CONTACT INFORMATION
Mining Records Curator
Arizona Geological Survey
416 W. Congress St., Suite 100
Tucson, Arizona 85701
520-770-3500
http://www.azgs.az.gov
inquiries@azgs.az.gov

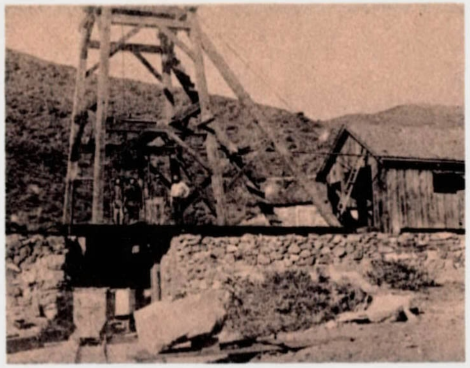
Foreword

Over a hundred years ago General Stephen Watts Kearny and a troop of U.S. soldiers encamped at Mineral Creek. One of the officers in the group was far-sighted enough to observe the large ore deposits in the area, and he prophesied correctly that a man would one day put this extensive ore body to good use. Time has shown how correct he was. ■ Prospectors wandered through the area during the next few decades prospecting more for silver than anything else. A little was found, but it was the copper ore found lying under the surface of the ground that proved the lure which attracted large investments. ■ Since the time a prospector first named his claim Ray, in honor of his daughter, the name Ray has become synonymous with copper in Arizona. The Ray Mine operated under several companies before Kennecott Copper Corporation took over in the early 1940's and eventually turned the underground operation into the nation's seventh largest open-pit copper mine. ■ The men who trudged through these hills a hundred years ago would be amazed at the changes that have taken place since the initial discoveries were made. More money than they ever dreamed existed has been invested in Ray Mines Division in the past twenty-five years to increase production and, at the same time, increase its importance to the economy of the state. ■ Literally the horse and buggy days of a hundred years ago have been replaced by what we commonly call the 'jet age' now. Man continues to explore the earth, and now is setting sail for space and the new worlds beyond. Copper will play an ever-increasing role in the world of the future – a role that perhaps we haven't even dreamed about. It is interesting to think about, and makes us realize how important the work we are doing now will be to the generations which follow us.

I. G. Pickering

I. G. PICKERING
General Manager
Ray Mines Division

Typical old-time mine, right, had a head-frame of heavy timbers atop its vertical shaft. Winch and cable hoisted ore buckets to surface.



Few early-day miners were fortunate enough to have wives to boil their laundry. A great many were forced to "batch it" — or take up residence in a boarding house.

Blast-holes for explosives were hand-drilled in the rock. Ore was hauled in wheelbarrows or small mine cars.

Above photo shows the wood supply which was needed by an early-day smelter. Obtaining coal was too costly.

Freighters risked their lives to haul equipment, food, and medical supplies to mines through Indian country.

The large mines hauled ore out in tandem-hitched wagons drawn by many teams of horses or mules — over dangerous mountain roads. Some mines used pack-burros to transport ore.

Arizona's early-day copper miners toiled long hours with pick and shovel for small wages. When "pay dirt" petered out, as it often did, they had to seek jobs elsewhere. When a miner got hurt, his friends fed him until he could return to work. If he was killed in an accident, they passed the hat to bury him — or to buy his widow and children transportation to their nearest kinfolk.

Once a prosperous community, this mining town was abandoned long ago to the coyotes, lizards and bats.

The "worthless" mountain that has contributed over 765 million dollars to Arizona's Economy

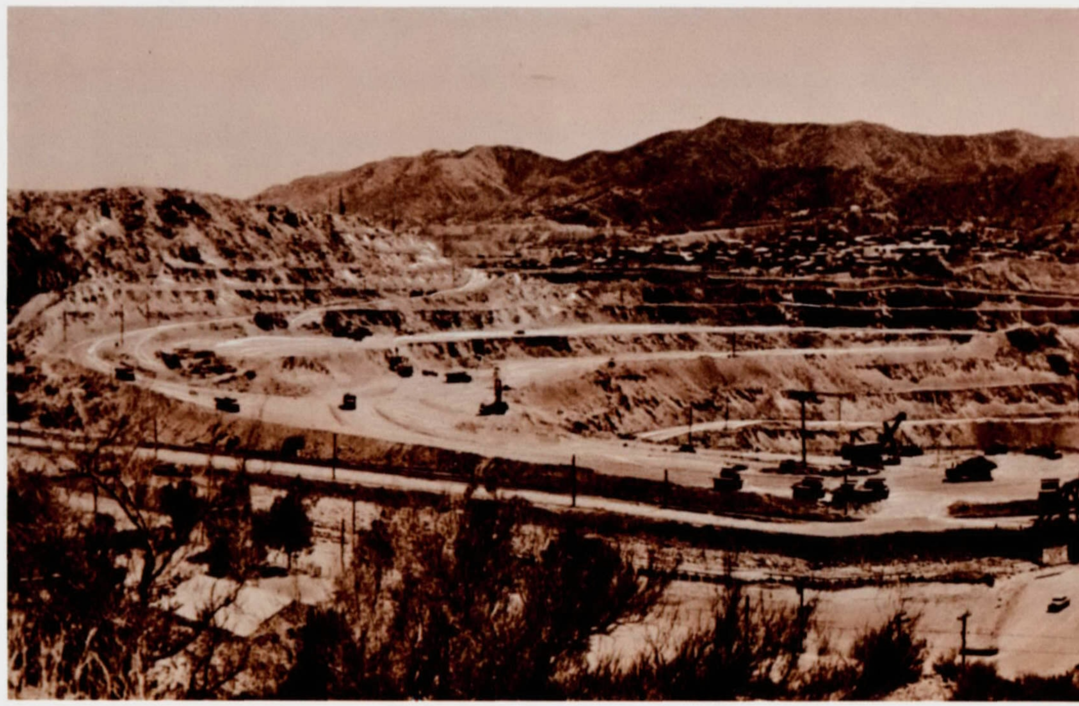
—through wages and salaries, taxes, plants and equipment, and purchases in the state.

These "before" and "after" photos, taken almost fifty years apart, tell a dramatic story – and one of significance to Arizona's economy.

The top picture shows the mountain as it looked in 1912, when it still contained enough fairly high-grade ores to be profitably operated as a "shaft, drift, and tunnel" mine. But with each passing year the ore became progressively lower in copper content – until, in 1948, the mountain was judged by experts to be worthless for further underground mining.

Kennecott engineers dedicated themselves to the task of finding a lower-cost method of extracting the vast quantities of low-grade copper ore still remaining in the mountain. The answer—open pit mining—required the investment by Kennecott of millions of dollars in new equipment and machinery.

The lower photograph, taken in 1961, shows the result – an open pit mine 126 times larger than a college football stadium.



Open pit mining:

Excavating low-grade ores on a vast scale

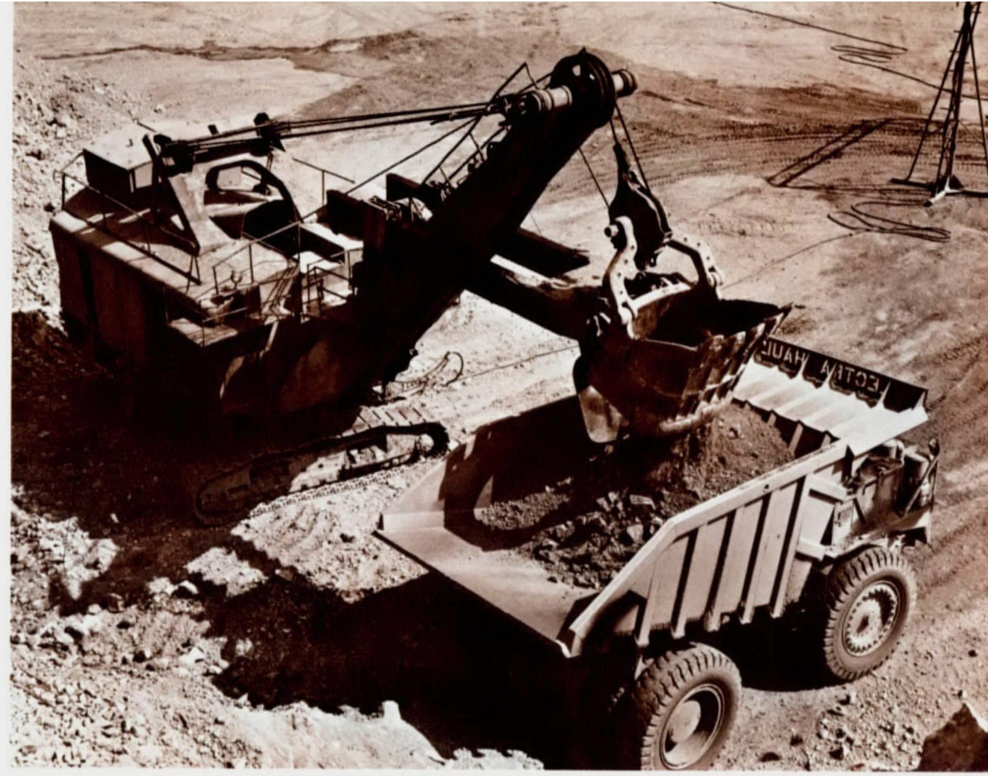
Years before actual excavation begins, an exploration crew drills hundreds of test-holes to locate and take samples of copper ore deposits that lie buried in the mountain. At that time, maps and other records are made — from which mining engineers develop a long-range Master Plan for excavating the ore.

Left: Survey crews at Kennecott's Ray Mines Division, using Master Plan maps which have been frequently up-dated to keep them current, mark spots where blast-holes are to be drilled. Tractor-mounted rotary drills move in to sink 45-foot holes.

Below: Under supervision of the Blasting Foreman, each hole is loaded with the precise amount of explosives needed. The most rigid safety precautions are observed in the blast area.

Hauling and dumping 6,500 pounds of ore and rock — to get 17 pounds of copper

The ore at Kennecott's Ray Mines Division averages only 85/100ths of 1% recoverable copper — just 17 pounds of copper per ton of ore. And for every ton of ore recovered from the pit there are 2¼ tons of additional rock which must be removed. This material is all sent to special dumps. Much of it is being leached with acid and water to recover the small amounts of copper it contains. In the future, dumps containing material now considered to be "waste" may also be leached.



Each bite of the 15-yard dipper on this giant electric shovel contains over 20 tons of material for the 85-ton truck. A truck and shovel represent an investment of over one million dollars.

One of Ray Mines Division's newest electric shovels can fill an 85-ton truck with 4 scoops of its huge dipper. The blade-equipped vehicle is used to help keep haulage roads clean.

After the blast-holes have been loaded with explosives, the charge is set off (left) and upwards of 40,000 tons of copper-bearing material is broken, ready for loading.

Continuous blasting and hauling turned former mountain into huge man-made crater at Kennecott's Ray Mine. Each stair-like "bench" is 40-feet high.

Samples of the rock broken by the blast are taken by Quality Control workmen to be assayed and classified as ore to be milled or material to be leached.

One example of the sophisticated equipment used in modern mining operations is the atomic absorption spectrophotometer shown here being used by Quality Control technician.

To provide better working conditions for Kennecott's workmen — and to minimize abrasive wear on equipment — dust is controlled by frequently sprinkling the truck haulage roads with water.

Kennecott's large fleet of haulage trucks — two of which are shown below — is maintained in top mechanical condition for around-the-clock use by crews of three 8-hour shifts.

Even a giant haulage truck — upper right corner of photo — looks small compared to mountain of waste rock onto which it is dumping 85-ton load.

Material classified as "ore" is hauled by trucks and dumped — one truckload approximately every 5 minutes — into Primary Crusher, which prepares it for shipment to Reduction Plant.

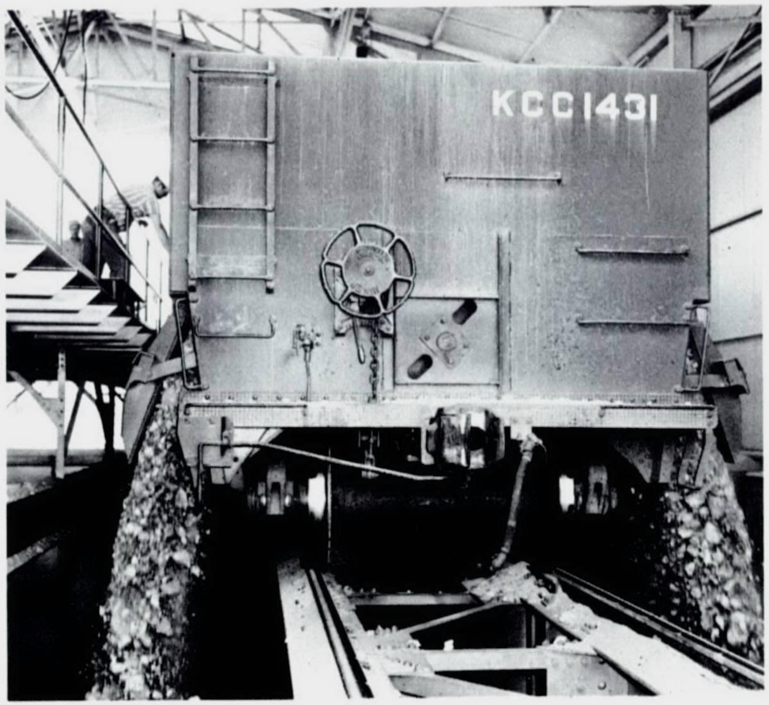
Starting the trip from mine to smelter

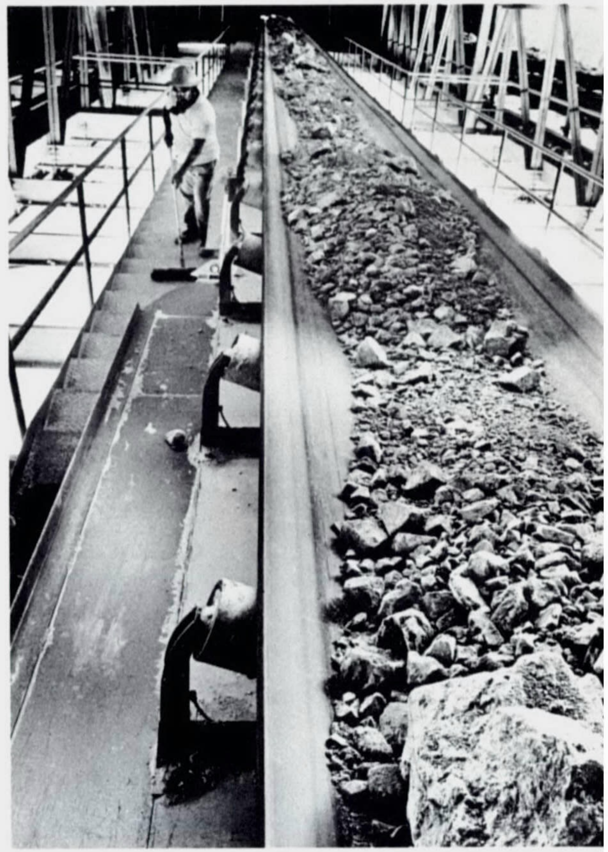
It takes excellent long-range and day-to-day planning to maintain a smooth, uninterrupted flow of copper ore from Kennecott's open pit mines at Ray, to the Reduction Plant in Hayden — a distance of twenty-two miles. It also requires a high degree of efficiency in the utilization of both manpower and equipment during every step of the journey from mine to smelter.

The Primary Crusher's powerful mechanical action reduces the freshly-mined ore to chunks no larger than 10 inches. A conveyor belt moves the ore to the top of a Loading Tunnel. 100-ton-capacity cars are then loaded through chutes in the top of the tunnel.

To maintain daily production of 25,400 tons of ore, seven 38-car trains make the trip every 24 hours from Ray to Hayden. On their 22-mile journey, these trains traverse picturesque, sparsely-settled country that is little changed from the days of "Boom and Bust" mining.

Upon arrival at Hayden, a whole trainload of ore can be unloaded in minutes. The ore cars, of side-dump design, unload their cargo in Kennecott's big underground Track Hopper. Over 50 feet deep, the Hopper has a capacity of 6,000 tons — over 1½ trainloads of ore.

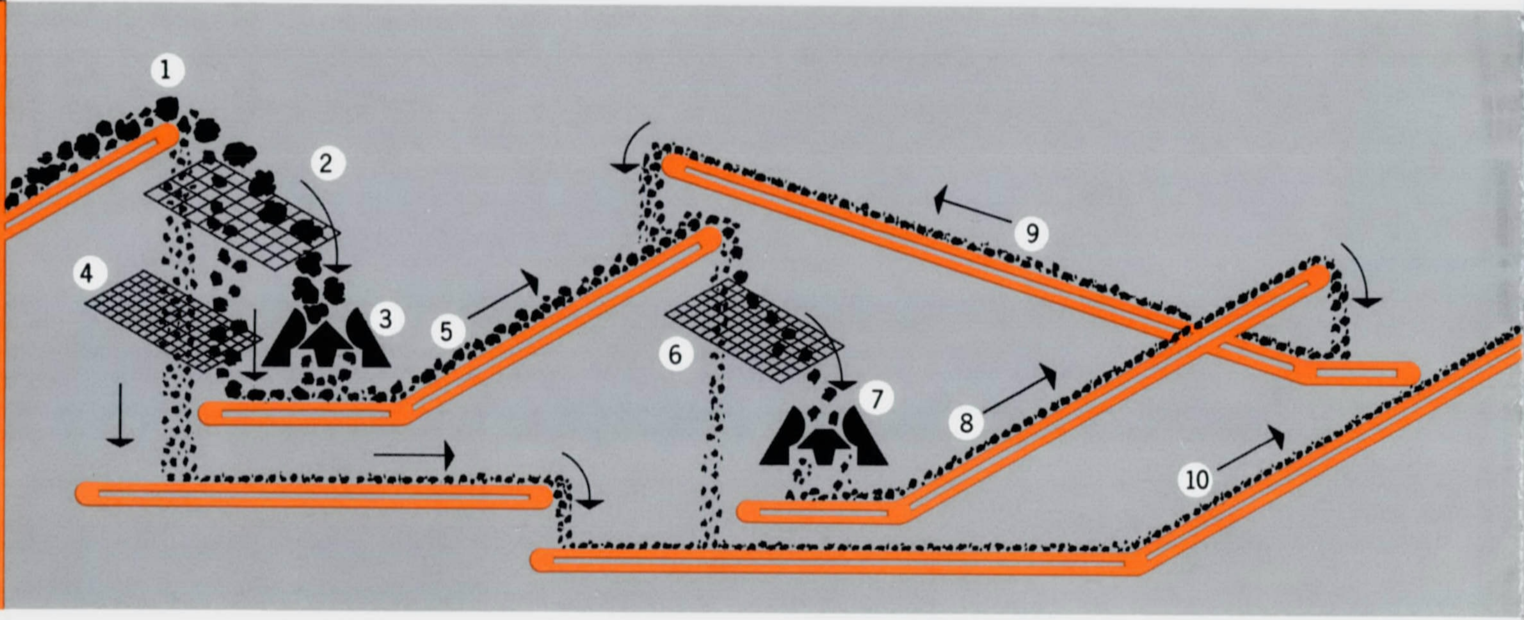




At the bottom of the Track Hopper there are six hydraulically-operated "feeders" that supply ore to three 48-inch wide conveyor belts. They take the ore up an incline for a distance of 535 feet to a point high inside the huge Crushing Plant.

Above: Three conveyors feed ore into the standard cone-crushers.

Crushing and transporting ore on conveyor belts to the mill



Sketch above is an overhead view of a cone-crusher. The two dotted circles show how cone-shaped "head" revolves and crushes ore against the outside walls of a crusher.

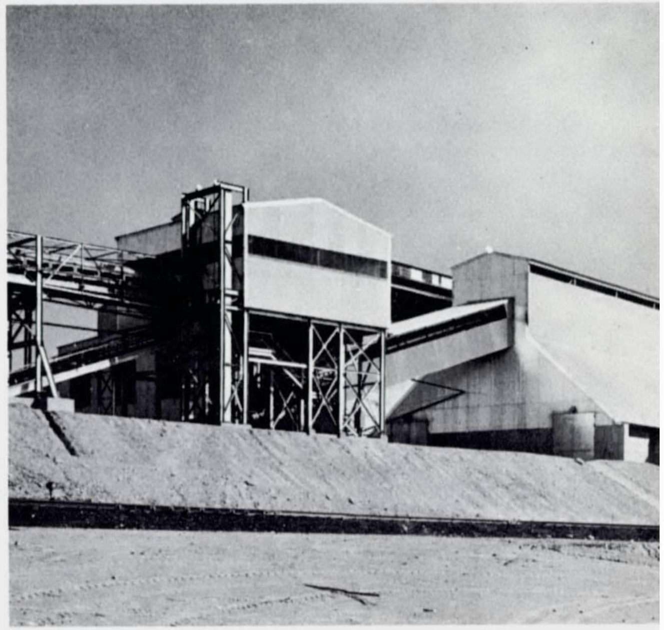
This Control Panel operates the entire crushing process.

The function of the Crusher Plant is to reduce the incoming random-sized ore from the Mine into sizes ½-inch or smaller. The ore passes through three Second Stage and four Third Stage cone-crushers. The above diagram shows, in simplified form, how the ore is processed in the Crusher Plant.

Ore from Track Hopper enters on a conveyor belt (1). Bits of ore which are smaller than ½-inch fall through a double-deck screen directly onto belt that by-passes crushers. Large chunks of ore are diverted by top screen (2) into Second Stage Crusher (3). Lower screen (4) diverts intermediate-sized ore larger than ½-inch onto conveyor belt (5) that also carries ore crushed by Second Stage Crusher up incline to ½-inch mesh screen (6) which diverts ore larger than that measurement into Third Stage Crusher (7). Conveyor (8) receiving ore from Third Stage Crusher transfers it to belt (9) that empties onto conveyor "feeding" ½-inch mesh screen over Third Stage Crusher. This "closed circuit" system re-circulates all of the ore which enters the Crushing Plant until it is small enough to fall through ½-inch screen onto the bottom conveyor (10) which carries ore toward the Fine Ore Storage buildings.

"Weighing a mountain in motion." As it leaves the Crusher Building on conveyor belt a "weightometer" keeps a record of the ore tonnage produced by each eight-hour shift.

Below: This conveyor is the longest, 2067 feet, in the network of conveyors connecting Kennecott's vast facilities in Hayden. Ore is transported by it from Crusher to the big Fine Ore Storage Building.

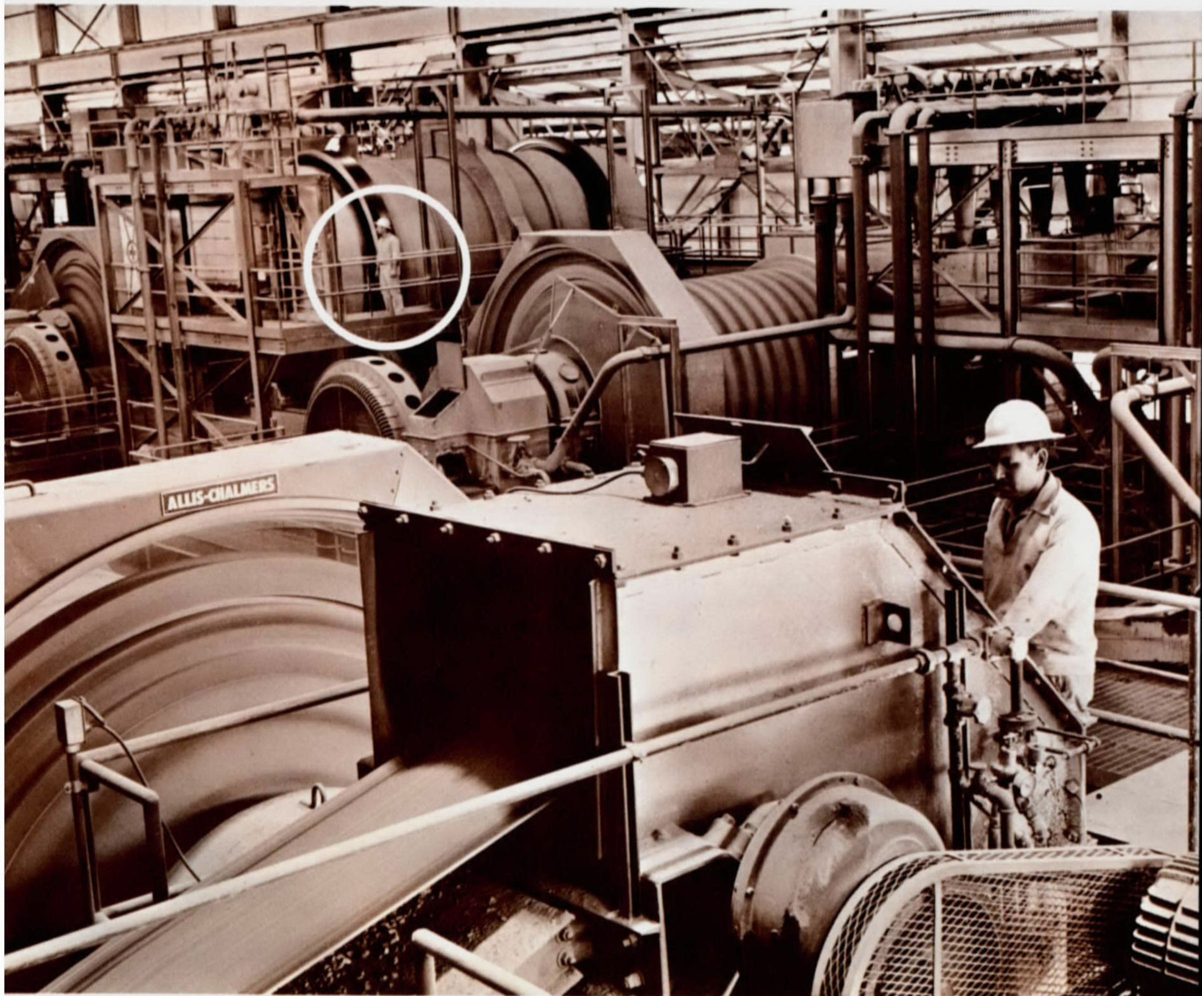


The smaller of the two buildings above is the "Transfer House" that receives up to 1800 tons of ore each hour from Crusher, and deposits it in the larger building which is Fine Ore Storage Bin. This tent-like steel and concrete building is longer than a football field and has ore storage capacity of 28,000 tons.

