNELIA** | | | | 91,000 | 32,000 | 0.776 | | CHALCOCITE CHALCOPYRITE BORNITE |
| **MIAMI COPPER CO.** | 1911 | [7] | [8] | 40,000 | 12,000 | 0.66 | | CHALCOCITE CHALCOPYRITE |
| KENNECOTT COPPER CORP. **RAY** | 1911 | | | 74,000 | 24,000 | 0.85 | | CHALCOCITE CHALCOPYRITE |
| **CHINO** | 1912 | | | 74,000 | 22,000 | 0.975 | | CHALCOCITE CHALCOPYRITE MOLYBDENITE |
| INSPIRATION CONSOLIDATED COPPER CO. **INSPIRATION** | 1915 | | | 42,700 | 16,500 | 0.898[9] | 0.0124 | CHALCOCITE CHALCOPYRITE |
| **CHRISTMAS** | 1962 | | | 3000 | 3000 | 1.493 | | CHALCOPYRITE BORNITE MAGNETITE PYRITE |
| MAGMA COPPER CO. **SUPERIOR** | | | | 1600 | 1500 | 4.78 | | CHALCOCITE CHALCOPYRITE BORNITE |
| **SAN MANUEL** | 1956 | | | 35,000 | 35,000 | 0.83 | 0.025 | CHALCOCITE CHALCOPYRITE MOLYBDENITE |
| **BAGDAD COPPER CORP.** | 1937 | | | 43,200 | 7000 | 0.76 | 0.03 to 0.05 | CHALCOCITE CHALCOPYRITE MOLYBDENITE |
| AMERICAN SMELTING & REFINING CO. **SILVER BELL** | 1954 | | | 29,000 | 9000 | | | CHALCOCITE CHALCOPYRITE MOLYBDENITE |
| **MISSION** | 1961 | | | 90,000 | 15,000[1] | n.a. | n.a. | CHALCOPYRITE MOLYBDENITE |
| **PIMA MINING CO.** | 1957 | | | 48,000 | 8000 | 1.0 | | CHALCOPYRITE |
| THE DUVAL CORP. **ESPERANZA** | 1959 | | | 30,000 | 12,000 | 0.55 | 0.021 | CHALCOCITE CHALCOPYRITE MOLYBDENITE |
| **MINERAL PARK** | 1965 | | | 30,000 | 14,000 | 0.5 | 0.03 | CHALCOCITE MOLYBDENITE |

OPEN PIT MINE

UNDERGROUND MINE

COPPER CONCENTRATOR

MOLYBDENUM PLANT

SMELTER

CEMENT COPPER PLANT

ELECTROLYTIC REFINERY

VAT LEACHING PLANT