The "dry grinding" cycle – which began at the mine's Primary Crusher in Ray – is completed by the storage of finely crushed ore in Fine Ore Bin at Hayden.

Milling and Grinding

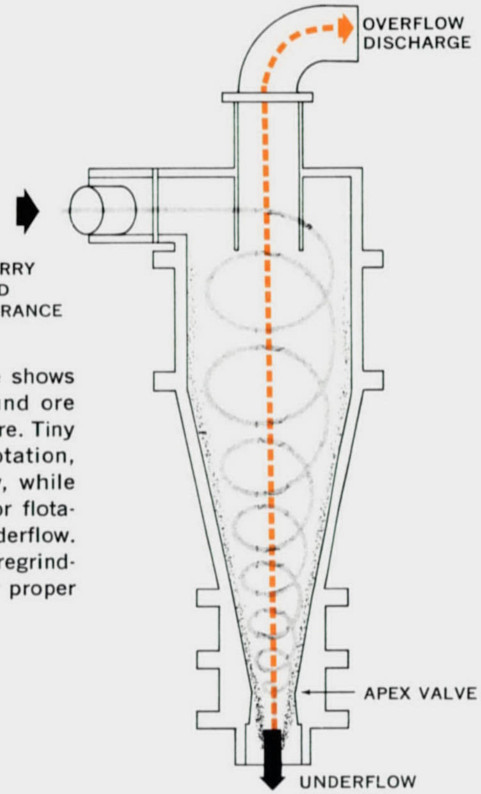
Reducing copper ores to powder fineness



The "wet grinding" cycle begins when the minus-half-inch ore is mixed with water and fed into the six Grinding Sections at Kennecott's Concentrator in Hayden. Each of these sections is headed by a rod mill for coarse grinding, ball mills for fine grinding and cyclones for classification.

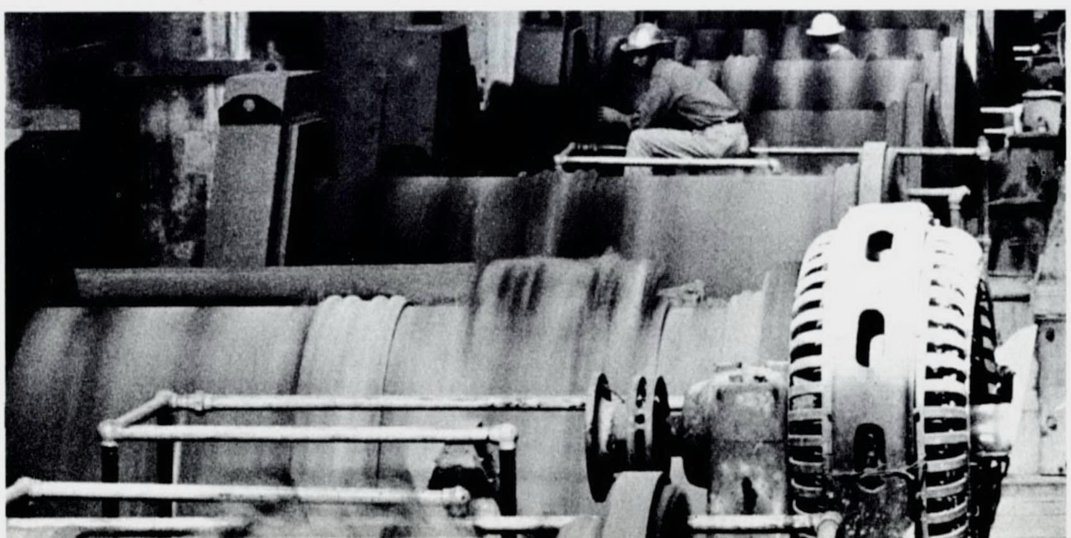
Left: A Kennecott grinding operator checks flow of finely crushed ore into one of the rod mills. Man at upper left of photo is a ball mill operator.

The end-plate of a rod mill, below, was removed to permit taking this photograph. The round objects are the ends of heavy steel rods that tumble over and over as the mill revolves. Copper ore, mixed with lime and water, is pulverized by this action.

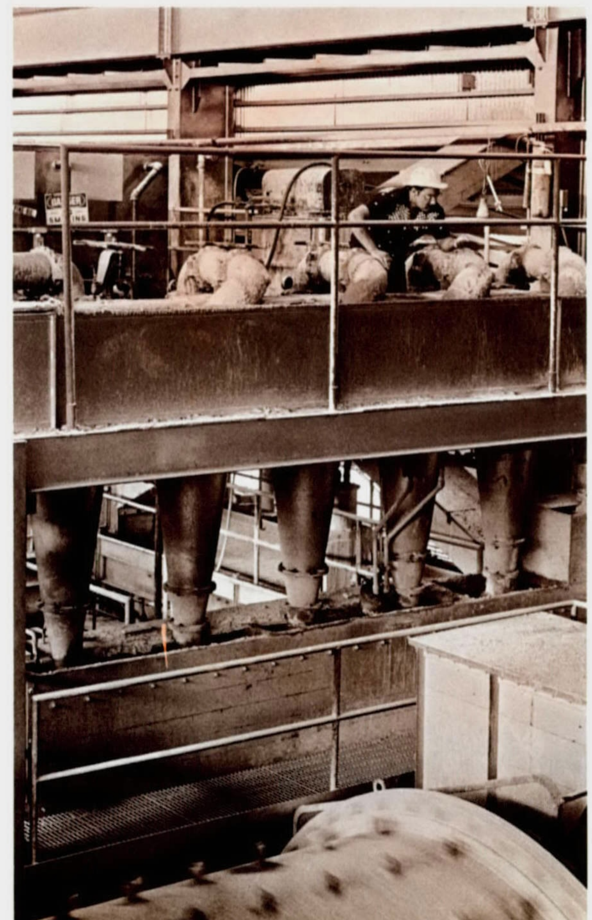


Cross section view of a cyclone shows where the slurry of finely-ground ore and water is fed in under pressure. Tiny particles, properly sized for flotation, are carried off in the overflow, while larger particles not yet ready for flotation drop out by gravity as the underflow. This material will be subject to regrinding and then cycloned again for proper classification.

Battery of 16 ball mills pulverizes rod mill discharge to further fineness. Classification by cyclones at various points in the milling circuits determines if the material is ready for flotation or further grinding. Ball mills work like rod mills, except that baseball-size steel balls are used to crush ore instead of tumbling steel rods.



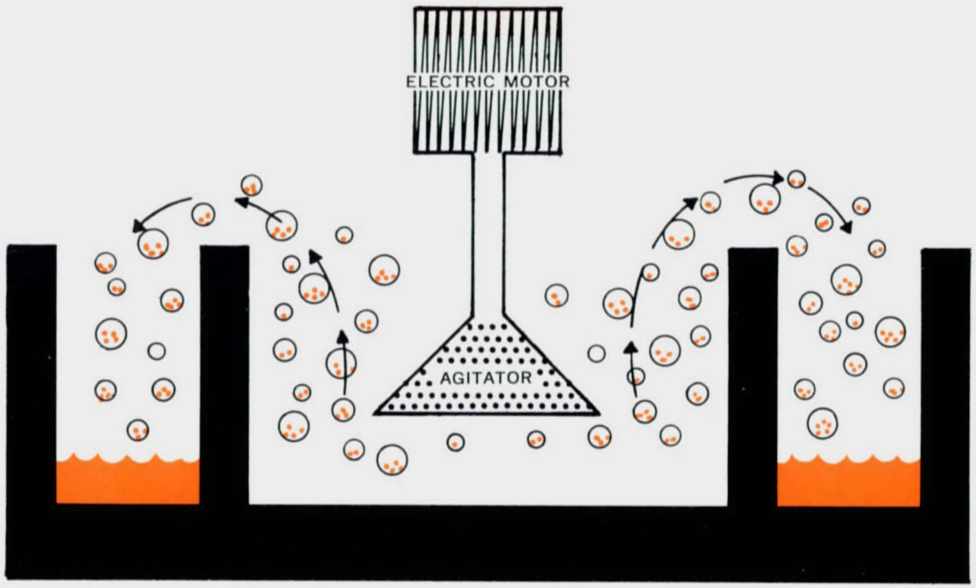
In the "wet grinding" circuit, cyclones are used at various points to properly size the material for optimum flotation recovery. Material rejected for flotation feed is returned for regrinding.

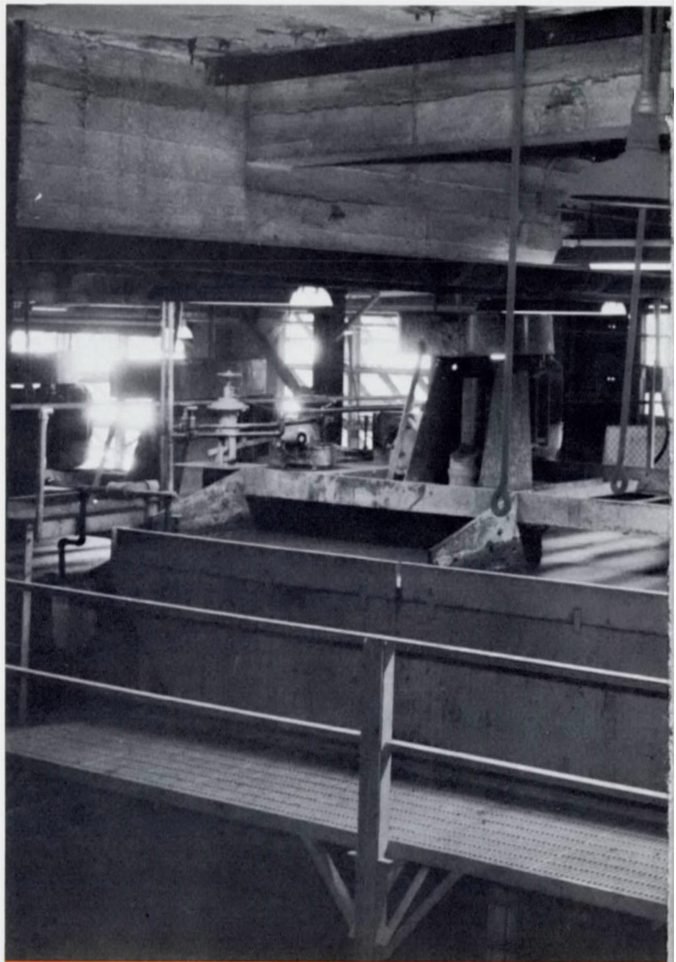


Flotation:

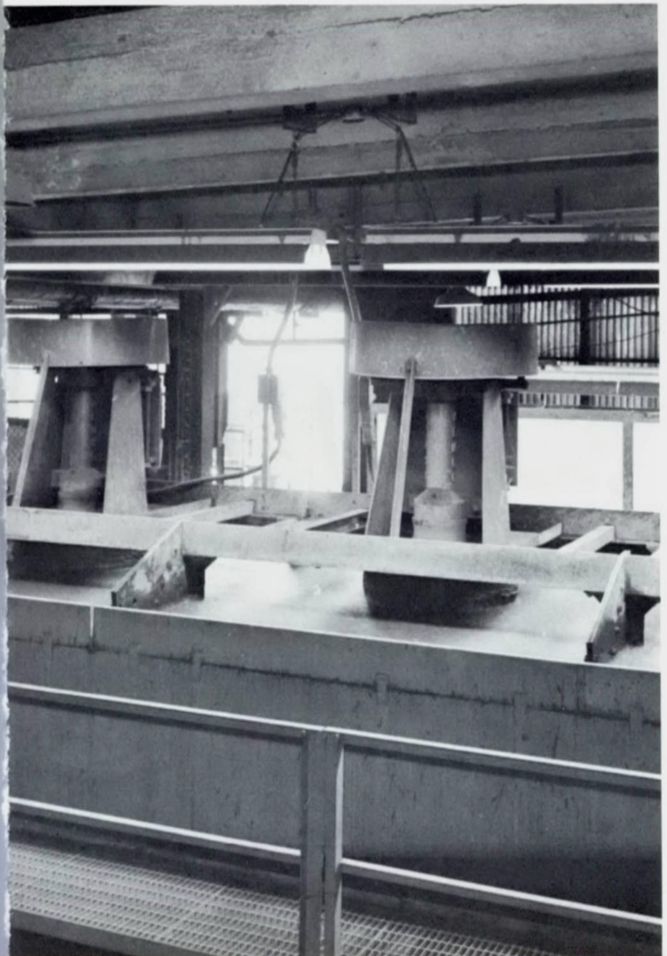
Tiny ore particles "hitch-hike" a ride on rising bubbles

In the Flotation process, the ore – mixed with two reagents, a "frother" and a "collector" – flows through flotation cells. The sketch below shows an end-view of the cell and the collecting "launders" on each side. Agitation in each cell section is provided by a whirling disk to create bubbles from the "frother". This action causes millions of oily, sticky bubbles to form and rise, carrying ore particles up and over the top of the cell's center section into "launders" on each side.



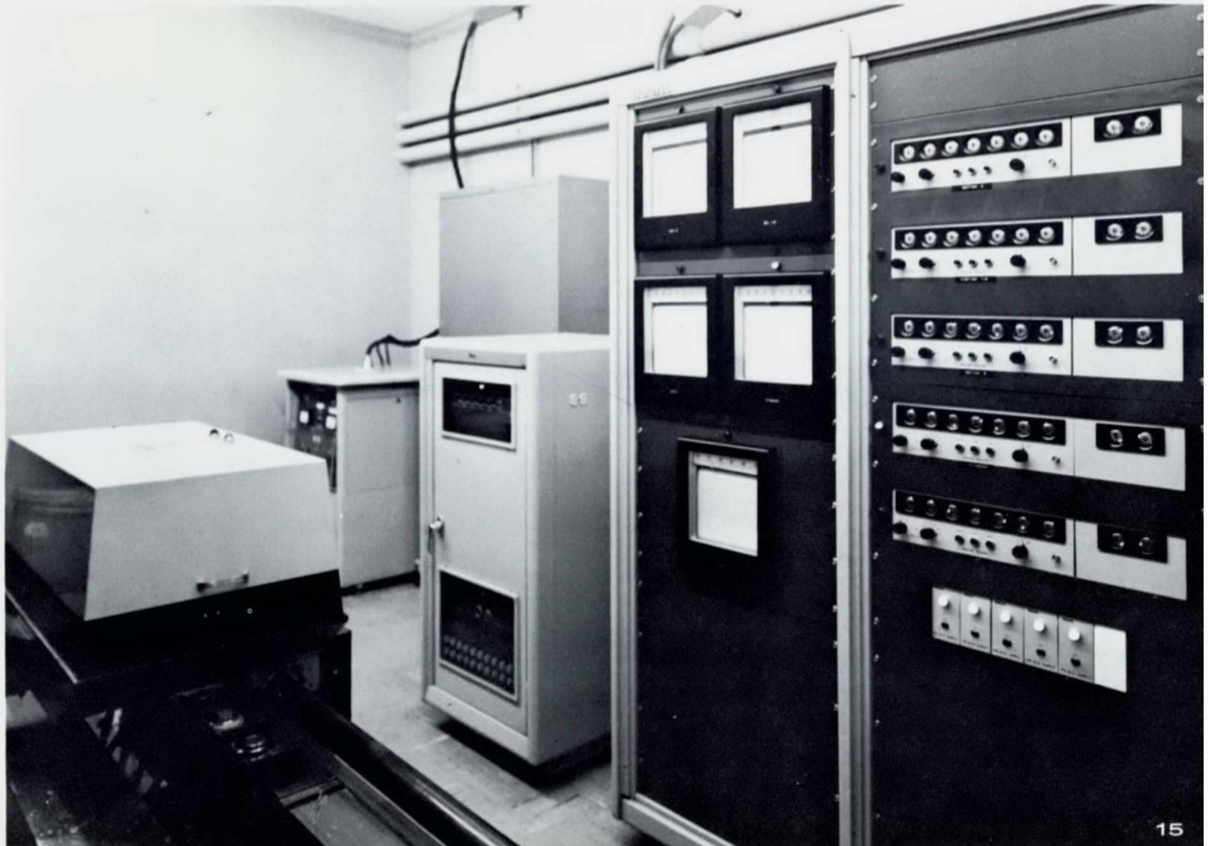


Modern, high-volume mechanical flotation cells have recently been installed in the Hayden Concentrator replacing older, smaller air flotation cells. Five, 15-cell rows of these



latest-type units have greatly modernized the concentration process at Kennecott's Arizona operation providing increased throughput of an improved product.

An important unit in controlling the quality of the concentrate copper is the "On-Stream X-Ray Analyzer." It provides immediate information about the chemical makeup of materials from five key stages in the flotation circuit.

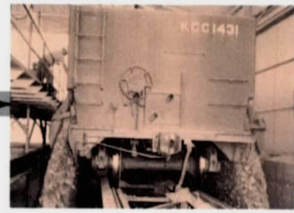


MINING at Ray, Pinal County

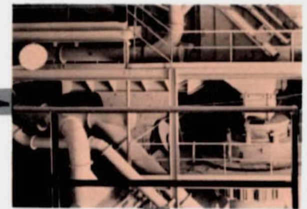
M

DRILLING & BLASTING

PRIMARY CRUSHER



BY TRAIN TO THE MILL



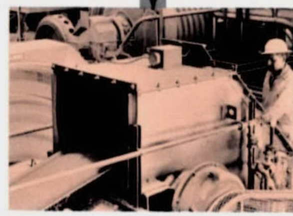
SECONDARY CRUSHER

FLOTATION

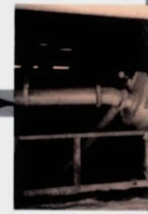
LEACH AND SILICATE ORE REMOVAL

SILICATE ORE CRUSHING

WATER



FINE GRINDING



CYCLONE

LEACH DUMPS

ACID

WATER

VAT LEACHING

99.9% PURE COPPER CATHODES TO MARKET OR FURTHER TREATMENT

ELECTROWINNING

COPPER PRECIPITATION PLANT

Three Step

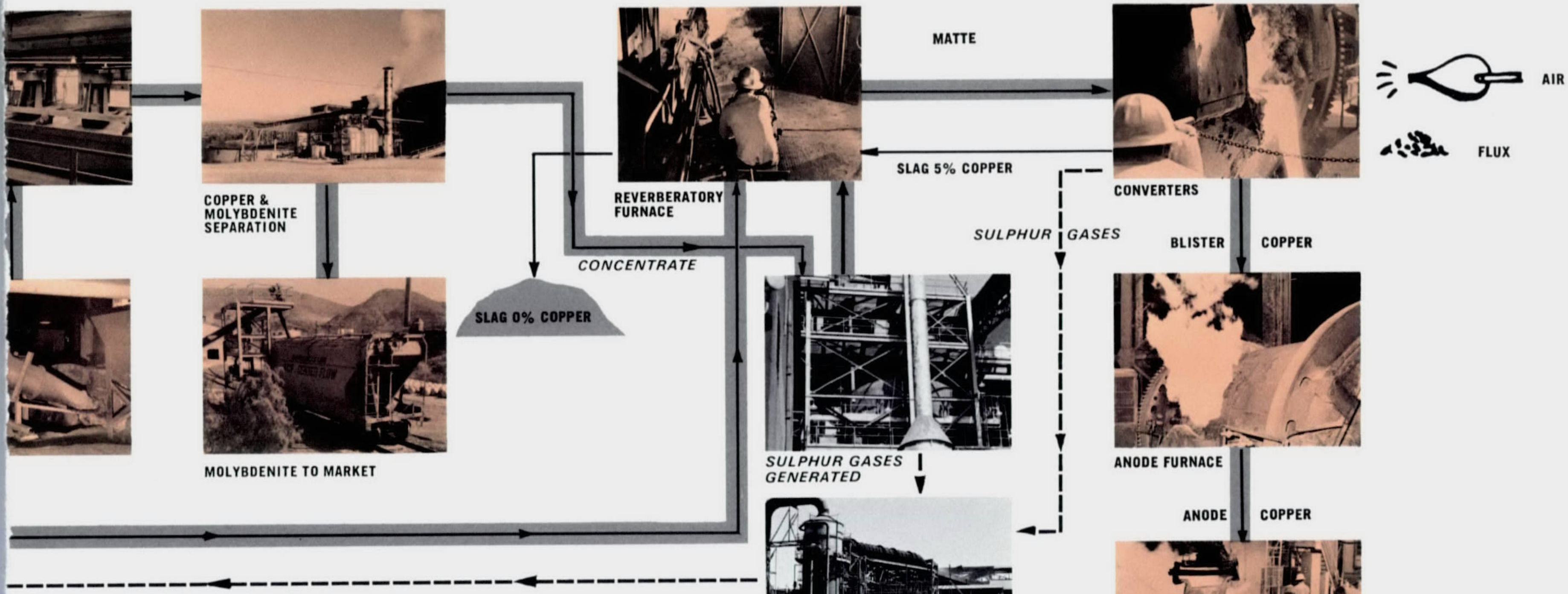
1. Mining. Working around the clock, we remove an average of 25,400 tons of ore every day from our mine at Ray, along with about 75,000 tons of overburden, or waste material. These figures do not include ore for processing in the Silicate Plant. The usable ore contains only about 0.85% copper — about 17 pounds of copper per 2,000 pounds of ore.

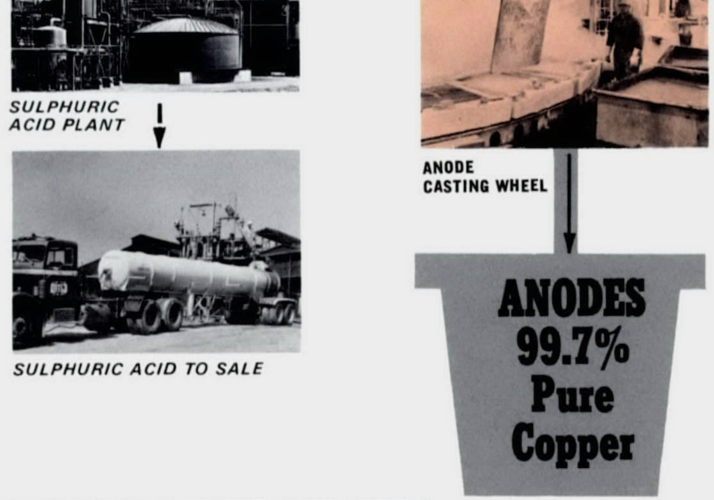
2. Milling. By the time the ore moves through primary crushing, secondary crushing and the wet grinding cycle, it's about the consistency of beach sand. Cyclones are utilized to separate the very fine flotation size material from larger bits, which are returned for additional grinding. In flotation, the dust-size ore particles are subjected to a chemically-treated solution which separates the copper particles from worthless waste called "tailings." A concentrate of 20% copper is produced in flotation. Before this concentrate is sent to the smelter, molybdenite is removed by additional flotation. The "moly" concentrate is sent to Kennecott's Utah operations for processing into a saleable product.

3. Smelting. Heat and more heat does the job here. At a temperature of 2800°F., the concentrate melts in the reverber-

Solid lines on the above flow chart indicate flow of the normal mining, milling and smelting operations.

ILLING at Hayden, Gila County SMELTING



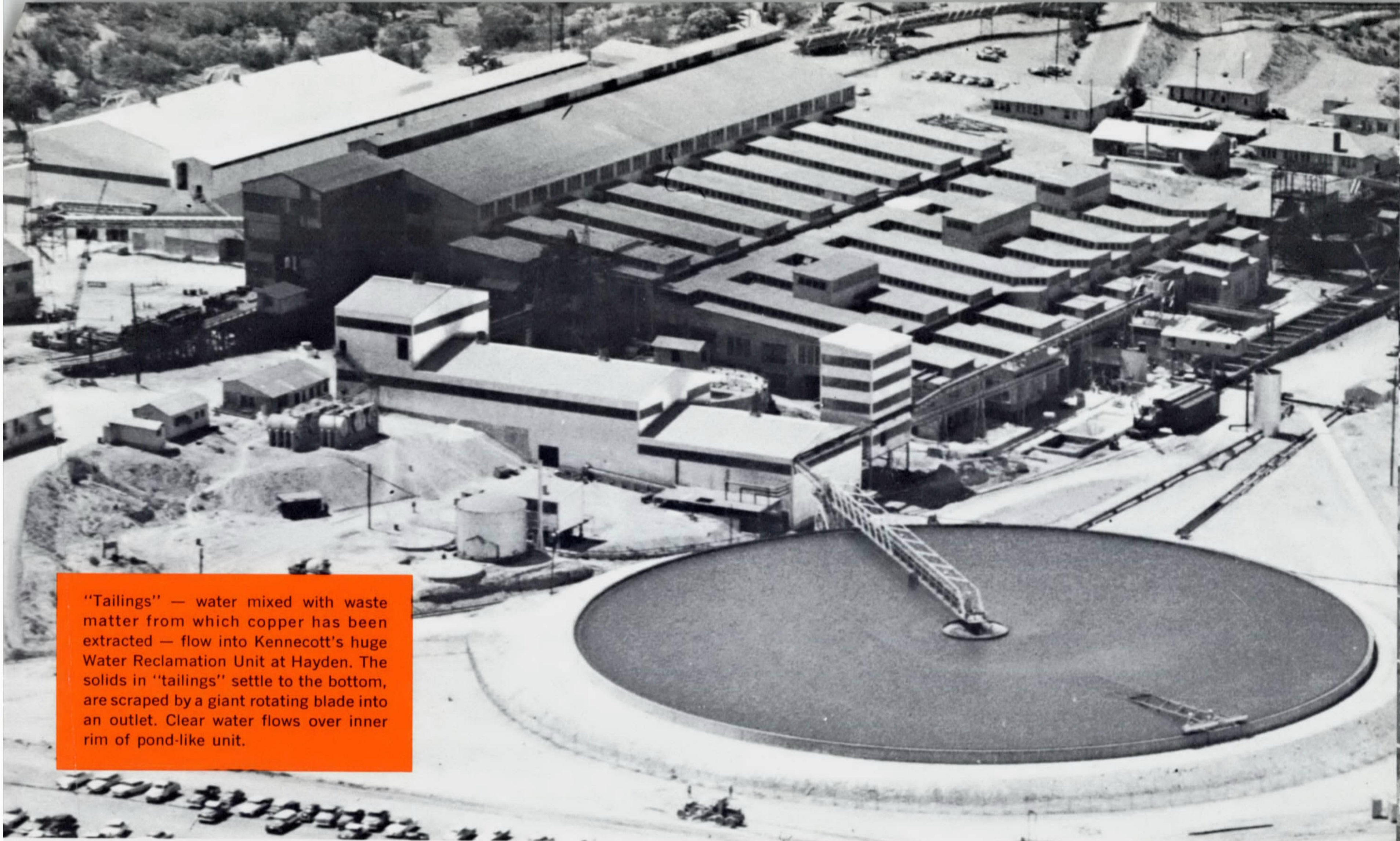


s to Copper

atory furnace, worthless slag floats to the top to be skimmed off, while the matte, a mixture of iron, sulphur and about 30% copper, is tapped from the bottom of the furnace. Iron and sulphur are removed in the converters, and the resulting "blister copper" (99.5% pure) is then further purified in the anode furnace. The orange-hot liquid is poured into molds on the slowly revolving anode casting wheel, and comes out as 700-pound wedges or "anodes." From Hayden, the copper goes to Kennecott's electrolytic refinery in Maryland. Though they're 99.7% pure copper when they leave Arizona, our anodes need still further purification before they meet today's exacting standards.

Completed in 1969, the Silicate Ore Leach Plant in the mine area and the Acid Plant, adjacent to the smelter at Hayden, together will result in about 24,000 tons of new copper production annually. The acid is used to leach, or dissolve, the copper in the silicate ore. The acid-water-copper solution is circulated through the electrowinning cells, electrical current is passed through the solution and the copper is plated onto starting sheets. The resulting copper cathodes are almost 100% pure. More details will be found on page 29.

Broken lines on the above flow chart indicate flow of the Silicate Ore Leach Plant and the Acid Plant operations.



"Tailings" — water mixed with waste matter from which copper has been extracted — flow into Kennecott's huge Water Reclamation Unit at Hayden. The solids in "tailings" settle to the bottom, are scraped by a giant rotating blade into an outlet. Clear water flows over inner rim of pond-like unit.

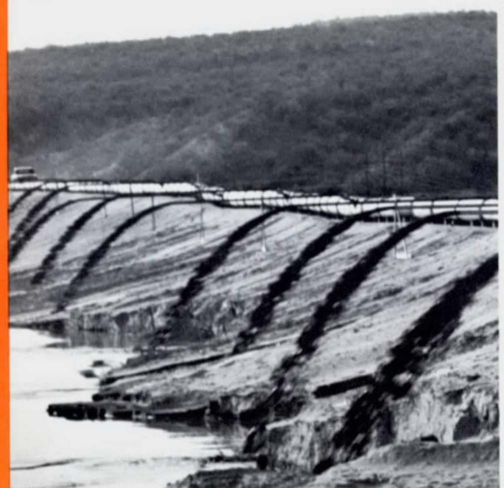
Water Conservation: 13,400,000 gallons per day...

The amount of water available to Kennecott's Ray Mines Division for processing copper ores is limited by Government decree, which apportioned water in the Gila and San Pedro rivers to the legal users. It was therefore necessary, in order to expand copper production to its present-day capacity, to devise methods for reclaiming and re-using large quantities of water. This has been accomplished by building the above Water Reclamation Unit and a tailings water recycle complex. The latter unit consists of huge siphons on the pond to recover water and piping to move it to a 10 million gallon holding pond where it is pumped back to the mill circuits.

A Kennecott workman walks over bridge-like structure alongside big pipe through which tailings flow to center of the 325-foot-diameter Tailings Thickener at Hayden.

This device utilizes radioactive isotopes to measure density of tailings, and to activate valves which maintain most efficient ratio of water to the waste materials.

This dial records the amount of tailings handled by the thickener pond, and other information about system's operation. Saving: 5 million gallons of water per day.

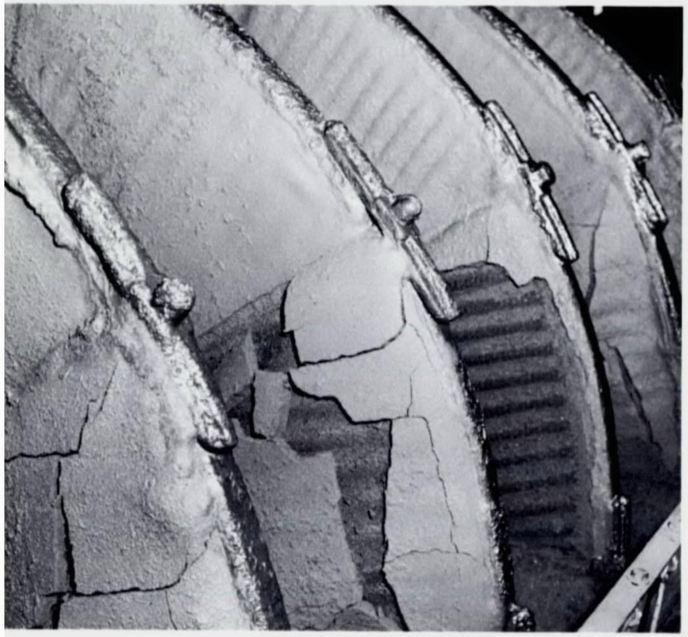


Tailings pour into a 900-acre disposal area. A crew of 13 men, two drag lines, three dozers and two scrapers are required to build dikes, maintain and patrol them around the clock. Water in the pond is siphoned off and sent back to the mill for re-use. Photo at right: night dike-walker.

Smelting:

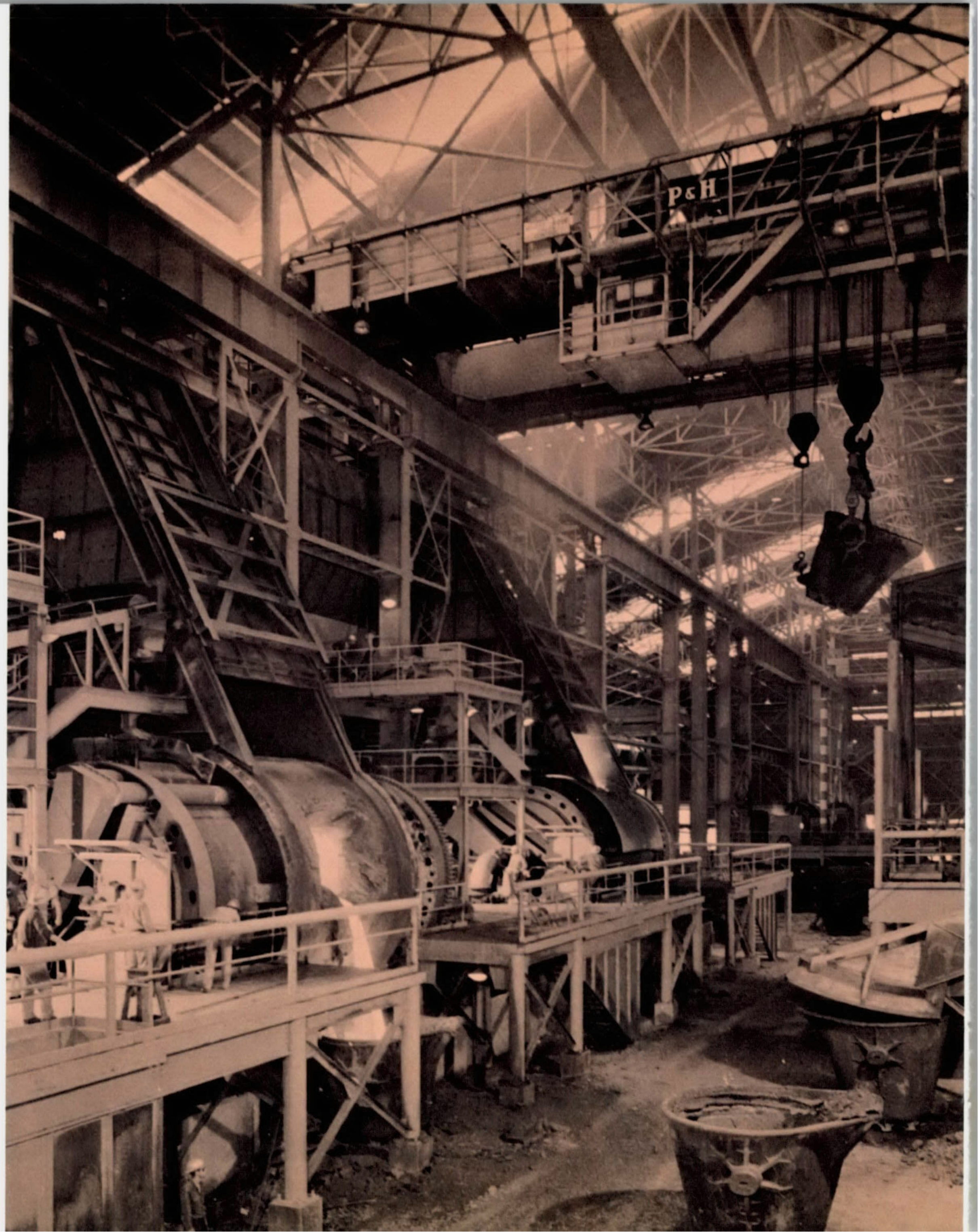
2800° F heat

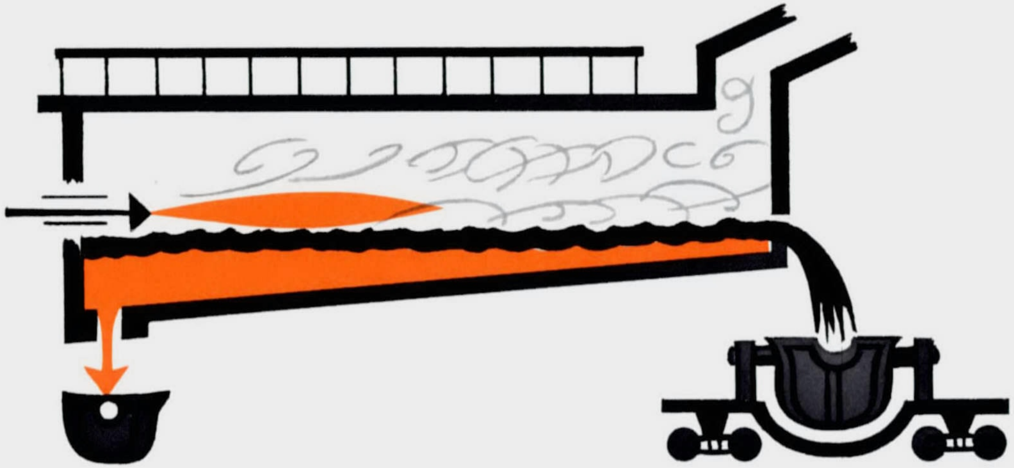
that liquefies metals



Above: The wet copper "concentrate," which at this stage contains 20% copper, is dried on these disc-type vacuum filters. After being dried, it goes to storage bins — and from there to Smelter Building.

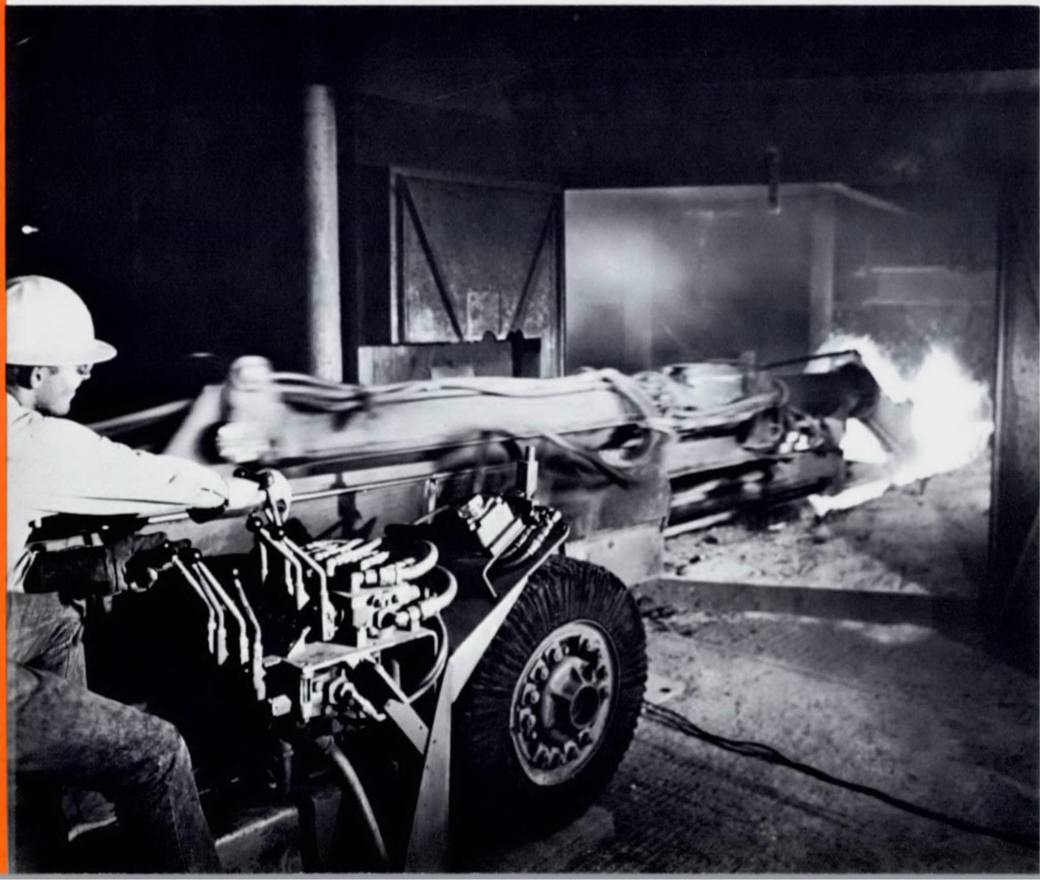
Kennecott workmen, in lower left corner of photo at right, are dwarfed by immense size of the equipment in Converter Aisle of Smelter Building. High above them another Kennecott workman operates huge crane that travels full length of the Converter Aisle.



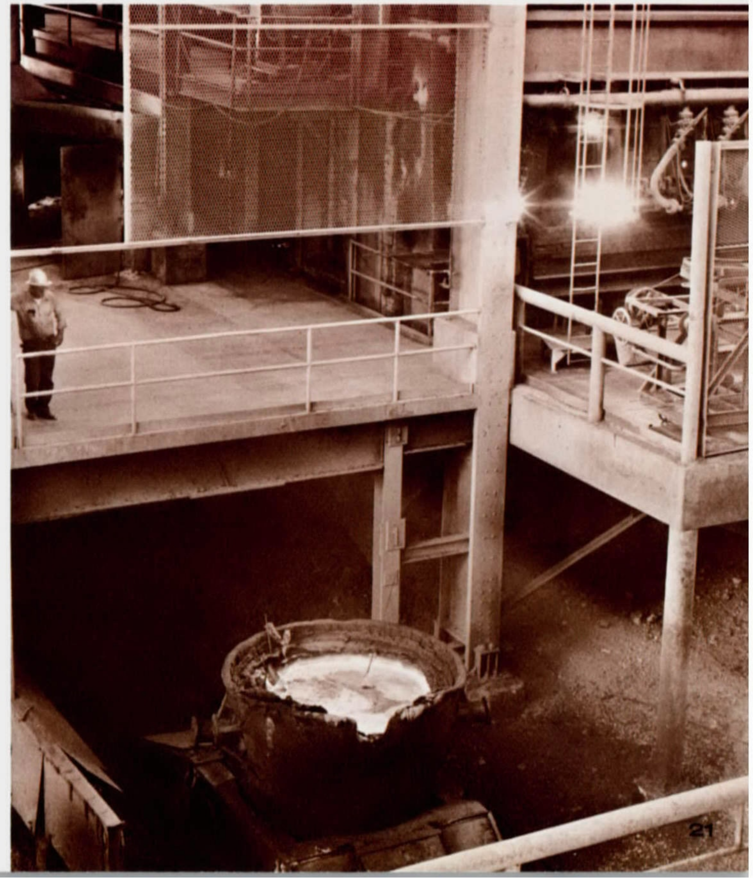


This sketch shows how copper concentrates are liquefied by 2800-degrees Fahrenheit heat in 35-by-120-foot Reverberatory Furnace. The molten material, called the "bath," is maintained at a depth of four feet. It consists of "slag," which contains valueless impurities — and of "matte," which is a mixture of iron, sulphur, and copper. Slag floats to the top and is skimmed off into steel pots of 15-ton capacity which are mounted on rail-cars that haul it to disposal area. The matte flows into 20-ton capacity steel ladles, for transportation by overhead crane to a Converter Furnace.

At a safe distance from molten metal, operator of Matte Tapping Machine extends long two-inch drill and bores a hole in furnace wall — allowing matte to flow into huge steel ladles. Later, the tap-hole will be filled with wet clay extruded under intense pressure from the tube above drill which bored hole.



Kennecott workman at left of photo below is operating controls that move matte-car, containing 20 tons of matte copper, into Converter Aisle. The ladle will be lifted off car by overhead crane and taken to one of the three huge Converter Furnaces.



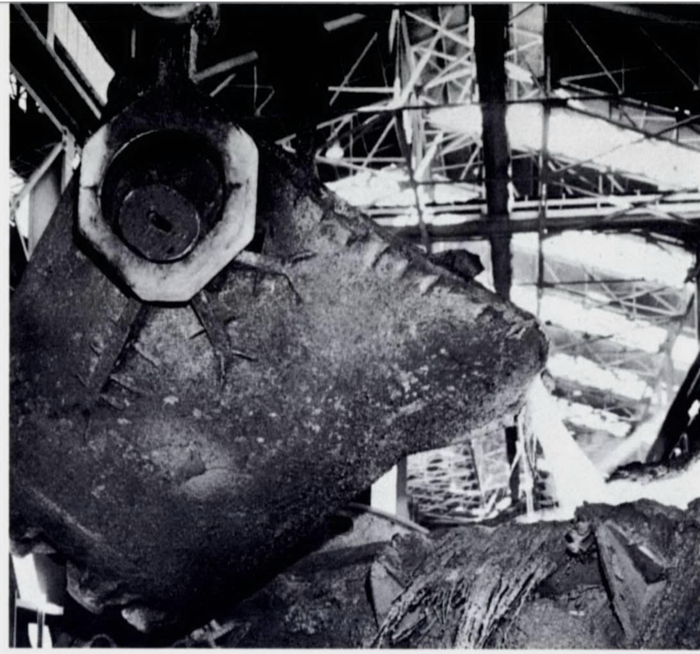
SLAG

Left: A slag train of three steel pots, each filled with 15 tons of molten waste matter, makes trip from Reverberatory Furnace to disposal area.

Below: Pouring of slag at night creates a spectacular sight. It flows downhill like lava from a small volcano crater, and solidifies as it cools into rock-hardness. Result: man-made mountains that never stop growing.

MATTE

Matte is poured into cylindrical Converter Furnace. Then compressed air is blown into it, causing sulphur in the matte to go up the flue in form of sulphur dioxide. A new plant processes the SO_2 into sulphuric acid, which is used to recover copper from silicate ores. Iron impurities become iron oxide, are removed by adding silica rock flux to form slag that is skimmed off for reprocessing.



Sampling . . .

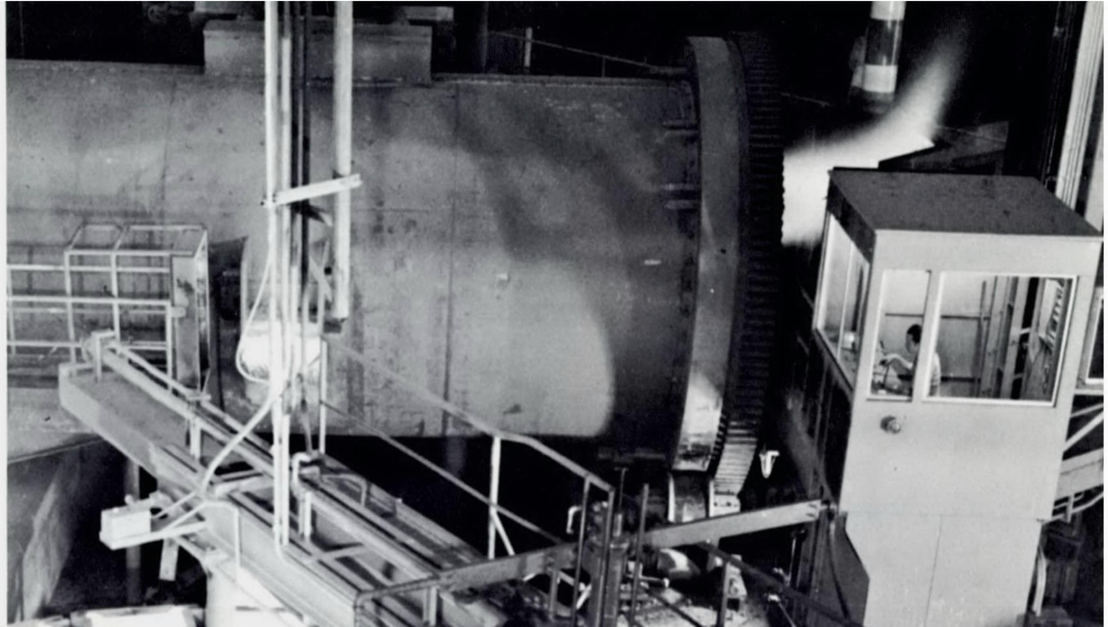
The Quality Control department plays a vital role in mining, milling, and smelting of low-grade copper ores by Kennecott's Ray Mines Division. Analysis of rock samples taken in the pit enable the production planners to schedule the most efficient handling of material – and to supply the Reduction Plant and Smelter with an uninterrupted flow of the required quantity and quality of ores. Around-the-clock sampling also provides a constant check on the operating efficiency of each process and piece of equipment.

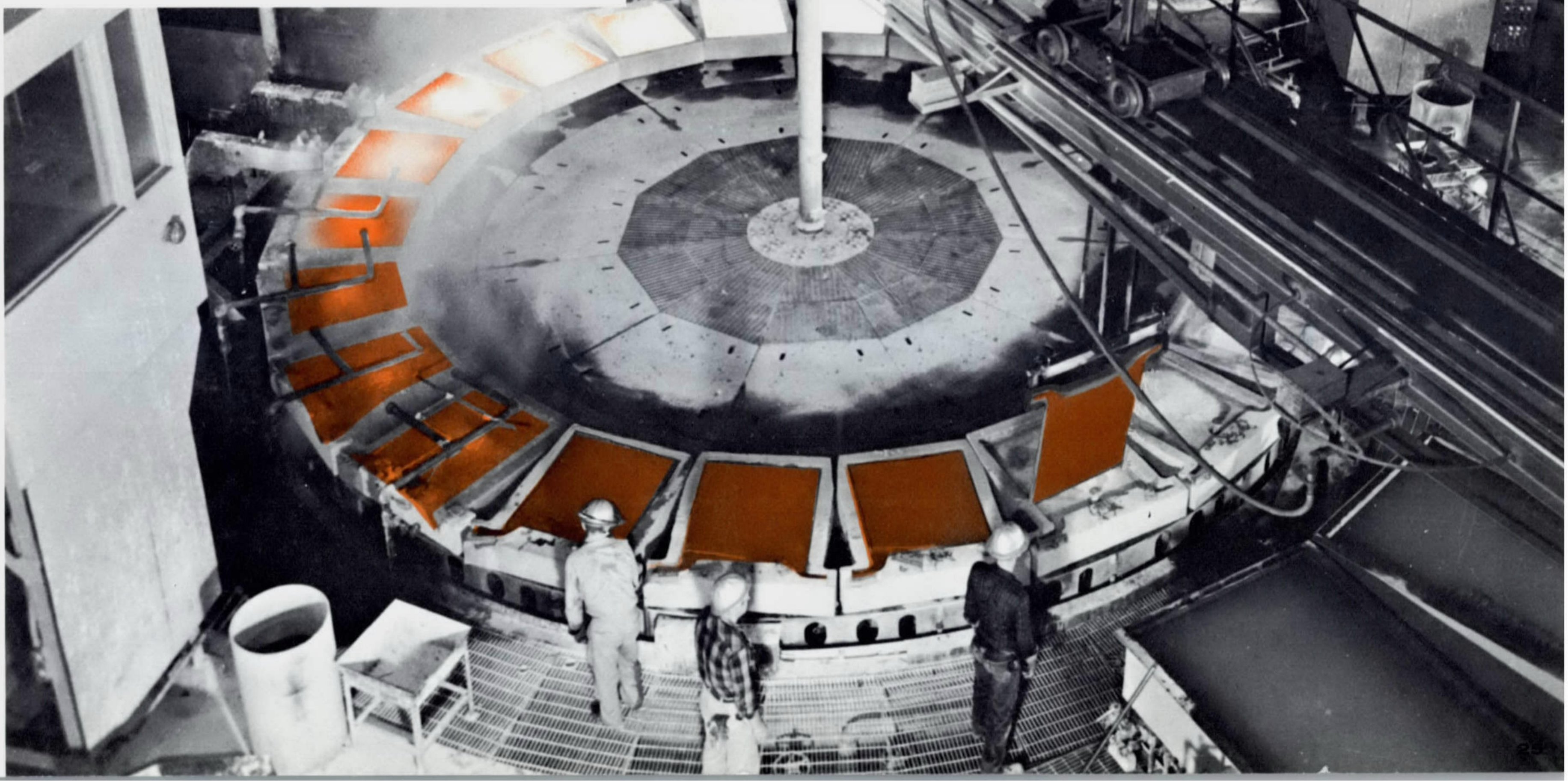
As molten copper is poured from Converter Furnace into giant ladle, a Kennecott workman on a platform uses long-handled "spoon" to collect a sample for analysis by Quality Control.

Left: Twenty tons of molten "blister" copper — more than 99% pure, but still not yet pure enough to be used commercially — is transported by overhead crane and poured into Anode Furnace.

...and casting

Molten copper is refined by blowing in propane gas. When the proper grade is reached, the anode furnace rolls and fills a pouring spoon — which, in turn, fills the molds on the slowly revolving casting wheel. The shape of the molds forms the metal, as it cools and solidifies, into wedge-shaped slabs with ear-like projections. The ears simplify handling, and will be used later to hang the anodes in tanks for electrolytic refining. After partial cooling, anodes are lifted from the molds and immersed in water for further cooling.

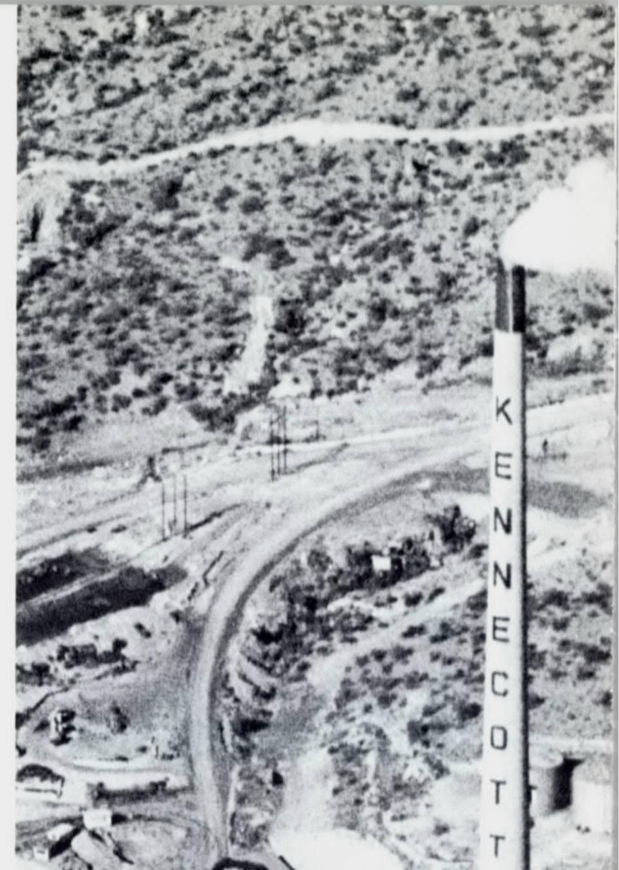


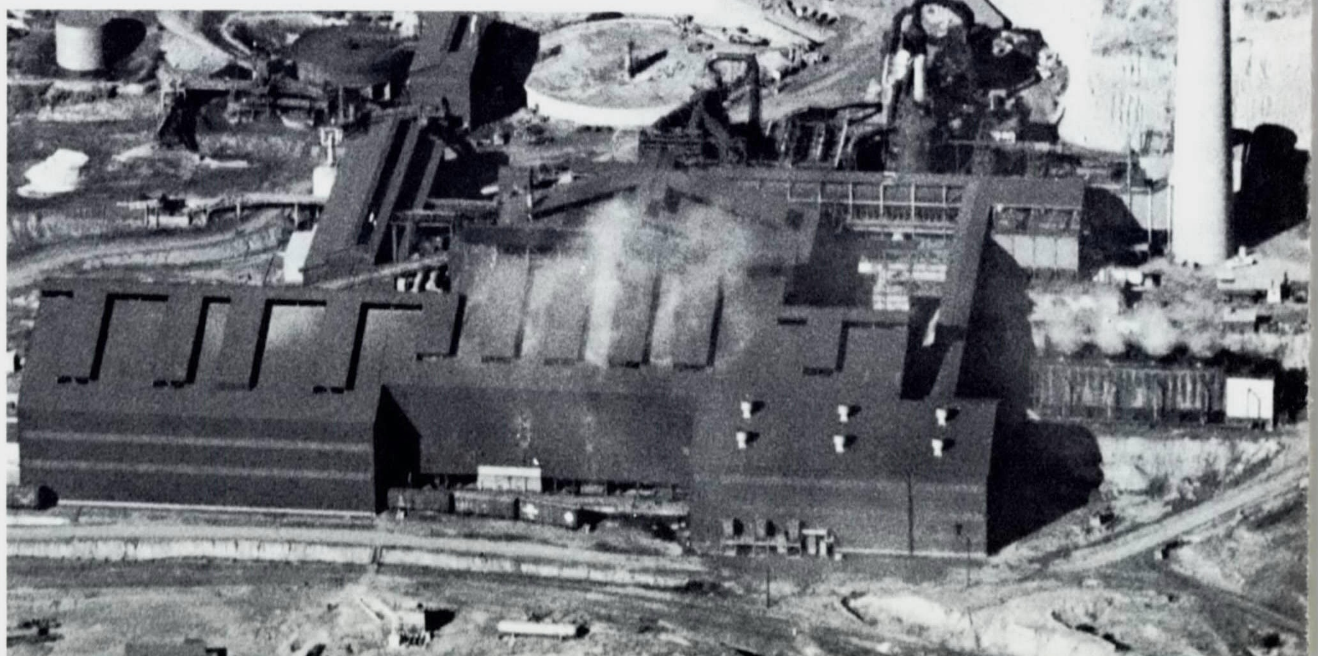


99.7% pure copper anodes start a journey

Anodes, after being approved by Quality Control, are picked up, several at a time, by fork-lift trucks and loaded in railroad cars for shipment to the electrolytic refinery.

Despite the 99.7% purity of the anodes, the copper is still not free enough from impurities to be used in manufacturing. The output of the Ray Mines Division's smelter is sent to the Kennecott Refining Corporation in Maryland for electrolytic refining. There the grade of the metal is increased to 99.997% pure copper by dissolving the anodes in an acid solution, then "plating" the copper onto pure copper sheets.





Aerial photo shows Smelter Building and supporting facilities of Kennecott Copper Corporation's Ray Mines Division in Hayden, Arizona. For each 700-pound anode produced here, 98,000 pounds of copper ore must be processed.

Lime Quarry:

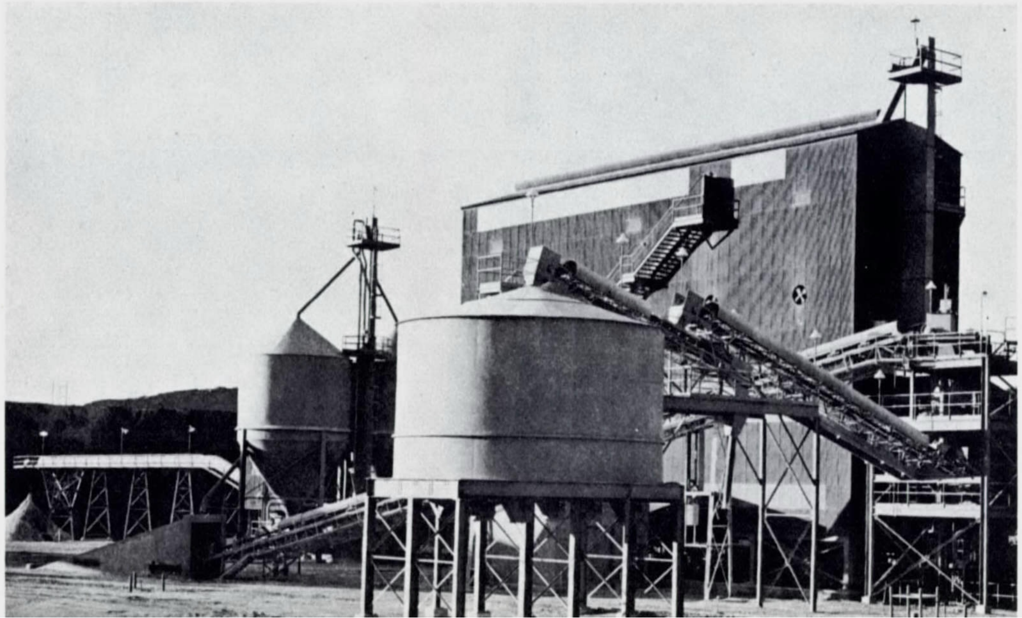
MINE-WITHIN-A-MINE

Milk of lime required for "pH" control in the flotation process at the Hayden Concentrator, is produced in a special plant. Impure limestone comes from a quarry one mile east of Hayden. Some 6,000 tons per month are treated in Kennecott's Lime Processing Plant.

Lime quarry's operation is similar to the Ray copper mine. Blast-holes are drilled in the lime rock; an explosive charge is detonated; the broken rock loaded by shovels into trucks and transported to the Lime Processing Plant.

Lime Processing Plant consists of four sections: crushing, screening, calcining, and slaking. It takes only three men to operate plant, which can process 200 tons of lime rock per day to produce 100 tons of burned lime.

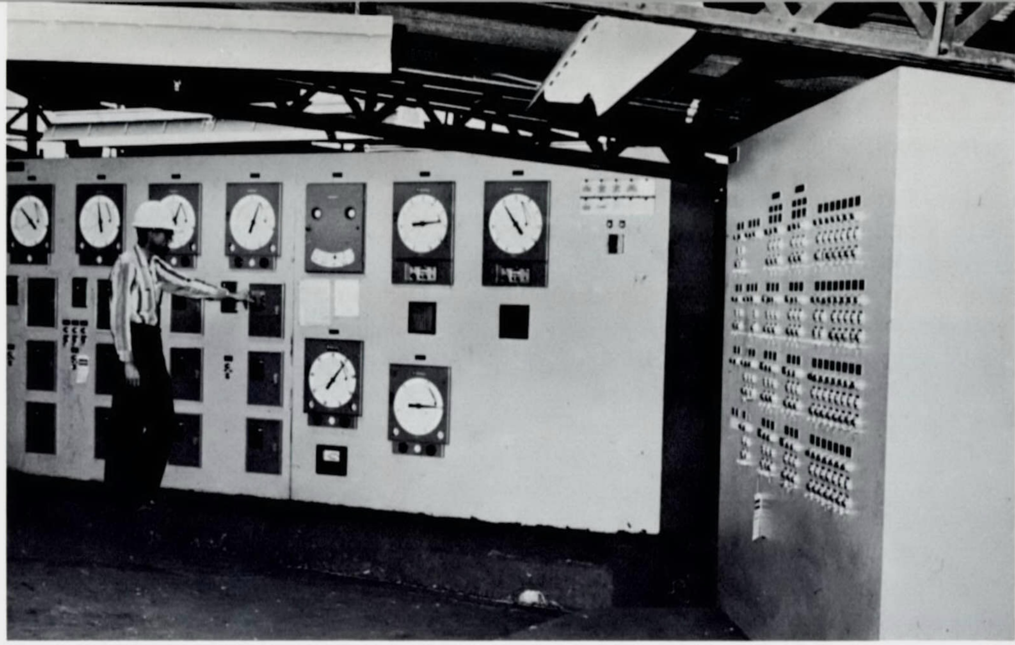
Like all Kennecott's facilities at the Ray Mines Division in Hayden, the Lime Processing Plant utilizes conveyors to increase efficiency, cut costs.



Moly Plant

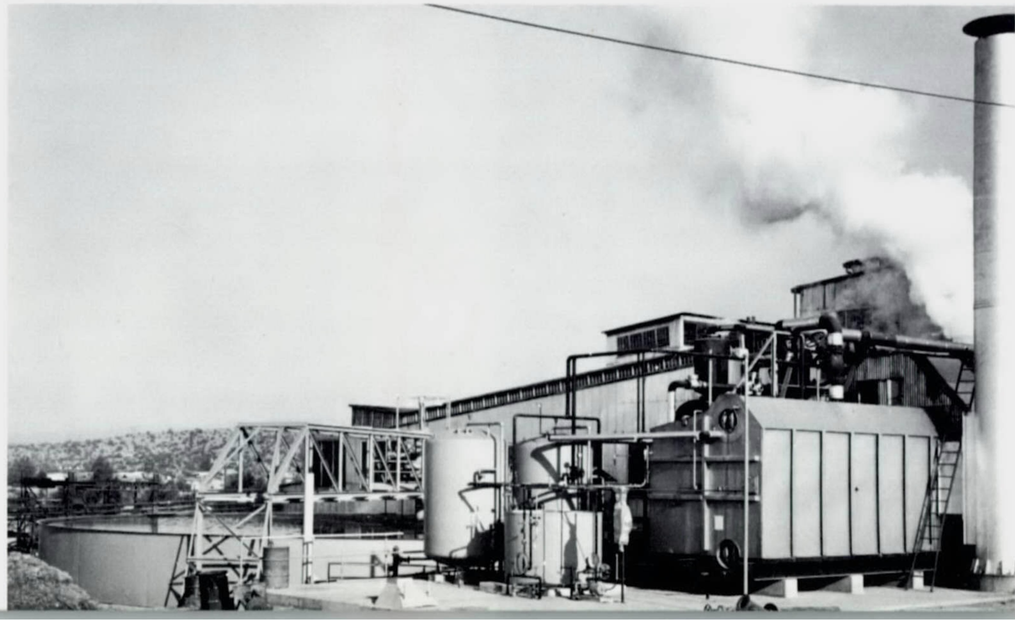
Early in 1967, Ray Mines Division began operation of a molybdenite or "Moly" Plant for the first time in its history. The plant utilizes the latest in metallurgical techniques to recover molybdenite sulfide that previously went out to the tailings ponds. The moly concentrate is now shipped to Kennecott's Utah Copper Division for processing into marketable molybdic oxide.

Some 900 tons of copper concentrate containing minute amounts of molybdenite are processed daily. Steps include conventional flotation in mechanical cells such as those shown below — followed by steps of cleaning, filtering, drying.



The control center for the Moly Plant is the heart of the operation. Direct reading meters allow the operator to constantly check and adjust the flow of material from one phase to another.

The Moly Plant is located immediately adjacent to the concentrator building at Hayden. Included in the over-all project are railroad car-loading facilities to allow bulk shipment of the moly concentrate direct from the plant.



Silicate Plant

Silicate ore is brought from the mine by huge haulage trucks and dumped into the ore pocket at the primary crusher ❶ where an 84" by 60" jaw crusher breaks the ore down to seven inches in diameter. The coarse-crushed ore is taken by conveyor belt to the stockpile ❷ and, when needed, is conveyed to the secondary and tertiary crusher building ❸. Cone crushers reduce the ore to minus ⅜" and it is moved to fine ore storage ❹. In the classifier building ❺ a two-step classification is made using dry sizers, followed by rake-classifiers. All material over 80-mesh (3/16 of an inch) goes to the vats in the sands circuit, while the balance starts through the slimes circuit.

Sands Circuit:

Sands are taken by conveyor belt to the leach vats ❻ where, with the aid of "bridging conveyors," they are deposited in the 100′ by 110′ vats. The bridging conveyors span the vats and run the length of the vat area on railroad tracks. There are 14 leach vats, each running on a 14-day cycle — one day for loading, ten days of leaching and three days for the washing and unloading operation — and each holding about 10,000 tons of ore. During the ten-day leach period, a sulphuric acid and water solution is pumped into first one, then another of the vats, until it has passed through all ten of the vats being used for leaching. As the solution goes from vat to vat, it dissolves more and more of the copper in the ore and finally, heavily laden with copper, is pumped into the solution storage tanks ❼. Following leaching, the spent ore is washed and then removed from the vats by a large clamshell suspended from a giant gantry crane, and finally sent to a tailings pond. In the electrowinning building ❽, the pregnant solution is pumped through 400 cells in which are suspended thin copper sheets. An electrical current passed through the sheets and the solution causes the copper to be plated onto the sheets and recovered. The cathode copper resulting from electrowinning is 99.9+% pure and ready for market.

Slimes Circuit:

At the classifier building, slimes are mixed with weak tails (solution from which most of the copper has been removed) from the electrowinning section. These almost dust-fine particles are leached in the rake classifiers by the acid remaining in the tail solution. The resulting slurry mixture is then fed through a series of five wash thickeners ❾ from which the overflow is pumped to a precipitation plant where the copper is removed. This precipitate copper will then be redissolved in an acid-water solution and used to make up a portion of the electrowinning feed. Slimes underflow from the last thickener is pumped to a second disposal area.

Quick facts about man's oldest metal:

COPPER

Copper ranks next to iron as a metal of commercial importance. It has the best electrical conductivity of any base metal. Aluminum's conductivity is only 61 percent of copper, but three and one-half times that of iron. Copper is, therefore, the most important metal in the electrical field.

Copper has enough strength for minor structural purposes. It is easily rolled and drawn into wire. It has great resistance to weathering and is of moderate cost compared with competitive materials.

Copper is widely used alloyed with zinc to form brass, which is easily worked and offers good resistance to weathering. Brass is fairly strong and elastic, and because it has good thermal conductivity, has many uses in heat-transfer units such as fins and water heaters. Copper, alloyed with zinc and tin, forms bronze, noted for its resiliency, the ease with which it can be machined, and its resistance to corrosion.

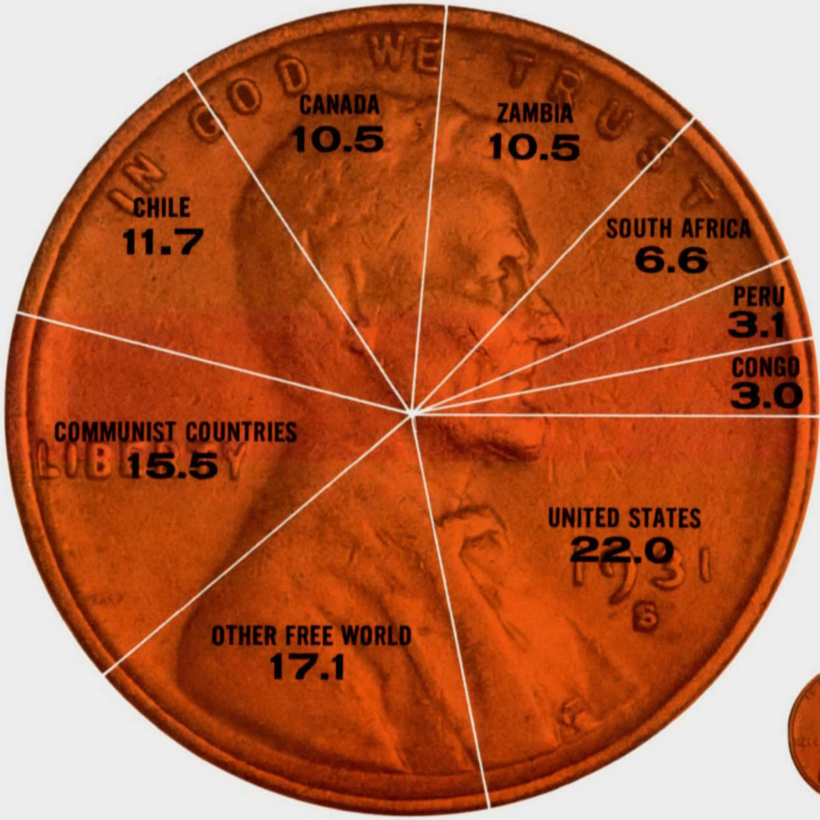
A large percentage of copper is recovered as scrap after it has outlived its usefulness in its originally fabricated form. Of the total copper consumed in the United States, an estimated 60 percent returns to use as copper or copper alloys.

PHYSICAL PROPERTIES OF COPPER

Symbol — Cu . . . Atomic Weight — 63.54
Specific Gravity — 8.96
Melting Point — 1981.4° F.
Boiling Point 4700° F.
Electrical Resistivity — Microhm-cm — 1.673
Tensile Strength — H.D. — 60,000 pounds per square inch (annealed 30,000)
Crystal Structure — Face-centered cubic
Valence — one and two

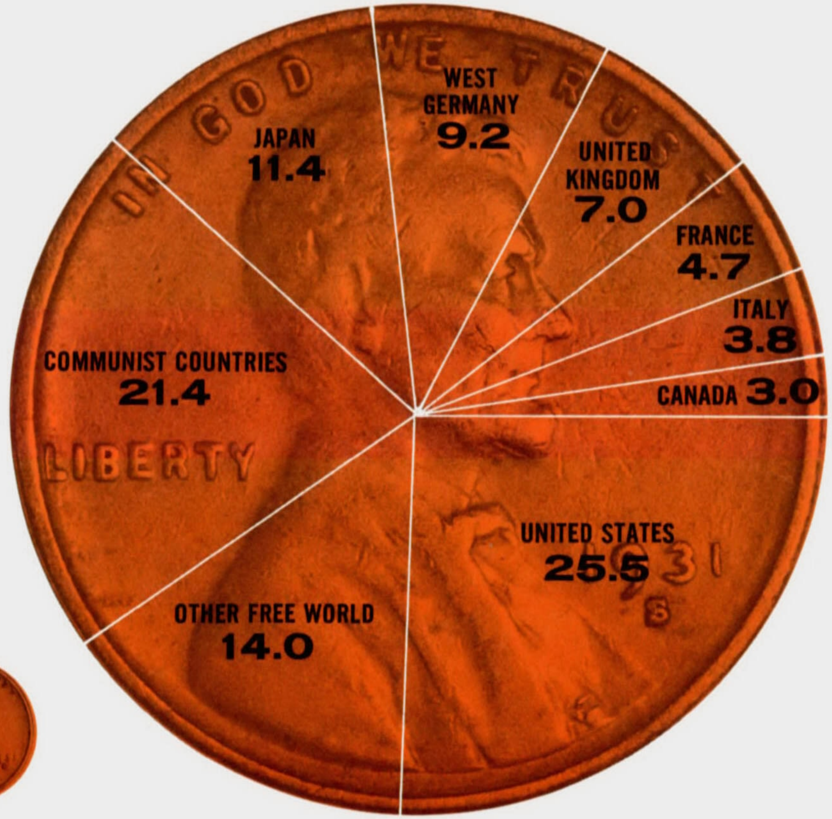
WHERE THE COPPER COMES FROM

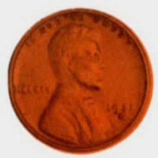
(Mine Production of Copper)



WHERE THE COPPER GOES

(Consumption of Refined Copper)





We've sliced up a familiar copper penny to show the major producers — and the major users — of man's oldest metal.

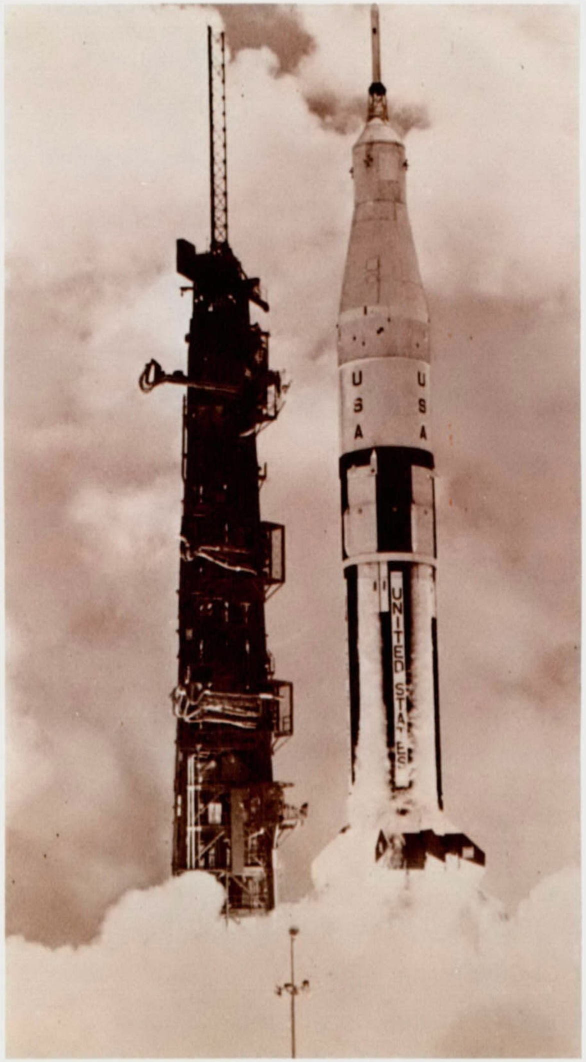
THE UNITED STATES produces more copper than any other free world country.

KENNECOTT is the world's largest mine producer of copper.

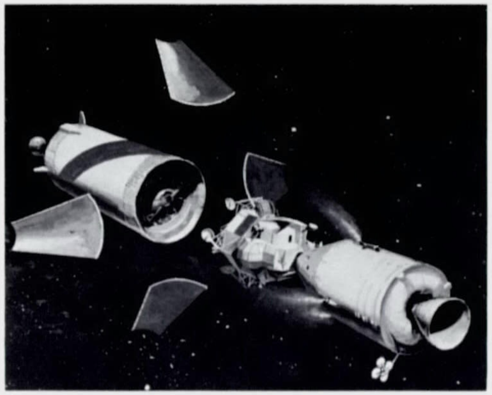
ARIZONA produces more copper than all of the other 49 states combined.

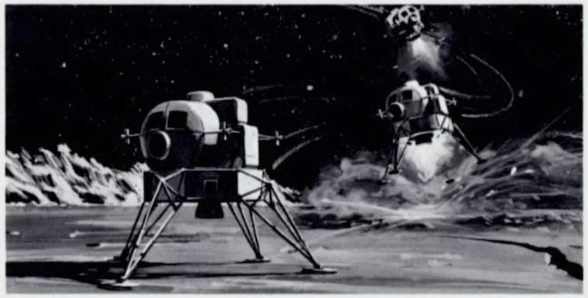
RAY MINES DIVISION produces some 100,000 tons of Arizona's copper every year (at the same time contributing $40 million annually to the state's economy).

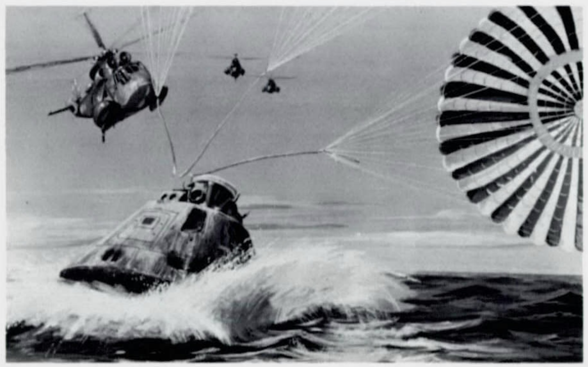
Copper's role in the World of the Future



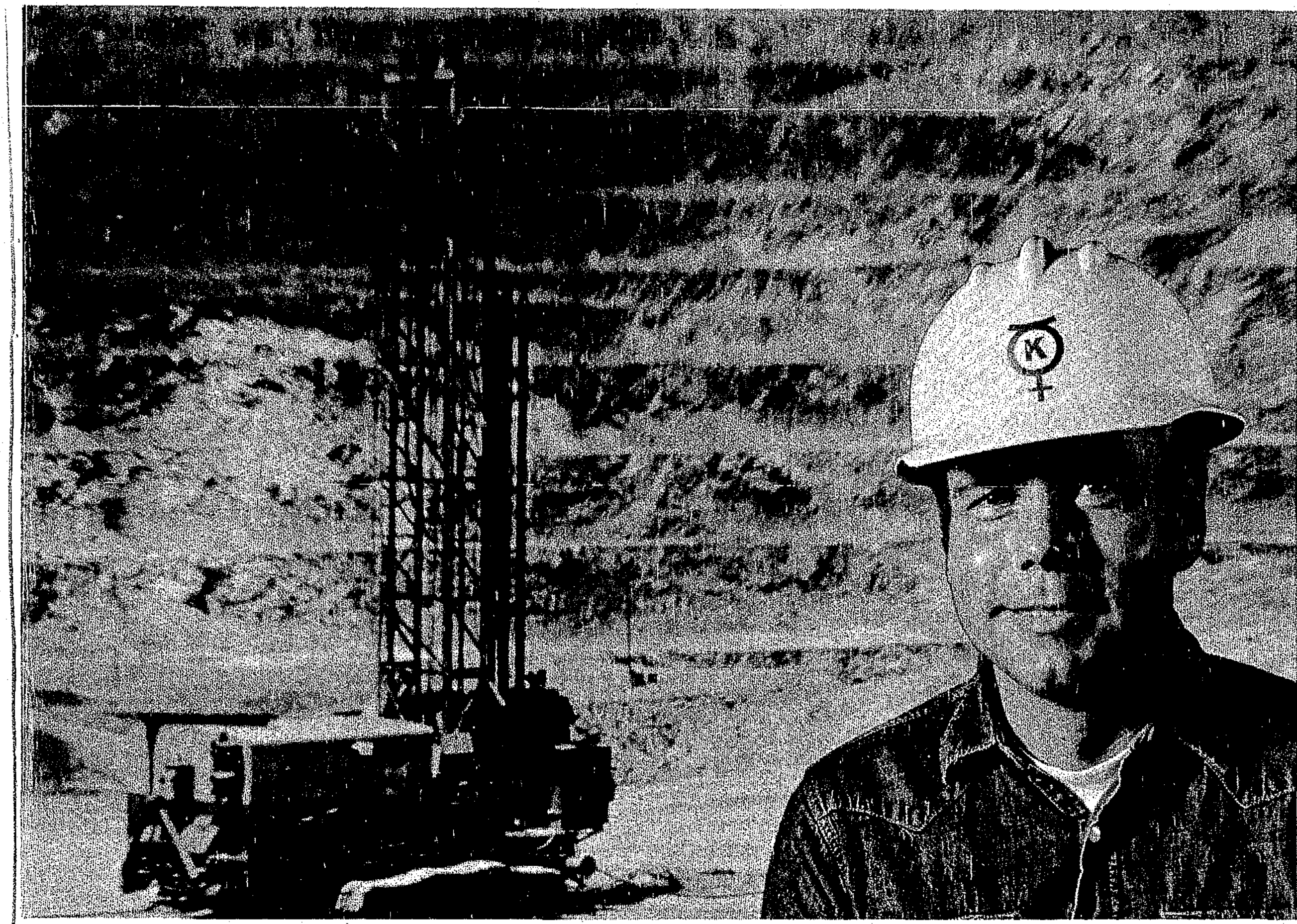
Man's oldest metal, copper, is today contributing more to progress, the preservation of peace, and the betterment of mankind than at any time in history. Kennecott's role will continue to be an important one in the World of the Future – for Kennecott is the world's largest mine producer of copper.







Drawings courtesy of North American Rockwell Corporation and Lockheed Missiles and Space Company



In the past half-century tremendous changes have taken place in Arizona's copper mining industry — brought about by improved mining technology and the investment of hundreds of millions of dollars in large-scale, high-efficiency facilities for the mining, milling, and smelting of low-grade ores.

Today's Arizona copper miners — and mill and smelter men — are highly skilled workers. They work shorter shifts, for wages that are among the highest of any U. S. industry. At Kennecott's Ray Mines Division, employees receive many benefits over and above their regular pay: Premium pay for overtime and time worked on holidays, paid vacations or pay in lieu of vacations; payment for holidays not worked; paid sick leave; group health and life insurance.

These extra benefits paid by Kennecott exceed $3,000 per employee per year — an average of over $250 per month per employee in addition to paychecks. Also, Kennecott contributes, for all employees, into the legally required state and federal funds.

Kennecott Copper Corporation
Ray Mines Division

Off-the-job Citizenship

Kennecott is proud of the excellent citizenship record of its employees at Ray Mines Division. They play a vital role in civic affairs, Parent-Teacher and Scouting work, and the encouragement of character-building sports and activities for boys and girls. Their record of donations to the Red Cross Blood Bank and purchases of United States Savings Bonds is

TOURS

Ray Mines Division offers individual and group tours for persons over 12 years of age. For full information contact the Public Relations Department.

On-the-job Safety

The National Safety Council rates mining as one of our nation's most hazardous industries. Yet, because of the outstanding Safety Programs at Kennecott's Ray Mines Division, its employees are even safer on the job than is the average industrial worker in the United States. And the average industrial worker is 7 times as safe **on** the job as **off.**

**Extra copies of this publication may be obtained by writing to the Public Relations Department
Ray Mines Division
Kennecott Copper Corporation
Hayden, Arizona 85235**

Ray pit factsheet

Owned by: Kennecott Copper Corp.
Location: South of Superior on state route 177, Mineral Creek mining district, Ray, Arizona.
Production: 45,000 tpd ore grading 0.8% sulphide Cu and 0.9% silicate Cu over a five-day week; 90,000 tpd waste over a seven-day week.
Startup: 1911 as underground mine; 1952 as an open pit, after four years of prestripping.

Major mining equipment

Drills (rotary): Five Bucyrus-Erie 40R (9-in. bits), two Bucyrus-Erie 60R (9⅞-in. bits).
Shovels (electric): Two Marion 4161 6-cu-yd, three P&H 1600 7-cu-yd, three Marion 191M 15-cu-yd, one P&H 2100 15-cu-yd, one P&H 2800 25-cu-yd (just erected).
Haulage: 12 85-ton Dart trucks (inactive on present schedule), four 100-ton Darts, 33 120-ton Wabco trucks.
Ancillary equipment: Three Cat 16 graders, two Cat 14 graders, one Cat 814 rubber-tired dozer (all for road maintenance), plus nine rubber-tired dozers, two D9 dozers, six D8 dozers, three TD25 dozers, one HD21 dozer.

copper and nonsulphide copper, together with estimated concentrate grade and probable recovery factor. Each section of the sampled bench face is then color-flagged as silicate ore, sulphide ore, or waste. The cutoff grade for ore is currently 0.4% Cu. Ray now mines 45,000 tpd of ore—30,000 tpd of sulphide and 15,000 tpd of silicate.

Along with regular operating personnel, Ray employs quality control technicians in the field on all production shifts. They are there to advise pit supervisors on all questions concerning the quality of ore sent to the crushers. In cases where further refinements of mill head blending is needed, a front-end loader is assigned to dig and load a specific section of bench.

Production is now concentrated in three pit areas: the west pit, the central area (mostly sulphides), and the eastern slope (mostly silicates). Silicate ore is vat-leached at Ray, while sulphide ore is crushed outside the pit, then moved 20 mi by rail to the concentrator at Hayden. Currently, most sulphide ores are chalcocite with minor chalcopyrite. The sulphides contain molybdenum and traces of gold and silver, recovered in downstream processing. Silicate ore is principally chrysocolla, averaging 0.9% Cu. Waste is removed both from the perimeter of the pit and from the deeper benches, as inclusions between sections of ore.

The pit is now 800 ft deep, and one-way haulage distances to the sulphide ore crusher, the silicate ore crusher, and the waste dumps average 5,000 ft, 7,500 ft, and 9,500 ft, respectively. The waste haul is adverse all the way. An average of 25 trucks work every shift, fed by five shovels—two in ore and three in waste. Availability of shovels, trucks, and the 12-cu-yd loader is figured at 75%, 75%, and 55%, respectively.

Seven drill shifts per day are needed for blastholes. A 40R averages 350 ft per shift; a 60R, 500 ft per shift. Bit life averages 3,000 ft, with a wide range of 1,500 ft to 9,000 ft. Blastholes are drilled and blasted in single rows, on 18- or 24-ft centers, 45 ft deep.

Dry holes are loaded with Carbamite (prepackaged and oiled ammonium nitrate prills). About 12 50-lb bags are slit and hand-loaded into each hole, providing for 15 to 18 ft of top stemming with drill cuttings. The explosive column is detonated by a 1-lb Atlas Kinepak booster attached to the detonating cord downline, 2 ft from the bottom of the column. If more than one row is blasted at a time, 9-ms and 17-ms delays are used between the rows. Wet blastholes are pumped dry and a plastic liner is inserted before charging. Holes that can't be pumped dry are loaded with explosive gels and detonated with one Kinepak for every 50 lb of gel.

About 900 operating personnel are employed at Ray, including maintenance and supervisory staff. The operating costs for mining (excluding depreciation) break down as follows: truck haulage (including tire costs) 52%, haul road maintenance 11%, loading 21%, drilling 6%, blasting 7%, and waste dump maintenance 3%. Tire life for the Wabco trucks is 5,000 hr, and life of the Detroit Diesel or Cummins engines is over 8,000 hr between major overhauls. □

Ray — Arizona

1-17-74

Neil Gamble =

Prod: 25,000 tpd sul + .80% cu
10,000 oxide leach " "
12% of copper produced in dump leach -

± 65% of reserves in diabase
ult pit limits ± 3000 E of present pit —

file J. H. C.

NOV 27 1973

HYDROTHERMAL ALTERATION AND ZONING IN THE RAY DEPOSIT

C. H. Phillips, N. A. Gambell and D. S. Fountain

INTRODUCTION

The Ray copper deposit is situated in Pinal County, Arizona, about seventy miles due north of Tucson. The current production from Ray is 35,000 tons per day made up of roughly equal amounts of three ore types: chalcocite, chalcopyrite and copper silicates. By far the greater part of past production has been from secondary chalcocite ores. It is only in the last decade that the primary sulfide mineralization has become an important ore type.

Despite the existence in 1968 of detailed surface and subsurface studies of the stratigraphy and structure and preliminary data on the alteration and geochemistry (Metz and Rose, 1966) in the vicinity of the Ray orebody, several pressing geologic questions concerning the Ray deposit remained unsolved. Among them were (1) the peculiar shape of the orebody, which had been developed by drilling during the mid-60's, (2) the apparent lack of the symmetric zoning found at some other porphyry copper deposits, (3) the direction and amount of displacement on major faults through the orebody and, perhaps more important, the time of their movement, pre- or post-mineral, and (4) the exploration-related question: where would the ultimate vertical and horizontal limits of ore mineralization be found? The limit of the ore-grade copper was the most urgent of these questions due to necessary engineering and property decisions.

Should "Genes, AH, 1971" reference be [illegible]?

A review of the pre-1968 geologic work on the Ray deposit indicated that additional detailed work on alteration and sulfide zoning would be the best means of further defining the Ray geology. It was assumed that some kind of regular zoning must exist, even if atypical. After indications of a pyrite halo were located, the copper distribution in various rock types was roughed out. Once this was done, it became obvious that the Ray deposit was concentrically zoned, and the general sulfide relationship discussed below was evident. The preliminary study of copper and sulfide distribution was so successful that by the end of 1969 it was decided to complete the study in detail and to include a study ~~zoning~~ of the alteration zoning. At that time the project was divided into a study of the ~~three parts:~~ diabase, porphyry, and quartzose Precambrian rocks.

Same order as rest of this

Vertical sections through the sulfide system which have maximum drill hole density and rock type continuity were selected for the detailed study. The purpose here was to obtain the maximum amount of interpretable data in the minimum time. Within the rock types, the drill samples were composited into approximate 50-foot samples; heavy minerals were physically separated, and the total weight percent sulfide and magnetite as well as the chalcopyrite:pyrite ratios were determined. The method used for sulfide and magnetite determinations was a physical separation which tended to give low values for both total sulfides and chalcopyrite:pyrite ratios. Generally these numbers calculate to within 20 percent of the copper assays, and curves plotted from different data sets consistently have the same shape. Some of the data presented here in graphic form have been adjusted to approximate agreement with the copper assays.

In the quartzose Precambrian rocks, assay averages for MoS_2 were also contoured, but these data were so incomplete that only a very general pattern was evident.

The scope of the study was limited to outlining the vertical and horizontal distribution of those alteration minerals which could be readily identified with a hand lens or petrographic microscope with a minimum of X-ray or microprobe assistance. Because of the time involved, no attempt was made to count or estimate percentages of specific minerals; the frequency of occurrence was noted by utilizing the same system used in core logging at Ray as outlined in Figure 1. It is important to stress that the conclusions derived in this paper are the result of a detailed study of a small portion of a large, complex porphyry copper orebody. Optimistically, the data are a good approximation of the truth and will be of interest to those engaged in mining geology or related fields.

DISTRICT GEOLOGY

Because the geology and ore deposits of the district have been discussed in detail by Ransome (1919), Metz and Rose (1966), and by Cornwall, Banks and Phillips (1971), only a brief resume of the Ray geologic setting follows.

The Ray sulfide system is developed in a variety of Precambrian rocks and in Laramide intrusives (Figure 2). The oldest of the Precambrian rocks is the Pinal Schist. This is a sequence of metamorphosed shale, siltstone, sandstone and conglomerate with flows or plutons of a rhyolitic (?) porphyry. Rarely, some biotite-rich zones which appear to have been a porphyry of dioritic composition, possibly the Madera Diorite that crops out north of the mine.

Intruding the schist but ~~unaffected by~~ the metamorphism ~~is~~ the Ruin Granite, a coarsely crystalline quartz monzonite, Although the Ruin does not crop out in the mine area, it is consistently encountered in the subcrop along the eastern side of the sulfide system.

Overlying the Pinal Schist and Ruin are the Pioneer Formation and Dripping Spring Quartzite of the upper

Precambrian Apache Group. These are quartzitic clastic rocks ranging from tuffaceous mudstone to arkosic conglomerate. and They are not differentiated in Figure 2.

The youngest Precambrian rock, diabase, occurs as dikes and sills in all the older rocks. The diabase is the most receptive rock to copper mineralization at Ray. The sills in the Pioneer Formation, the Pinal Schist and the Ruin Granite are the most important hosts of mineralization. Some of the diabase in the Dripping Spring Quartzite contains ore-grade mineralization, but most of this sill is restricted by erosion and geologic structure to the pyrite halo.

A series of Laramide intermediate to acidic dikes and stocks intrude all the older rocks. These intrusives are discussed in detail by Cornwall, Banks and Phillips (1971). The Ray sulfide system affects most of the Laramide intrusions including the Tortilla Quartz Diorite (Sonora Diorite of Ransome), the Teapot Mountain Porphyry quartz monzonite, the Granite Mountain Porphyry, and many of the dikes.

The sulfides were introduced after crystallization of the Granite Mountain Porphyry, and this rock is assumed to be genetically related to the ore deposit. The unaltered rock is granodiorite and commonly porphyritic; locally, however, it grades into sub-porphyritic and equigranular textures. The two breccia pipes in the mine area appear to be associated with the Teapot Mountain Porphyry. The age of the mineralization is not unequivocally established, but we believe, on the basis of limited cross-cutting relationships, that the breccia pipes and the Teapot Mountain Porphyry are younger than much, but not all, of the mineralization.

Stratified Oligocene, Miocene and later volcanic and clastic rocks overlie parts of the sulfide body. These post-mineral

wall rocks tend to thin and/or pinch out over the Ray deposit, indicating arching along the northeasterly trend of the Granite Mountain Porphyry intrusions.

The relation of geologic structure to placement of the sulfide system is obscure. Though the entire region is complexly faulted, fault and fracture zones have no major effect on the shape of the sulfide or alteration zones beyond very local and minor disruption of the pattern. The foliation of the schist, which parallels the trend of the porphyry stocks as well as the mid-tertiary arching, may represent some sort of deep structure that controlled the location of the porphyry stocks, but this is a problematical relationship. At least one igneous contact does modify the zoning. This is the north trending contact between Precambrian granite and schist on the eastern side of the deposit.

Two large faults cross the orebody, the Diabase-Ray-School Fault (hereafter referred to as the Diabase Fault) and the Emperor Fault. The Diabase Fault dips to the west and trends northerly across the orebody and at the surface separates older rocks on the west from younger rocks on the east, resulting in apparent reverse movement. The Emperor Fault is relatively flat and is considered to be a thrust. It is cut by the Diabase Fault and is known only on the west ~~or hanging wall~~ side of the Diabase Fault. The thrust places older rocks above younger rocks so that at depth the movement on the Diabase Fault is apparently normal (contrary to the above description). The direction and total displacement on these faults have never been determined satisfactorily. The displacement on the Diabase Fault exceeds 1500 feet, while the minimum movement on the Emperor Fault is about 3000 feet with some very late movement indicated on both faults. Obviously, large post-mineral displacement of the sulfide system (and orebody) must be considered as a possibility on both of these faults.

The hypogene sulfide minerals identified in or near the Ray deposit are pyrite, chalcopyrite, molybdenite, galena and sphalerite. Occasionally, small amounts of tennantite, tetrahedrite and bornite have been seen.

HYPOGENE COPPER, SULFIDE AND ALTERATION ZONING

Systematic changes of sulfide content and copper grade related to rock type changes in the Ray orebody have long been recognized (Metz, 1964). Consequently, the zoning study was separated into specific rock units: (1) quartzose Precambrian rocks, (2) Laramide porphyry, and (3) diabase.

The distribution of sulfides and the surface location of the Granite Mountain Porphyry stocks are shown in Figure 3. The central part of the sulfide system is characterized by a low content of total sulfide and a high ratio of chalcopyrite to pyrite. Despite the high percentage of copper sulfide in the total sulfide, the total copper in the rock mass is relatively low; consequently, this zone is referred to as the "low grade core." The high copper "doughnut" surrounding the low grade core is much more copper-rich than the core, even though the ratio of chalcopyrite to pyrite is lower. This is due to the increase in the total sulfide content. The increase in total sulfide continues regularly with distance from the center of the system and is accompanied by a decreasing relative amount of chalcopyrite, finally resulting in a high-sulfide, low-copper, pyrite halo around the high copper zone.

Note that the center of the sulfide system does not coincide with any of the porphyry stocks but that the stock to the southwest very definitely affects the sulfide zoning.

Quartzose Precambrian Rocks

Copper Distribution

The average copper content intersected in drilling of the quartzose Precambrian rocks is shown in Figure 4. The contours are in increments of 0.1 percent copper and demonstrate the circular nature of the high copper zone. The open area to the northwest is caused by a combination of sparse drilling data through post-mineral cover and a large stock of late or post-mineral Teapot Mountain Porphyry (Figure 2). The southwestern bulge is related to the stock of Granite Mountain Porphyry located there (Figure 3). The low grade core averages from 0.2 percent copper to less than 0.1 percent while the high copper zone locally averages as high as 0.5 percent. The pyrite halo generally lies beyond the outer 0.2 percent contour.

published: 700 mil at .82% Cu

Sulfide and Magnetite Distribution

Additional details of the zoning are illustrated in the graphs of Figure 5. Except for the data at 600 and 2100 feet of Figure 5, all data are from drill holes along the line A-A' in Figure 4. Total sulfide content, percent chalcopyrite in the sulfide portion of the rock and the abundance of magnetite are plotted along this line. The low grade core lies on the left side and the pyrite halo, on the right. The total sulfide content increases with distance from the center of the sulfide system to the outer part of the high copper zone or inner pyrite halo. As shown by this particular set of data, there is usually a break in the total sulfide curve at the boundary between the low copper core and the high copper doughnut, and the maximum total sulfide in the schist typically falls between three and five weight percent; the minimum would fall far to the left of the samples plotted in the graph and would be less than 1 percent. The slope of the chalcopyrite curve also changes in the high copper zone with a decrease from more than 40 percent chalcopyrite in the core to 2 percent or less in the pyrite halo.

The magnetite content in the schist is usually low with the maximum concentration falling near the exterior limit of the high copper zone or in the pyrite halo as in Figure 5.

The major (granite-schist) contact noted in Figure 5 is the only known pre-mineral structure which has an appreciable effect on the sulfide system. Chalcopyrite increases relative to pyrite, and the percent total sulfide tends to level out or decrease at the contact. These changes occur in both rocks and extend laterally as much as 300 feet on either side of the contact.

Alteration Zoning and Paragenesis

The common alteration products from oldest to youngest are: orthoclase, biotite, sericite, epidote, calcite, and anhydrite. Chlorite has apparently had a long period of stability and shows no consistent age relationship to the other alteration minerals. Rutile in vein envelopes, is common in small amounts, but its relative age is undetermined; ~~it~~ is definitely an alteration product. Epidote probably has about the same age position as sericite. Much of the calcite is as recent as epidote, but some could be as early as orthoclase. Some biotite may also be as old as orthoclase, but some is definitely associated with later veining. This age sequence is the earliest common occurrence; some overlapping or intermittence with later alteration minerals is common, except for anhydrite.

Chalcopyrite and pyrite probably appeared at about the same time as biotite. Though chalcopyrite mineralization did not normally persist beyond the formation of sericite, pyrite veins do cut the latest pyrite-sericite veins. Molybdenite appears to be a late sulfide mineral but probably no later than sericite.

Anhydrite is rare in the siliceous Precambrian rocks, occurring as late fracture fillings, ~~but~~ The age relationship of anhydrite is only tentative. Barren quartz veins are apparently later than most of the sulfides but may pre-date anhydrite. The barren quartz veins appear to be localized in specific areas, but the distribution has not been mapped. Epidote is present only in the samples from the pyrite halo and propylitic zone.

The calcite occurs in quartz or quartz-orthoclase veins and apparently crosscuts most of the alteration as well as the sulfide mineralization. Calcite is mainly limited to grains and stringers filling the centers of veins and is not clearly related to any stage of sulfide mineralization, although there is more calcite in the high copper zone than elsewhere.

Vein quartz may be formed as early as orthoclase and biotite. It certainly seems to occur in almost every type of vein and is rarely absent where sericite is present. In the low grade core of the deposit, the quartz veins tend to be thin, and the frequency of occurrence is high in a finely reticulated pattern. The veins become thicker, more continuous, and fewer in number in the high copper zone and then grade outward to a very low rate of occurrence in the pyrite halo.

Sericite occurs within quartz and quartz-orthoclase veins but more often is present as an envelope along sulfide or quartz-calcite-sulfide veins. Sericite seems to be the latest major alteration product associated with economically significant sulfide introduction. The relative amount of sericite is low within the core of the sulfide system and reaches a maximum from the center of the high copper zone through the inner portion of the pyrite halo. Though sericite becomes less common in the outer part of the pyrite halo, the envelopes along quartz or pyrite veins persist into the propylitic alteration zone.

Because of its creamy-white to colorless appearance and small size of crystals, orthoclase is difficult to find in hand specimens although it is commonly observed in thin sections. It normally occurs as a discontinuous selvage along veins that also contain quartz, calcite, and variable amounts of sulfide. Orthoclase is considerably more abundant in the core of the sulfide system than in the high copper zone, but it is found as far out in the system as the propylitic zone. Orthoclase is present in the oldest veins and is usually absent in those associated with or later than sericite. Most of the orthoclase alteration is believed to pre-date the formation of secondary biotite even though some formed contemporaneously with or after the biotite.

Secondary biotite is concentrated in the groundmass of the siliceous rocks, often in the vicinity of chalcopyrite veins or disseminations. Selvages of biotite along veinlets are rare. The biotite is more strongly developed in the low-copper core and the inner third or half of the high-copper doughnut. The amount of biotite decreases outward in the doughnut as sericite increases, but biotite persists as sporadic occurrences to the outer limits of the pyrite halo. Mafic units of the schist are more susceptible to the development of secondary biotite than the iron-magnesium deficient units. These mafic units also contain more copper and vein magnetite where they intersect the sulfide system.

(5) Chlorite and clay do not show any definable pattern in the siliceous rocks. They occur in trace amounts in all parts of the sulfide system. Although chlorite and epidote are the most common alteration products in the propylitic zone, more chlorite probably exists in other parts of the sulfide system. Epidote is present only in samples from the propylitic zone
is rare except in the propylitic zone, where it may locally constitute a significant part of the rock mass.

Diabase

Because of the limited drilling beyond the 0.1 percent copper cutoff, the preore mineralogy of the diabase in the Ray area is uncertain. Wide variation in the mineralogy of the diabase is reported in central Arizona (Short and others, 1943; Peterson, 1962; and Shride, 1967). The lower diabase sill at Ray contained significant quantities of hornblende (Table I) and is almost certainly similar to Short's "normal diabase" at Superior.

Table I Preore composition of the diabase in the Ray area after Rose, 1960

Plagioclase, An_{45-55}	40-70%
Hornblende or pyroxine	25-50%
Quartz	5%
Biotite	(?) 5%
Orthoclase	0-5%
Magnetite	3%
Apatite	1%

The following description of alteration and mineralization in the diabase is derived primarily from work on the lower sill on the eastern side of the Ray orebody. This sill extends from the core of the sulfide system eastward into the pyritic halo and is the most extensive diabase sill within the zone of hypogene mineralization. In the low sulfide, high chalcopyrite core, much of the lower sill has been oxidized and now forms a large part of the Ray silicate copper orebody.

Sulfide Mineralogy

The bulk of the sulfide mineralization in the diabase is controlled by stockwork fracturing. The sulfides are concentrated in both the veins and the adjacent alteration envelopes, decreasing outward into the wall rock to occasional disseminated grains.

Chalcopyrite and pyrite are the major hypogene sulfide minerals in the diabase. Bornite is present in minor quantities and is always found as incipient to partial replacements of chalcopyrite. Bornite in the diabase, schist, and porphyry is generally restricted to that portion of the sulfide system in which the abundance of chalcopyrite exceeds that of pyrite. Molybdenite in the diabase occurs most frequently along the outer edges of veins and is less abundant than in the more siliceous rocks. Limited assay data indicate that the highest concentration of molybdenite in the diabase occurs inside the copper ore zone ~~(+ 0.40%)~~.

Sphalerite with minor galena is present in veins with chalcopyrite, pyrite, quartz and calcite. These veins are late stage and occur in the zone of highest copper concentration and outward through the high pyrite zone.

Tennantite is found in veins with quartz, calcite, chalcopyrite and pyrite. The veins are usually pinkish in color and are presumably epithermal because of their banded texture. [illegible] for [illegible] presumption?

Magnetite, though not a sulfide, is an important mineral [illegible] . ZV.)

Copper, Sulfide and Magnetite Distribution

The horizontal distribution of copper in the lower sill has been contoured from drill hole data (Figure 6a). The figure was generated by averaging copper assays from over 100 diamond drill holes that penetrated the sill. The copper distribution exhibits a horseshoe shape with the shoe opening to the north. The north-south elongation of the horseshoe is perpendicular to the northeasterly trend of the porphyry intrusions. If, however, a plot of total sulfides including those in the pyrite halo is considered, an elongation approximately parallel to the intrusions is observed. The north-south elongation of the copper values in the diabase is probably the result of the premineral distribution of the diabase because the diabase is terminated against the Emperor Fault on the western side of the orebody (Figure 6b). The open end of the horseshoe is the result of the effects of post-mineral faulting, intrusion of Teapot Mountain Porphyry stock and erosion which, combined, have eliminated the diabase in this area.

Two vertical sections, a-a' and b-b' (Figure 6a), in an area of fairly complete drilling were selected for a detailed study of the copper distribution within the sill. The copper distribution in diamond drill holes along these two sections is illustrated in Figures 7a and 7b. Here the lower diabase sill has intruded the Pinal Schist, splitting into two branches on the west side of the section. In section a-a' (Figure 7a), the maximum copper grade follows the top of the sill in holes 1 through 4 and plunges abruptly between holes 4 and 5. In contrast, section b-b' (Figure 7b) clearly shows no such rapid plunge of the maximum copper grade; instead, the maximum concentration of copper appears to deepen regularly with respect to the top of the sill as the mineralization is followed from hole 8 through holes 9 and 10. The downward plunge of the highest copper values below the diabase is an interpretation based on data from other drill holes in the near vicinity.

Figure 8 contains four graphs illustrating the zoning of copper, total sulfide, chalcopyrite, and magnetite along section a-a'. The dotted ~~dashed~~ line in each graph is the average across the total thickness of the lower diabase sill.

In holes 1 and 2 (Figure 8a) where the sill branches around a large included lens of schist, the average copper content for the top branch is shown by line a, for the bottom branch by line b, and for the schist by line c. The maximum average copper content for the entire thickness of the diabase sill is in hole 3 with rapidly decreasing average copper content on either side. Note the break in the curve at hole 5, marking the change from the high copper to the pyrite zone.

The histogram in the upper right-hand corner of Figure 8a shows the frequency distribution of copper assay values in the diabase along section a-a'. The positive skewness in the distribution is the result of an overabundance of lower copper values. This is to be expected in a zoned porphyry copper deposit where there is low grade copper both in the low total sulfide-high chalcopyrite zone and in the high total sulfide-low chalcopyrite zone.

Along section a-a', total sulfide, total magnetite and the percent chalcopyrite in the sulfides were determined on pulp composites for each of the holes with the exception of hole 2. Samples from this hole were not available. In Figures 8b, 8c and 8d, points a and b represent the upper and lower branches of the diabase while point c is the schist.

The total sulfide content along a-a' by weight is shown in Figure 8b. An average of the sulfide data for the diabase in hole 1 shows that there is little difference between it and the schist. The sulfide content gradually increases from hole 1 to 4, then dramatically increases between 4 and 5. This change in gradient represents the inner edge of the pyrite halo. In hole 6 the sulfides begin to drop off as the strong sulfide mineralization weakens outward in the pyrite halo.

The affinity of the diabase for copper is illustrated in Figure 8c, where the proportion of chalcopyrite in the sulfides along section a-a' is plotted. The schist in hole 1 shows a drastic difference in chalcopyrite content relative to the diabase in the same hole. The ratio of chalcopyrite to pyrite in the diabase is about 83/17 while in the schist it is 40/60. Referring to Figures 8a and 8b, the sulfide content of the schist is approximately equal to that of the diabase, while the copper grade in the schist is lower than the diabase. From the standpoint of total copper and the ratio of chalcopyrite to pyrite, the schist in hole 1 is equivalent to the diabase between holes 4 and 5. Figure 8d illustrates what the authors believe could be one of the more important aspects of this study: At Ray the diabase contains both disseminated and vein secondary magnetite in addition to primary magnetite. The shape of the magnetite curve resembles the copper curve (Figure 8a).

Hypogene Alteration

Biotite is one of the most common alteration products in the diabase. It occurs as a fine-grained mesh in vein envelopes and as thin rims surrounding disseminated magnetite and sulfide grains in the wall rock. Megascopically, biotite envelopes are easily distinguished from the less altered wall rock. The width of the vein envelopes is directly related to the size and frequency of occurrence of the quartz-sulfide veins. In a well mineralized area with strong stockwork veining, the wall rock may be totally altered for tens of feet. Coarse-grained (2.5 mm) secondary biotite is encountered in some quartz-sulfide veins and is most common in the low sulfide-high chalcopyrite core of the deposit.

Two distinct color varieties of secondary biotite are present: brown and olive-green. The dark brown biotite exhibits a slight tendency to form closer to the vein than the olive-green. Based on a small number of observations, the olive-green variety becomes more abundant outward from the high copper zone. The difference in color may be due to variation of the titanium content (Heinrich, 1965) of the biotite. Additional work is needed on the color varieties of secondary biotite and their distribution in the sulfide system.

Within the vein envelopes most of the secondary biotite is an alteration product of pyroxene and hornblende. The biotitization in vein envelopes is accompanied by alteration of the plagioclase to an orange-brown clay. Secondary biotite may be present along the twin planes in the plagioclase.

Secondary biotite in vein envelopes has a widespread lateral distribution in the lower diabase sill. It is present in the low sulfide-high chalcopyrite core outward through the high copper zone and into the high sulfide-high pyrite zone. It is most intense in the high copper zone, where strong biotite alteration correlates with high copper values.

Secondary magnetite is found in the wall rock and vein envelopes as disseminated anhedral blebs and subhedral, needle-like crystals. Both forms commonly are surrounded by an inner envelope of sphene and an outer envelope of biotite or chlorite. Secondary magnetite also occurs in veins with quartz and sulfides. In some veins chalcopyrite occurs as islands in magnetite and appears early; however, chalcopyrite and pyrite veins appear to cut most magnetite veins. In the high sulfide-high pyrite zone some quartz-sulfide veins are cut by quartz-magnetite veins that, in turn, are cut by pyrite veins.

p.29 Secondary K-spar is a rare alteration product in the Ray diabase. Only occasional K-spar has been noted as pink blebs and wisps in veins, and these occurrences show no apparent zonal relationships within the sulfide system.

Like orthoclase, hypogene sericite in the diabase is not abundant within the limits of this study. In the high sulfide-high pyrite zone, sericite and clay are present as partial replacements of plagioclase in the vein envelopes. Biotite, after the mafic minerals, is also present in these envelopes. Late stage sphalerite-galena veins frequently have sericitic envelopes. Where these veins cut earlier quartz-sulfide veins with biotite envelopes, the biotite is altered to sericite.

Anhydrite was not noted in the thin sections studied; therefore, the following discussion will be based entirely on megascopic observations. Coarsely crystalline, light purple anhydrite is present as a major constituent of some quartz-sulfide veins. The principal sulfide may be either pyrite or chalcopyrite. Minor quantities of coarse-grained chlorite or vein biotite with rarer K-feldspar may also be present. The abundance of purple anhydrite increases with depth. For some unknown reason the greatest concentration of purple anhydrite is restricted to the high copper zone on the southwestern side of the orebody west of the Diabase Fault.

A light green variety of chlorite is common in veins, vein envelopes and the wall rock. Like biotite, chlorite may envelop disseminated sulfide and magnetite grains in the wall rock. There is usually some remnant biotite in or adjacent to the chlorite, and it is fairly certain that most of the chlorite was generated later than the secondary biotite. Primary hornblende is partially to completely altered to chlorite-biotite. Chlorite in vein envelopes seems to be related to the introduction of late calcite in the vein. Such veins frequently exhibit an inner chlorite and an outer biotite envelope. Coarse-grained, leafy chlorite was noted as the chief constituent of some pyrite veins in the pyrite halo. Minor quantities of chlorite are encountered in many veins throughout the sulfide system. The frequency of chlorite occurrence in the diabase increases outward from the center of the sulfide system.

Milky-white calcite in early quartz-sulfide veins commonly occurs near the center of veins as a filling with microveinlets cutting the sulfide grains. In some cases calcite floods the vein envelopes and replaces earlier formed clay minerals. Although it appears to be largely a late mineral, calcite is most abundant in veins in the high copper zone and shows a tendency to decrease, both inward and outward, from this zone. It is theorized that calcite crystallization or deposition may have been favorably influenced by the calcic nature of the plagioclase (labradorite) in the unaltered diabase.

Secondary sphene and rutile are present in the altered diabase, and they exhibit a zonal relationship with rutile closer to the veins than sphene. Light-gray to white sphene envelops some anhedral magnetite grains in the wall rock. In most cases the sphene is itself enveloped in secondary biotite or chlorite and may show some alteration to calcite. Bright orange, crystalline aggregates of alteration rutile are usually restricted to the vein envelopes associated with strong biotite alteration. The predominant sulfide in the vein and the envelope may be either pyrite or chalcopyrite.

Both early and late stage barren quartz veins are present in the diabase. Mineralized quartz veins are abundant in the low sulfide-high chalcopyrite core outward through the high copper zone. In the pyrite halo vein quartz decreases markedly. Fine anhedral quartz is present in many vein envelopes with biotite and clay.

The chief alteration product of the plagioclase in the diabase is a light orange-brown clay. This alteration is most intense in vein envelopes and accompanies strong biotite alteration of the mafic minerals. Kaolinite, identified by X-ray analysis, was observed as a constituent of a few quartz-sulfide veins. The varieties of clay present in the vein envelopes were not identifiable with the petrographic microscope.

Though occasional grains and radiating crystalline clusters of epidote occur in quartz-sulfide veins throughout the high copper zone, epidote is most abundant in the pyrite halo where it occurs in pyrite veins and more extensively in the vein envelope as an alteration product of plagioclase. Secondary biotite and chlorite are also present. Granular epidote rimming and veining a clay product in a plagioclase site suggests that the epidote is a late alteration stage.

Minor quantities of orange to white crystalline chabazite occur in some quartz-sulfide veins in the ore zone and outward through the pyrite halo. Chabazite appears to be a late-stage vein filling.

A major problem that needs additional work deals with when and how some alteration features took place, i.e., late deuteric and Precambrian or hydrothermal and Laramide. An example is uralitization. Much of the pyroxene in the diabase shows partial to complete alteration to fine-grained amphibole. ~~One of us~~ (Gambell, who did the work on the diabase) believes that at least part of the uralitization in the diabase is the result of hydrothermal alteration because this is compatible with the tendency to form hydrous silicate alteration products. and ~~because~~ petrographic studies ~~to date~~ yield decreasing uralitization and increasing pyroxene with increasing distance outward from the orebody.

Granite Mountain Porphyry

The porphyry, as exposed in outcrops and in drill core, does not form a single stock-like mass centrally located within the sulfide system but occurs as several irregularly shaped stocks or chonolithic masses and as smaller dikes and sills. On a district scale, the distribution of the intrusives is controlled by a poorly defined zone known as the porphyry break (Metz, 1964), which is some 3000 to 4000 feet wide and trends N70°E away from the main stock on Granite Mountain. The porphyry masses, dikes and sills now exposed on the surface and by drilling were emplaced and solidified in advance of the main stage invasion of ore-bearing hydrothermal solutions.

Drilling to depths in excess of 3000 feet has not encountered a large single stock that would explain the position of the Ray orebody by providing a central igneous source. Drilling does indicate extensive, small chonolithic intrusions that roughly connect the outcropping Granite Mountain stocks shown in Figure 2 at depth in the center of the sulfide system. There is some indication that the larger porphyry masses may have acted as individual centers for mineralization and alteration. An example is the small, isolated area of high copper zone mineralization around the intrusive on the southwest side of the high copper doughnut (Figure 3). The small size and irregular shape of the intrusives make it difficult to define zoning patterns or trends within the porphyries themselves.

Copper Distribution

The porphyry was a poorer host for copper mineraliztion than the diabase. Only 17 percent of the rock within the final limits of the open pit is comprised of Granite Mountain porphyry with an average, and rather uniform, copper grade of 0.21 percent copper. Only 6 percent of the porphyry contains more than 0.4 percent copper.

Alteration Zoning

Most of the alteration within the porphyry is restricted to veins or veinlets and their margins. Pervasive alteration is rare, occurring only where veins are strongly developed and closely spaced with merging or overlapping alteration envelopes. The predominant alteration mineral assemblage is orthoclase, quartz, biotite and sericite. Clays and chlorite are less common alteration products. Calcite and anhydrite are occasionally present.

Two main types of veins were observed in the porphyry. Biotite-orthoclase veining, common throughout the rock, appears to have been followed by a phase of less frequently encountered quartz-sericite alteration. Although most of the samples studied were drill core from the primary sulfide zone, it is possible that some alteration minerals such as clays, sericite and perhaps quartz may, in part, be supergene.

Secondary orthoclase is a common alteration mineral throughout most of the porphyry. It is most abundant as envelopes on early quartz veins and as a replacement of plagioclase and, rarely, biotite. Secondary orthoclase is distinguished by its association with quartz veins and its grain size, which is normally larger than matrix orthoclase and smaller than primary phenocrysts.

Most of the biotite in the porphyry occurs as fresh books that are a primary constituent of the rock. Hydrothermal biotite is not abundant. Typical secondary biotite is best developed as envelopes on quartz-orthoclase veins and as discrete crystals in veins. Some of the primary biotite is rimmed or completely replaced by chlorite. In or along the quartz-sericite veins, biotite is replaced by sericite. Sulfides also commonly replace biotite.

Sericite occurs throughout the porphyry as a weak to moderate replacement of feldspars, particularly along twinning planes of plagioclase. It is moderately to strongly developed as selvages on quartz veins, where it may replace all minerals except quartz. Strong pyrite mineralization is associated with this type of veining. Quartz-sericite alteration appears to be later, superimposed upon or crosscutting the biotite-orthoclase alteration. Where strongly developed, this later alteration nearly obscures evidence of the earlier biotite-orthoclase phase.

In areas where veining is not strongly developed or closely spaced, fresh books of primary biotite and plagioclase remain essentially unaltered.

Replacement quartz and vein quartz is ubiquitous and is associated with all phases of hydrothermal activity. Quartz replaces biotite and feldspars. Most early quartz veins have orthoclase selvages with or without secondary biotite. These veins contain pyrite and chalcopyrite, and in some areas calcite and/or anhydrite occur as late cavity filling or replacement minerals. Later quartz veins up to an inch or more wide have strongly developed sericite envelopes and frequently show strong pyrite mineralization with little or no chalcopyrite. Crosscutting both of these vein systems are clear quartz veins with very narrow, if any, alteration envelopes; these may also contain small amounts of molybdenite and chalcopyrite.

Though the limited extent of porphyry bodies within the sulfide system precludes the demonstration of systematic sulfide or silicate zoning in the porphyry, the limited data available suggest that in the porphyry stocks which overlap the core and high copper zone (Figure 3), sulfides are more abundant in the high copper zone. The small stock which lies to the southwest of the high copper doughnut (Figure 3), is associated with an isolated repetition of features characteristic of the high copper zone. This stock has the highest total sulfide content of any of the Granite Mountain stocks and contains slightly below the average of chalcopyrite in the sulfide. It is more pyritic than porphyry inside the high copper doughnut but not as pyritic as the adjacent schist. The frequency of occurrence of molybdenite is also much higher near the center of this porphyry than in the surrounding pyritic rocks. Recent field work indicates similar reductions in the total sulfide content accompanied by increased copper and sometimes molybdenum associated with other porphyry stocks that lie beyond the limits of Figure 3. This field work shows the gross extent of sulfide mineralization to be on the order of seven square miles and roughly coextensive with the area intruded by the Granite Mountain Porphyry.

SUMMARY AND CONCLUSIONS

Ray is atypical in the family of porphyry coppers in that the porphyry is present, not as a central mass, but as several stocks, each of which is mineralized and which cumulatively form a very small part of the total rock mass in the sulfide system; most of the hypogene ore is restricted to a much older ferro-magnesian host rock, diabase. The latter feature is nearly unique.

In plan view, the zonal distribution of the hypogene alteration and mineralization is concentric and symmetric and in a gross sense is similar to other porphyry copper deposits (Lowell and Guilbert, 1970). The total sulfide content is low in the center of the system and increases outward for a distance of about 3000 feet to a maximum of from three to eight weight percent sulfide and then decreases, approaching zero 6000 to 8000 feet from the center. The ratio of chalcopyrite to pyrite follows a reverse pattern with the highest chalcopyrite ratio in the center, decreasing outward. Changes in the gradients of total sulfide and chalcopyrite ratios define three zones:

1) A low sulfide-high chalcopyrite core that rarely contains ore grade copper (4000 ppm),

2) A zone of changing total sulfide gradient in which the total sulfide content increases rapidly and the ratio of chalcopyrite to pyrite decreases, and

3) The pyrite halo where the total sulfide content reaches a maximum and is largely pyrite, and total copper is low.

outward

While this pattern is present in all rock types, the actual quantity of sulfide and the ratio of chalcopyrite to pyrite is controlled by the host rock chemistry. The diabase sills contain both more sulfide, particularly outside the low sulfide core, and a higher ratio of chalcopyrite to pyrite than the siliceous rocks. Iron-rich units of the Precambrian schist tend to show the same affinity for sulfides and copper that the diabase sills do. The iron-rich rocks are much better hosts for copper mineralization at Ray than are the siliceous rocks, presumably because the iron-rich rocks are chemically more reactive and have altered the stability of copper within the hydrothermal solutions.

The zoning of hypogene alteration products ~~other than sulfides~~ is markedly affected by rock type. In the siliceous Precambrian rocks, an older biotite-orthoclase alteration extends throughout the area of the sulfide system. This alteration was most intense in the low grade core and weakened with distance from the center. Superimposed on the biotite-orthoclase alteration is a later period of sericite alteration that obliterated much of the earlier alteration. This later period need not be a discrete event but simply a stage of a continuing process. The sericite extends throughout the sulfide system but reaches maximum intensity near the interface of the high copper zone and the pyrite halo. Overlapping and extending beyond the sericite is an irregular propylitic zone in which epidote is the principal alteration product. In all rock types the frequency and abundance of quartz veins decrease outward from the center of the sulfide system.

The alteration in the diabase departs from that of the typical porphyry copper in the absence of a major zone of sericitic alteration. The characteristic alteration of the diabase is abundant biotite with clay. In the pyrite halo, biotite becomes less abundant; epidote and chlorite become more common, and sericite is seen rarely.

The diabase has a distinct propensity to alter to biotite rather than to orthoclase or sericite, both of which are uncommon in the diabase. In many instances biotitized diabase is only inches away from sericitized schist or quartzite, strongly suggesting biotite must have formed in diabase from the same solutions that produced sericite in the silicic rocks.

While the gross zoning pattern seems to be superimposed on some of the porphyry stocks, there are indications that certain-- possibly all-- of the stocks did act as separate centers of hydrothermal activity. The large concentric zoning pattern, which includes the Ray orebody, could be the result of the coalescence of the hydrothermal flow from the several stocks within the pattern. The alternative-- a single center of mineralization in the small, irregular intrusions in the core of the sulfide system-- still necessitates some additional source for areas to the west that have mineralization similar to the low grade core or the high copper zone.

Practical results of the study have been a clearer picture of the geometry of the Ray sulfide system as well as strong indications of where future prospecting should be concentrated. The presence of essentially the same kind of alteration and mineralization on opposite sides of all the major faults that cut the orebody, limits the postmineral displacement to no more than a few hundred feet.

Perhaps one of the most significant conclusions reached is an indication that magnetite in the diabase is concentrated in the vicinity of the high copper zone or inner pyrite halo. This magnetite concentration might affect the interpretation of magnetic data in southern Arizona.

Older publications on the Ray deposit state that the maximum copper concentration occurs at the top of the diabase sills and that the topmost sill would contain a higher percentage of copper than the next underlying sill. Although this is true for specific locations, we disagree with it as a general rule. We find shallow pyritic sills underlain by ore-bearing sills and in some cases we find the maximum copper content at the bottom of sills, depending on ~~the location~~ ~~in~~ the zoning pattern. ~~We believe that~~ the observed lateral expansion of the sulfide system with depth, indicates that the Ray orebody is near the top of the system. Very probably the flat-lying, reactive diabase sills accentuated the constriction of the high copper zone. If this is true, then the original orebody would have been much flatter than the rounded arch drawn at the top of most zoning models.

Other interesting features of the Ray deposit are the widespread occurrence of calcite, the zoning relationship of sphene and rutile, and the possible uralitization of pyroxene.

ACKNOWLEDGMENTS

As at most large ore deposits, the geologic work has been carried on by many able men. We wish particularly to acknowledge the work of Robert Metz as well as numerous geologists from Bear Creek Mining Company and Kennecott Exploration Services, especially Allen James, supervising geologist (retired) of Kennecott Operating Properties;

John Wilson, director of Kennecott Exploration Services; and Denis Norton, formerly chief of Geochemical Research and Laboratory Division of Kennecott Exploration Services. Henry Cornwall and Norman Banks of the U.S. Geological Survey have contributed to our work at Ray through many discussion sessions.

Geology Department
Ray Mines Division
Kennecott Copper Corporation
Hayden, Arizona 85235

REFERENCES

Cornwall, H. R.; Banks, N. G.; and Phillips, C. H., 1971, Geologic Map of the Sonora Quadrangle, Pinal and Gila Counties, Arizona: U.S.G.S. map G. Q. 1021.

Heinrich, W. E., 1965, Microscopic Identification of Minerals, McGraw Hill Book Company, ?.

James, A. H., 1971, Hypothetical Diagrams of Several Porphyry Copper Deposits: Econ. Geol. v. 66, pp. 43-47.

Lowell, J. D., and Guilbert, J. M., 1970, Lateral and Vertical Alteration-Mineralization Zoning in Porphyry Ore Deposits: Econ. Geol. v. 65, pp.343-408.

Metz, R. A., 1964, Structural and Lithologic Controls of Ore Deposition at Ray, Arizona: presented at Arizona Section A.I.M.E., Dec. 7, 1964.

Metz, R. A., and Rose, A. W., 1966, Geology of the Ray Copper Deposits, Ray, Arizona: in Geology of the Porphyry Copper Deposits, Southwestern North America, S. R. Titley and C. L. Hicks, editors; University of Arizona Press, pp. 177-188.

Peterson, N. P., 1962, Geology and Ore Deposits of the Globe-Miami District, Arizona: U.S.G.S. Professional Paper 342.

Ransome, F. L. 1919, The Copper Deposits of Ray and Miami, Arizona: U.S.G.S. Professional Paper 115.

Rose, A.W., 1960, Progress Report on Chemical and Mineralogical Studies at Ray, Arizona: Unpublished private report, Bear Creek Mining Co.

Short, M. N.; Galbraith, F. W.; Harshman, E. N.; Kuhn, T. H.; and Wilson, E. D., 1943, Geology and Ore Deposits of the Superior Mining Area, Arizona: University of Arizona, Arizona Bureau of Mines Bulletin 151.

Shride, A. F., 1967, Younger Precambrian Geology in Southern Arizona: U.S.G.S. Professional Paper 566.

Figure 1.

Symbol	Intensity	Explanation	Approximate Percent of Rock
1		Single or questionable occurrence	
2	Trace	Minute portion of rock but found by checking several samples with care	Much less than 1%
3	Weak	Minute portion of rock but common	- 1%
4	Moderate	Very common, easily found in any sample	Less than 5%
5	Strong	Obvious, a major constituent	5% or more
6	Intense	All available parts gone to this mineral (pyrox-biotite)	Generally more than 20%
7	Total	Rock consists mainly of this	More than 50%

Figure 1. Alteration-mineralization notation method at Ray. The advantages of this system over percentage estimates are that it is a little more rapid, provides three distinct categories of less than or near 1 percent, and does not imply the precision of a percentage.

Figure 2. Generalized geologic map of the Ray copper deposit

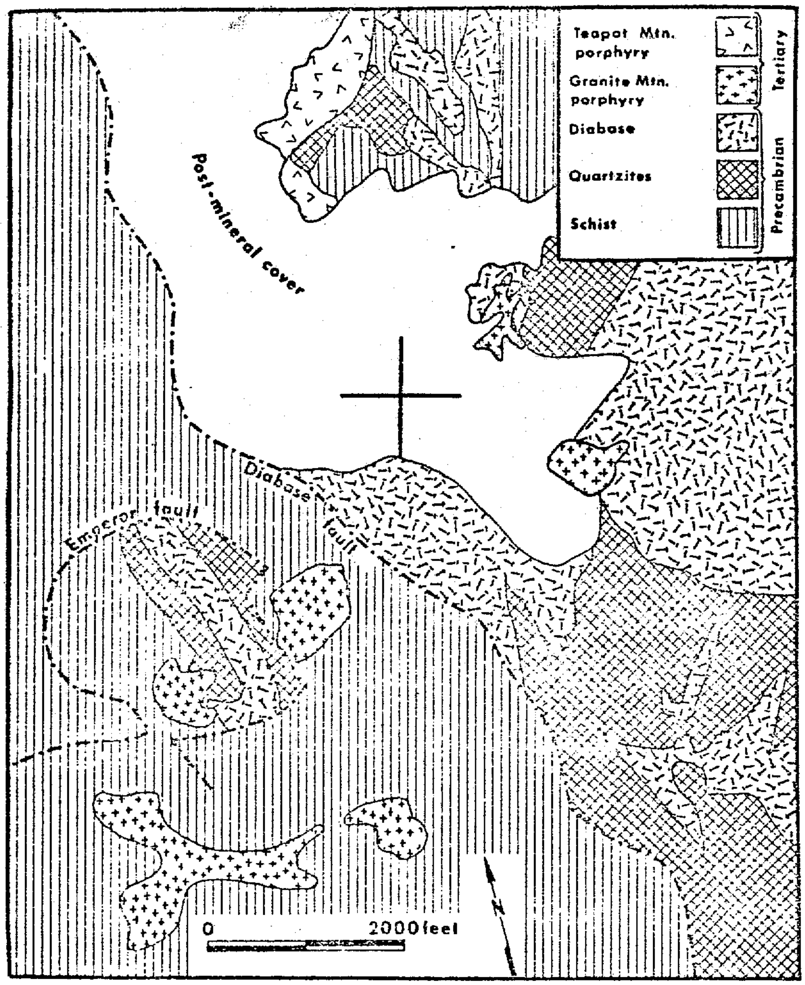


Figure 3.

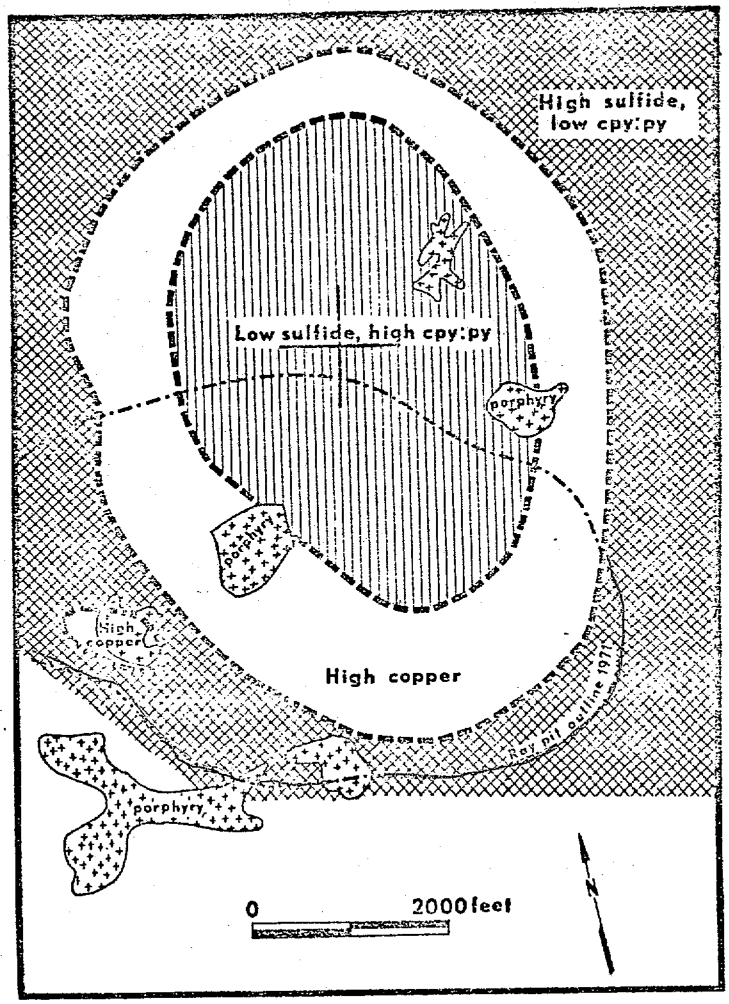

High sulfide, low cpy:py
Low sulfide, high cpy:py
porphyry
porphyry
High copper
porphyry
High copper
Ray pit outline 1971
0
2000 feet
N

Figure 4.

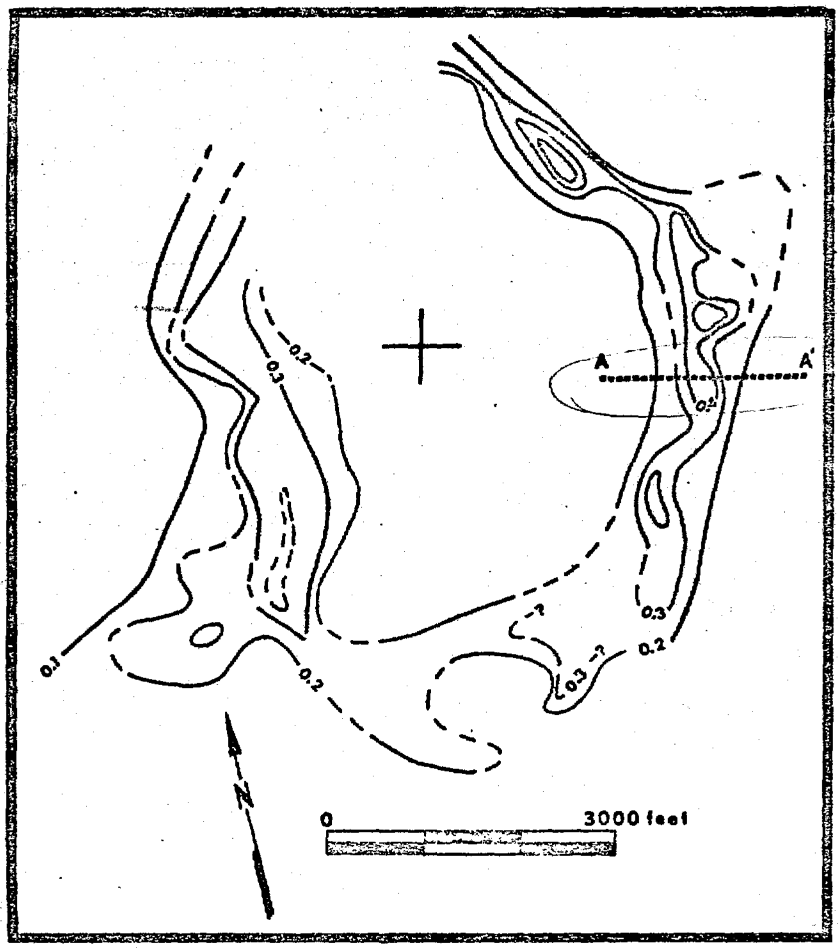


Figure 5

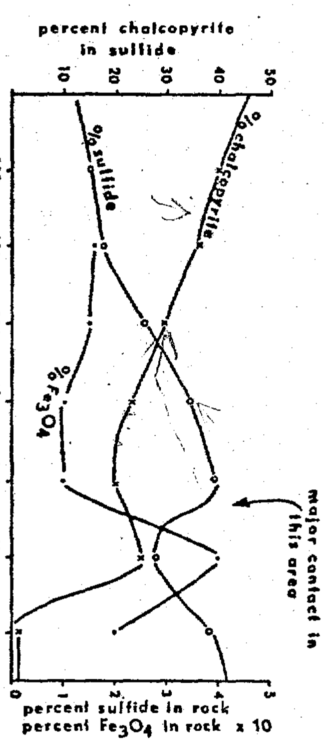

percent chalcopyrite in sulfide
low copper core
high copper zone (ore shell)
pyrite halo
major contact in this area
% chalcopyrite
% sulfide
% Fe_3O_4
Distance in feet
percent sulfide in rock
percent Fe_3O_4 in rock x 10

Figure 6

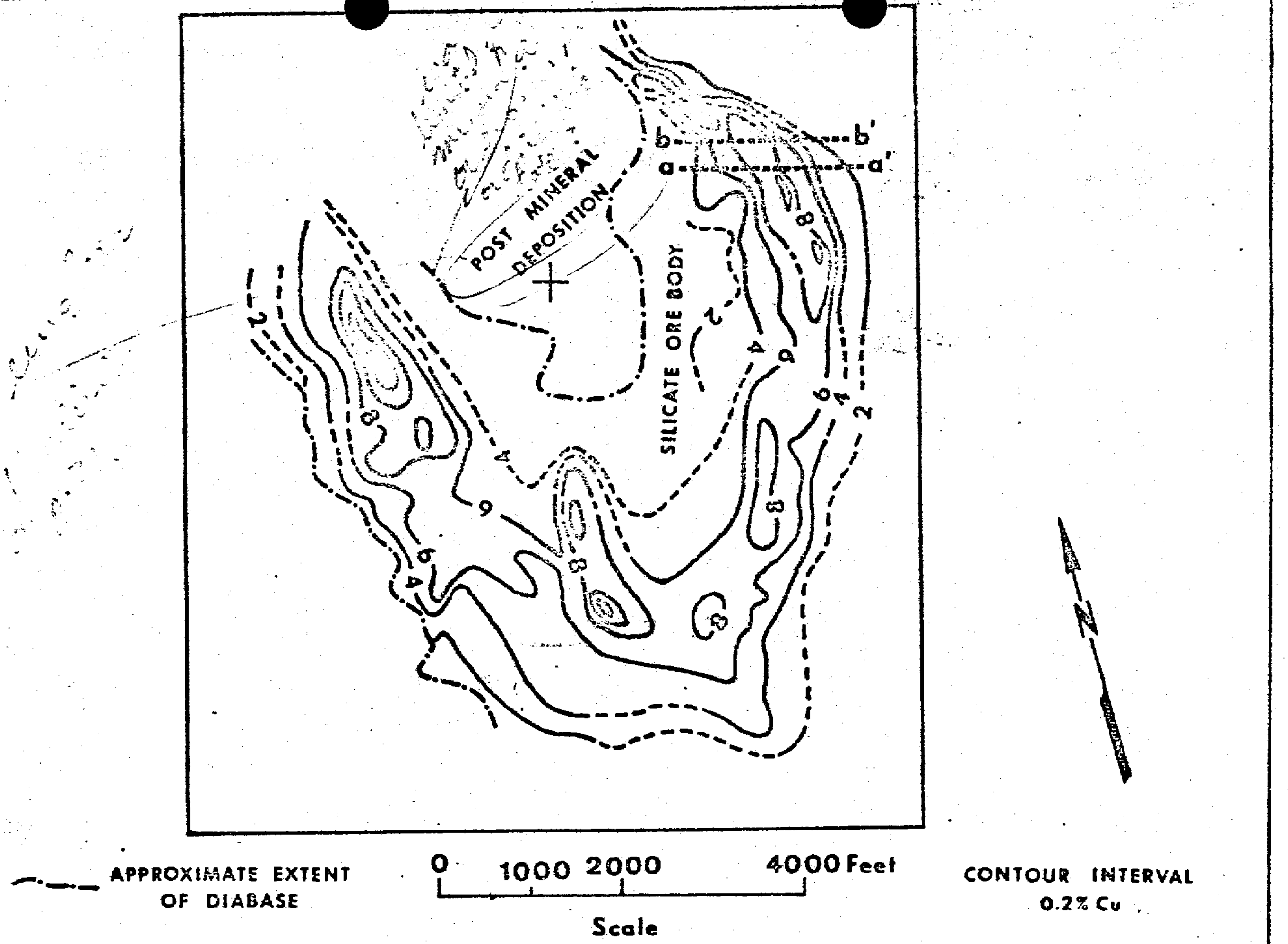


Figure 6a

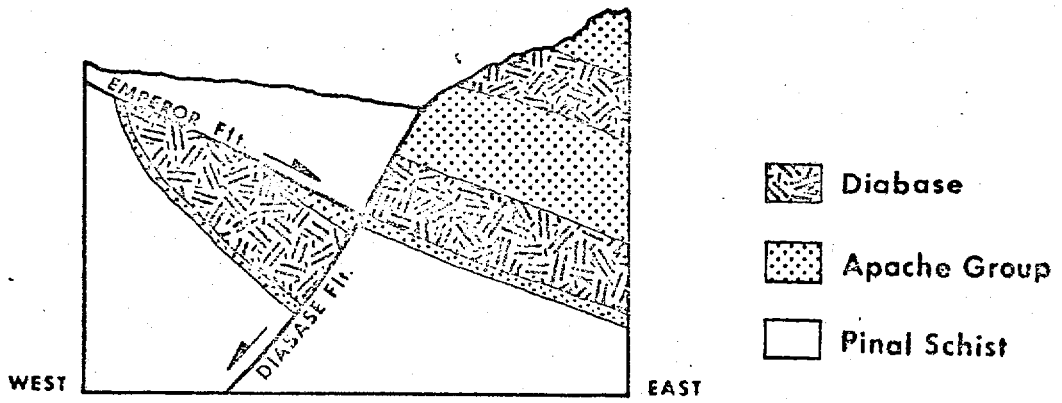


Figure 6b

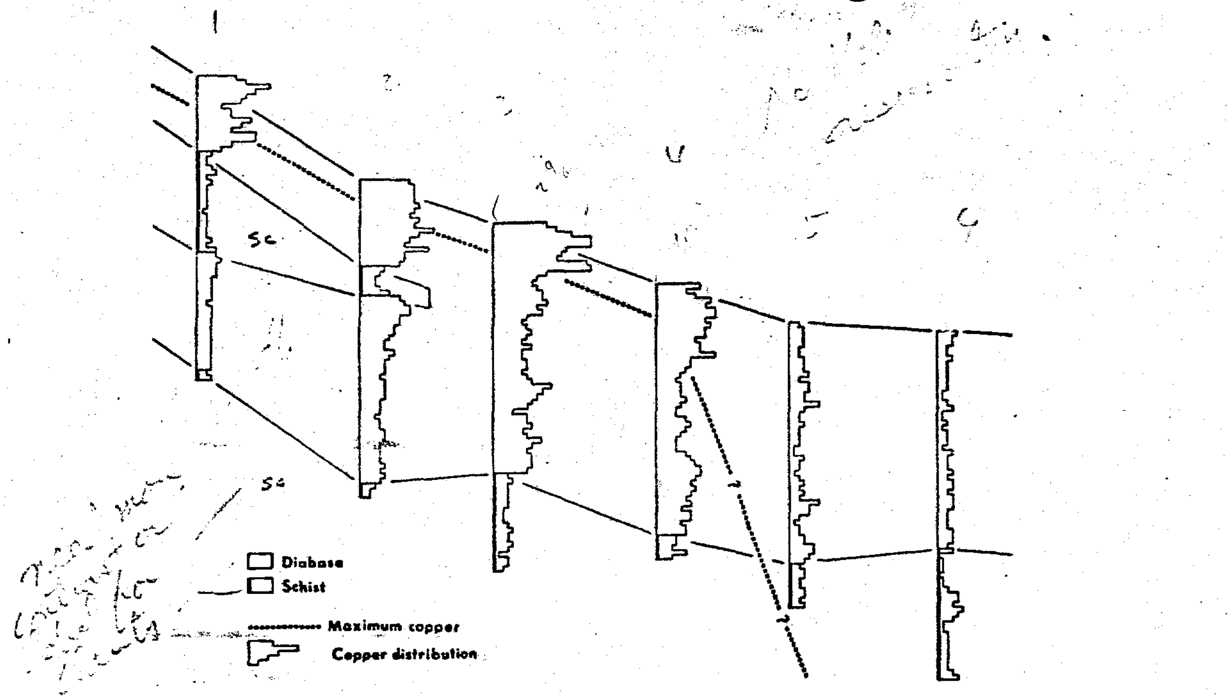


Figure 7a

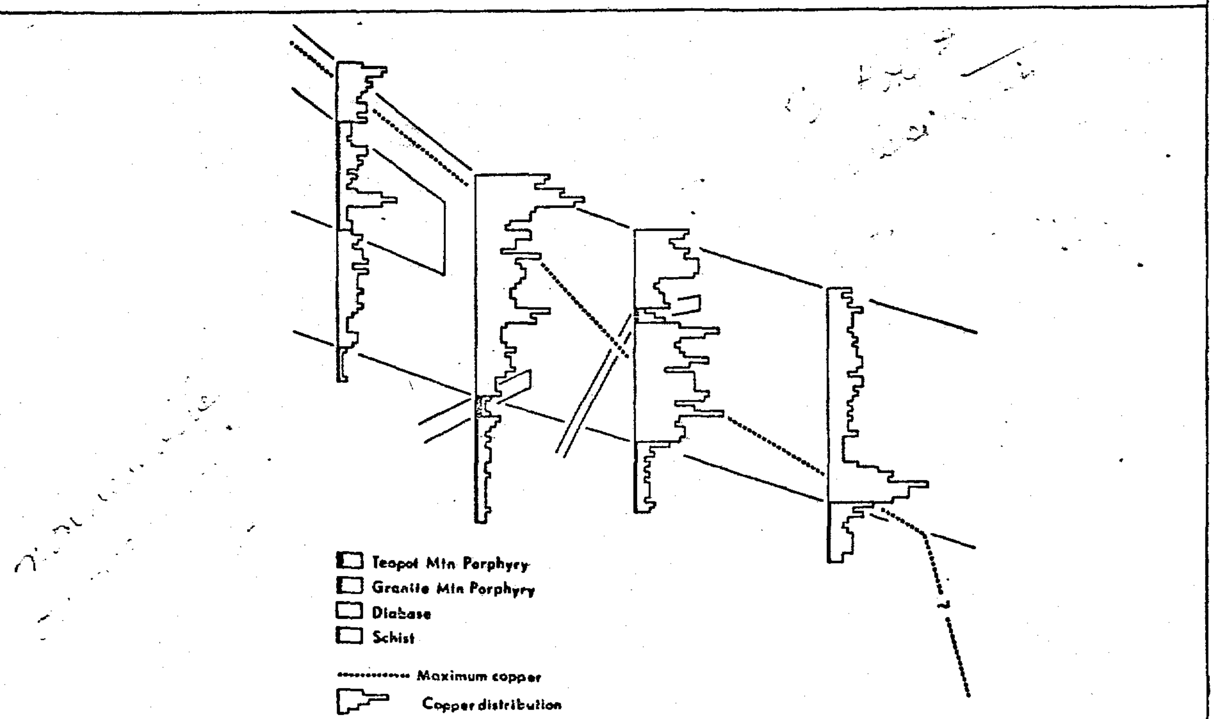


Figure 7b

Figure 8

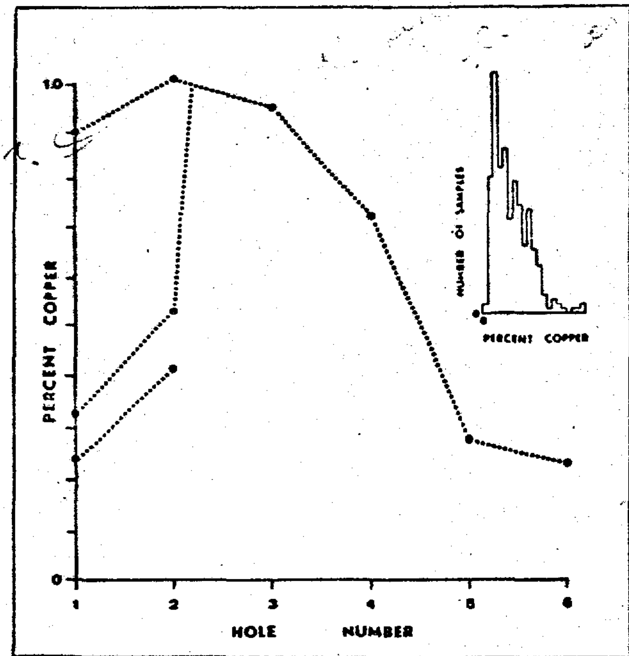


Figure 8a

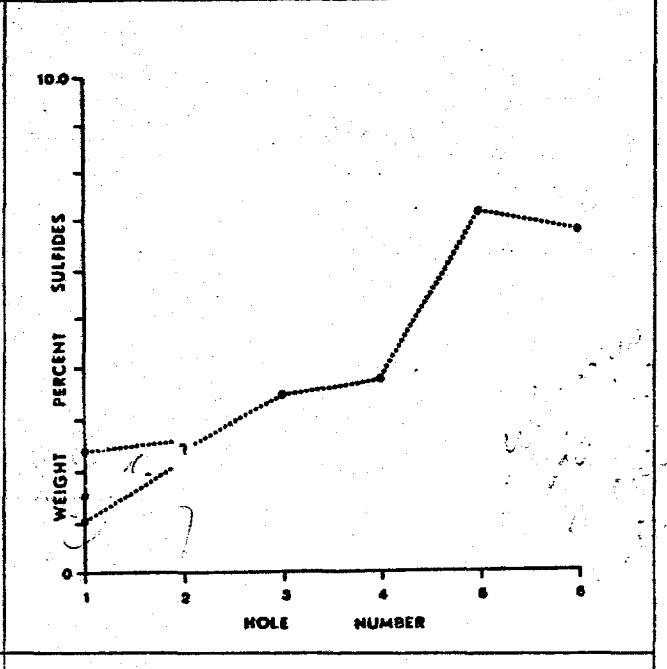


Figure 8b

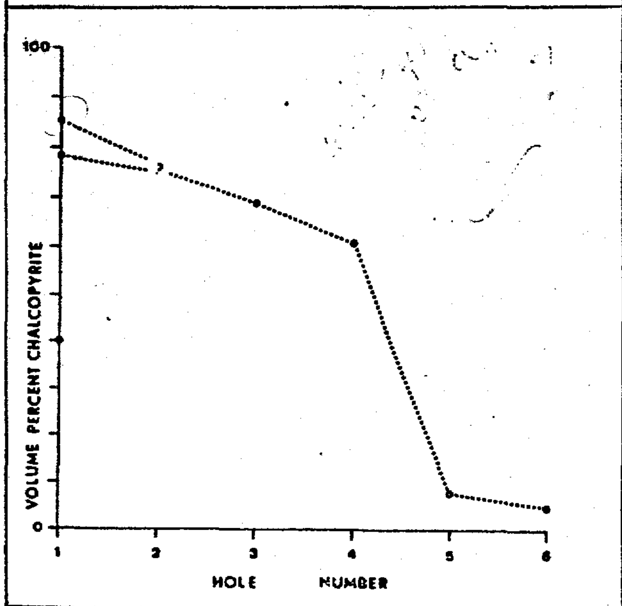


Figure 8c

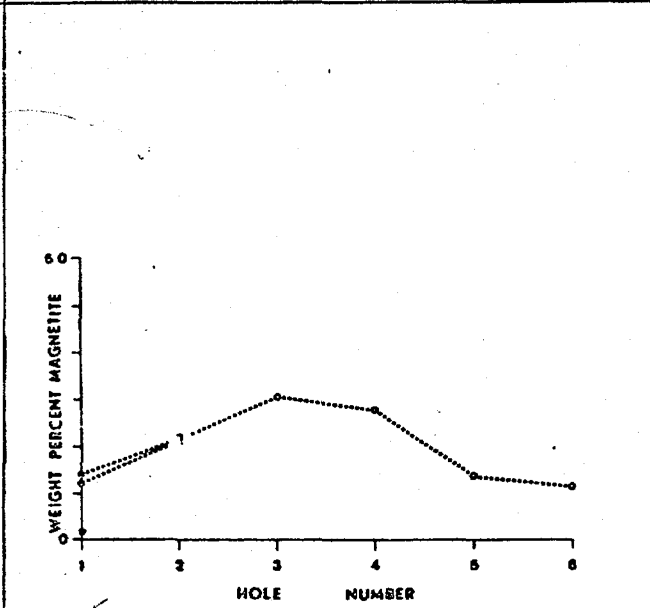


Figure 8d

Cutlines

Figure 2. Generalized geologic map of the Ray copper deposit.

Figure 3. Generalized zoning of hypogene sulfides in the Ray deposit projected to the surface. The porphyry shown is the Granite Mountain Porphyry.

Figure 4. Copper distribution in the quartzose Precambrian rocks at Ray. Contour interval is 0.1 percent copper. What is A-A' ?

Fig 6 ?

Figure 5. Distribution of magnetite and total sulfide and abundance of chalcopyrite in the total sulfide. A-A'

Figure 6a. Plan view of the hypogene copper distribution in the lower diabase sill at Ray, Arizona.

Figure 6b. Generalized cross section (not to scale) illustrating the extent of the lower diabase sill beneath the Emperor Fault.

Figure 7a. Hypogene copper distribution along section a-a' (Figure 6a). The scale of the section is 1 inch = 400 feet. The horizontal scale of the copper grade is ½ inch = 2% copper. Note the high copper concentration at the top of the sill.

Figure 7b. Hypogene copper distribution along section b-b' (Figure 6a). The scales are the same as those for Figure 7a. Note the high copper concentration in the lower part of the sill in Holes 9 and 10.

Figure 8a. Total copper distribution along section a-a'. Lines a and b represent upper and lower diabase while c is a schist lense. Classes in histogram are in units of 0.10% copper.

Figure 8b. Weight percent sulfides in the rock along section a-a'. Points a and b are diabase while point c is a schist lense and the average of a and b. Dashed line connects data points for the diabase.

Figure 8c. Volume percent chalcopyrite in the sulfides. See a-a'?

Points a and b are diabase and point c is schist. Note the drop in chalcopyrite in the schist.

See a-a'?

Figure 8d. Weight percent magnetite in the rock. Points a and b str diabase and point c is schist. Compare this curve to Figure 8a.

COPY

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

JHC file
Ray, Arizona

December 7, 1962

FILE MEMORANDUM

LARGE DIAMETER CORES
FOR METALLURGICAL SAMPLES

Kennecott recently completed 8 diamond drill holes with 6-inch coring bits in an area east of the Ray pit. The purpose of this program was the provision of a representative metallurgical sample of the diabase ore. Various data on the drilling are summarized below:

Total 6" coring	2200'
Core recovery	88%
Weight of 6" core per ft.	31 lbs.
Total weight of core	30 tons
Maximum hole depth	450'
Average distance cored per 8 hr. shift	14'
Cost per foot of coring	$15.50
Total cost (exclusive of overburden drilling	$34,100.00

Joy contracted the job for $12.00 per foot plus bit costs which amounted to $3.50 per foot. The drilling was carried out with a Joy 22 heavy duty rig, 10' swivel barrels and mud circulation. Kennecott rotary drilled through the overburden with their own equipment and cased the holes 8" ID.

Art Eklund of Joy stated that in drilling characteristics the diabase would closely approximate a well altered porphyry. He estimated that diamond consumption in formations such as the tactites and hornfels at the Mission would be somewhat higher than in diabase -- possibly 25%, or $4.00 to $5.00 per foot bit cost. The ore bearing formations of the Imperial area at Silver Bell are comparable to those at the Mission, although possibly somewhat less abrasive.

J.H. COURTRIGHT

JHC:kw

cc: CPPollock
DJPope
RBMeen
DRJameson
JEKinnison
JRWojcik

Personal file
J. H. C.

MAY 18 1966

<u>HISTORY AND GEOLOGY OF THE RAY COPPER DEPOSIT</u>

<u>RAY, ARIZONA</u>

Talk to be given at the Arizona AIME Open-Pit Mining Subsection May 16, 1966.

HISTORY AND GEOLOGY OF THE RAY COPPER DEPOSIT

Ray, Arizona

INTRODUCTION

The Ray copper deposit is located in east central Arizona 75 miles east-southeast of Phoenix, and 70 miles north of Tucson in the Mineral Creek Mining District of Pinal County. It lies in the valley of Mineral Creek five miles north of the Gila River between the Tortilla Mountains on the west and Dripping Spring Range on the east.

Although the copper showings attracted the attention of the Indians who mined chrysocolla with large diabase hammers such as these (show artifact), the first written record of them was made in 1846 by members of Kearny's Army of the West, who named Mineral Creek for the numerous mineral deposits found along its banks.

Development of the district, though, was hampered by its inaccessibility and the danger presented by raiding Apaches. These were gradually overcome and mining activity began in 1870 with the location of a mining claim by a prospector who, as legend has it, named it after his sister. The name, Ray, was immortalized by the ensuing mining companies and townspeople, who applied it to the corporate names as well as the community.

In 1880 the first attempt at production, albeit a short one, was made by the Mineral Creek Mining Company, which erected a five-stamp mill on the Mineral Creek claim located near the eastern limit of what is now the Pearl Handle Pit.

The silver-bearing copper prospects had also attracted the attention of a pair of Tucson merchants, Louis Zeckendorf and Albert Steinfeld, in the early 1870's. Through their efforts, The Ray Copper Company was organized in 1883 for development of the district. In 1884 the mine consisted of a 300-foot tunnel and a 100-foot shaft, with a 50-foot crosscut.

Hamilton wrote of the prospects:

> The Ray and Poorman are probably the most remarkable mines of the Territory....It seems almost beyond the possibility of belief that such immense masses of rock should be mineralized throughout; such, nevertheless, is a fact, as can be proven by personal inspection of the same. Scientific tests to determine values at the Ray mine are unnecessary....A concentrating mill for the handling of the ores from these properties has already been erected....These works have just been started, but, when fairly underway, the output of copper from Mineral Creek will be large and steady.

Unfortunately, this optimism was false, the venture failed, and in June, 1899, most of the property was acquired by Ray Copper Mines, Ltd., an English corporation. Their plans for a large scale mining operation also ran afoul when it was learned that too optimistic an estimate of the ore grade had been made. The 250-ton mill at Kelvin ceased operations after treating only 16,000 tons of ore, and the enterprise failed, putting an end to Ray's colorful era of steam tractors, polo ponies, and nightly formal banquets.

Although the establishment of railroad connections from Kelvin to Phoenix rejuvenated interest in it, the property lay dormant until 1906 when D. C. Jackling and associates gained control of the English company's holdings and organized the Ray Consolidated Copper Company. After extensive churn drilling and underground exploration, fifty million tons of ore averaging two percent copper were blocked out. By 1911, Ray Consolidated had attained a capitalization totaling $14,000,000.

Meanwhile, other companies had sprung up in the district, notably the Arizona Hercules Copper Company, the Kelvin-Calumet Mining Company (later succeeded by the Ray Central Copper Company), and the Gila Copper Company. The communities of Ray, Sonora, Barcelona and the temporary Indian camp, Vitoria, began to take shape. (The Town of Kearny was founded in 1958 mainly to replace Ray and Sonora which will be displaced by the mining operations.) [Slide 1, claim map of district 1/1/12 (Ransome, 1919, p. 101]

The Gila Copper Co. had been organized in 1907 to buy a number of claims which the English company had declined to sell until certain requirements were met. In 1910 nearly all the stock of the Gila Copper Company was exchanged for Ray Consolidated stock. The Arizona Hercules property, too small and difficult to be mined for itself, was acquired in 1927. By then all of these, including Ray Consolidated, had been acquired by the Nevada Consolidated Copper Company. The last corporate change of note in Ray's history took place when Nevada Consolidated was merged into Kennecott Copper Corporation in 1933.

A list of the men associated with the Ray mine during this period reads like a "Who's Who" of large scale mining - Seely Mudd, Henry Krumb, Daniel Jackling, and Louis Cates - only a few testifying to the cliche that mines are, in fact, made and not found.

With the completion of a 5,000 ton mill at Hayden, 25 miles away, the first ore was shipped in 1911. Mining was done by a combination of shrinkage and block caving methods and large scale operations increased Ray's production to 50,000 tons of copper per year by 1942.

However, caving properties and grade of the ore in many areas of the mine were somewhat less than ideal. In 1948, after considerable additional exploration drilling and study, it was decided that the Ray orebody could better be mined by open pit methods. The transition from underground to surface mining was completed in 1955. This step was followed by an expansion program resulting in the construction of a smelter and other facilities at Hayden and an increase in the mine's production from 15,000 tons of ore daily to its present rate of over 24,000.

Ore is presently mined from two open pits, the Pearl Handle and West Pits, separated by Emperor Hill. Exploration drilling in recent years, however, has disclosed an extension of the orebody east of Mineral Creek and mining operations are advancing in that direction.

Since 1911 Ray (Ray Consolidated including Ray Hercules) has produced more than one and a half million tons of copper, 40,000 ounces of gold and four million ounces of silver. Some copper has also been produced by leaching of caved workings and waste dumps, bringing the gross value of all production to well over a half billion dollars.

The growth of the property from one which spasmodically produced 250 tons a day at the turn of the century to one currently producing one hundred times that amount has necessitated a more complete understanding of the controlling geologic features, thus facilitating development and exploitation. Toward this end a program of detailed geologic mapping and study was begun at Ray as at other Kennecott properties. During the course of this investigation a number of old problems have been solved and several new ones arisen which, like the nebulous "hydrothermal solution", will require a bit of time for a complete understanding. Among other things, the results of this study have emphasized the importance of structure and lithology in controlling copper mineralization. The writer is indebted to Kennecott Copper Corporation for permission to make some of these findings public at this time.

REGIONAL GEOLOGIC SETTING

The Ray deposit is situated near the wetsern edge of the Mexican Highland Section of the Basin and Range physiographic province in a series of north-northwest trending mountain ranges which was referred to by Ransome as the Mountain Region of Arizona. The eastern boundary of the Sonoran Desert lies about twenty miles to the west, and the southern edge of the Colorado Plateau Province some eighty air line miles to the north.

More specifically, the district occupies the valley and adjacent slopes between the Tortilla and Dripping Spring Mountains. (Slide 2) Relief is fairly high with elevations ranging from less than 2000 feet in the valley of Mineral Creek to over 5000 feet at the top of Scott Mountain northeast of Ray. Generally, it may be said that these mountains are of typical basin and range structure with major fault systems paralleling the length of the range and the valley between having been filled in varying degree by detritus from the adjacent uplifted blocks.

Southeast of Ray the two ranges are separated by the valleys of Mineral Creek and the Gila River (Slide 3); to the north they coalesce into a ruggedly dissected plateau (Slide 4).

The Tortilla Mountains are composed essentially of Precambrian schist and granite (Slide 5). The Dripping Spring Range, (Slide 6) however, comsists primarily of younger Precambrian and Paleozoic sediments which dip moderately to the south. Both ranges also contain Precambrian and Laramide (?) intrusives and are covered in part by Tertiary volcanics and sediments.

DISTRICT GEOLOGY

As is apparent from the District Geologic Map, (Slide 7) Ray is endowed with an abundance of rock types ranging in age from Lower Precambrian to Quaternary and running the gamut of composition. The relative orderliness of surrounding areas disappears here because of faulting, unconformities, intrusions, or combinations of all three.

ROCK TYPES

The next slide (Slide 8) shows the normal stratigraphic (if not the field) relationships of formations in the Ray district. The Lower Precambrian basement rocks are overlain by more than 2500 feet of Upper Precambrian sediments, mainly quartzites and shales but including, however, the Mescal dolomitic limestone and vesicular basalt flow. An incomplete section of about 500 feet of Paleozoic limestones is present above the former, and well over 1100 feet of Tertiary and Quaternary terrestrial conglomerates and volcanics are also found in the district. Economic interests for the purpose of this slide can be restricted, however, to the formations below the Mescal limestone, which host the copper ores, and the post-ore Tertiary and Quaternary rocks which conceal a portion of the mineralization.

Illustrated here (slide 9) in somewhat simplified manner, are the intrusive relationships of the plutonic rocks at Ray. The Madera diorite and Ruin granite are both Lower Precambrian rocks which intrude the Pinal schist. The diabase, whose age is somewhat controversial, intrudes only the Precambrian rocks older than the Troy quartzite. It occurs primarily as thick sills in the sediments and low angle dikes in schist, often intruding along fault surfaces. Diabase with this intrusive relationship outside the district has been dated isotopically at 1000-1200 million years. Other workers report evidence of a Tertiary age for diabase. However, definite evidence of a Tertiary age has not been observed anywhere in the Ray area, and, therefore, a Precambrian age for the diabase seems acceptable here.

The next youngest igneous activity is represented by a series of Laramide or early Tertiary intrusives: quartz diorite, diorite, porphyry, the Granite Mountain quartz monzonite porphyry, andesite, Teapot Mountain quartz monzonite porphyry, and quartz diorite porphyry in that order. Of these the Granite Mountain porphyry is the most important, being the youngest pre-ore rock.

STRUCTURE

Structure within the Ray District is virtually as varied as its rock types. Faulting, however, has been the major type of structural deformation, with folding playing only a very minor part. As is fashionable for porphry coppers, Ray has also been endowed with a breccia pipe and several pebble dikes which occur in the northeastern part of the district. (Slide 10)

Several types of faults occur: normal, reverse, thrust, and others which cannot be typed because they cut only one rock type, namely the Pinal schist, whose outcrops cover so much of the district. Their attitudes, likewise, are quite variable, although they may be divided into several sets which roughly parallel the regional schistosity, such as the Rustler Fault and Porphyry Break, and those which roughly parallel the mountain ranges. Their dips vary from vertical to horizontal. They range in age from pre-diabase (probably Precambrian), such as the Diabase and Rustler Faults, to post-Gila conglomerate, such as the School Fault. Most of these have undergone more than one age of movement, sometimes in different directions. The Diabase Fault is an interesting example of the latter case. (Slide 11)

Pre-diabase movement is evidenced by the fact that diabase intrudes this fault zone a couple of hundred feet south of the outcrop shown in this slide. The obvious displacement as shown by the outcrop is in the reverse direction with Lower Precambrian Pinal schist in the hanging wall and Upper Precambrian Dripping Spring quartzite in the footwall. Drill hole and other information, however, indicated subsequent movement in both directions (normal and reverse) along the same fault which offsets flat-lying diabase intrusives that continue across the district to the east as well as the overlying Whitetail conglomerate. The net throw as shown by Stratigraphic evidence is still in the neighborhood of two thousand feet.

The outstanding example of thrusting in the district is the Emperor Fault whose trace circumnavigates the Pearl Handle Pit (Slide 12). Here Upper Precambrian Pioneer shale and Dripping Spring quartzite are exposed in its footwall. A vertical thickness of more than 400 feet of lower Precambrian Pinal Schist overlies these in the hanging wall of the fault. At present, the full significance, direction, age and extent of the thrusting are not known or understood, though it seems safe to assume that at least several thousand feet displacement have occurred along the Emperor Fault.

Because of its similar attitude and appearance, the recently discovered Empress Fault is also considered to be a thrust; the Bishop and Broken Hill Faults show normal movements and the West End and North End Faults are probably also normal faults.

One of the main controlling structures in the district, the Porphyry Break, is a very subtle, highly fractured zone of weakness up to 2000 feet wide which has been intruded by the Granite Mountain porphyry.

The School Fault, a reverse fault whose net displacement is similar to that of the Diabase Fault, probably had little to do with controlling primary mineralization; it did, however, serve to localize small amounts of exotic copper oxides.

The Calumet Breccia Pipe (Slide 13), the only feature of its kind known in the district, consists of fragments of Pinal schist, Scanlan conglomerate, Pioneer shale and diabase. Its maximum surface dimensions are 200 feet by 600 feet and it has a minimum depth of over 800 feet. Spatial distribution of the fragments, which range in size up to twelve feet in diameter, indicates a collapse origin. The breccia is weakly mineralized with copper oxides occurring near the surface and iron, copper, and molybdenum sulfides at depth in the interstices of the breccia.

As mentioned before, one of the occurrences of pebble dikes in the district is observed cutting the Calumet breccia. An interesting feature of these is that they contain fragments of Granite Mountain porphyry. No porphyry is known to occur within a quarter of a mile of the pebble dikes. Therefore, it may be inferred that prophyry exists at considerable depth below the breccia pipe. A similar relationship has been observed in an adit in upper Rustler Gulch where other pebble dikes are cut by Teapot Mountain porphyry.

"How does this collapse explain"

OREBODY GEOLOGY

Size and Shape

The copper mineralization at Ray occurs within an area bounded by the West End Fault to the west, the Broken Hill Fault on the east, the North End Fault on the north and less sharply by the contact between Precambrian granite and Pinal schist to the south.

The ore presently being mined in the Pearl Handle and West Pits has been a product of supergene enrichment. It occurs as an irregular blanket up to several hundred feet thick. Copper oxides are present in the eastern portion of the Pearl Handle Pit and generally become more abundant to the east.

Hypogene Sulfide Minerals

Hypogene sulfide minerals in the deposit are limited to pyrite, chalcopyrite, minor bornite and molybdenite, and traces of galena and sphalerite. Pyrite is ubiquitous as veins and disseminated grains and is relatively abundant in most of the ore. As discussed further below, the chalcopyrite content in primary mineralization tends to be considerably higher in diabase than in schist and porphyry. Molybdenite, which occurs in small amounts, is not being recovered from the ore at present. Equipment for molybdenite recovery is now being installed and will be in operation later this year. Galena and sphalerite are present in minor amounts in the outlying parts of the district and traces occur in the pit and in drill holes in the orebody area.

Secondary Mineralization

Chalcocite has been the main copper mineral in ore from the Ray deposit. It is most abundant in schist of the enriched zone but is also present in some porphyry and diabase. Minor amounts of covellite are also present.

Native copper, cuprite and chalcotrichite, brochantite, chalcanthite, malachite, and azurite are present locally in the oxidized zone of the deposit, and native silver has been found on the west side of the Pearl Handle Pit with secondary sulfides and various copper oxides. Much of the chalcocite ore has been slightly oxidized on grain surfaces and leach-precipitate-float process is used to treat that ore.

Chrysocolla and other copper silicates are relatively abundant in parts of the diabase, quartzite and schist to the east of the Ray Fault and in the upper levels of the Pearl Handle Pit. These bodies of oxidized mineralization appear to have resulted from oxidation of either primary or enriched sulfide ore with some leaching and lateral migration of copper.

Host Rocks

All intrusive rocks older than the quartz diorite porphyry as well as the Pinal schist and the Apache group may carry ore, and portions of the Whitetail conglomerate contain exotic copper minerals. No copper mineralization is known in the Paleozoic rocks but they do not occur in the area of the orebody.

Pinal schist: Nearly all the past production has been from supergene enriched ore in the Pinal schist. Grade is quite erratic but may go as high as

10% copper in areas such as the Bishop Fault zone in the southwest part of the Pearl Handle Pit where there is almost complete replacement of pyrite veins by chalcocite. In the West Pit, the replacement is generally less complete and the over-all grade is lower.

Protore grade in schist of the mine area averages between .1% and .2% copper. Thus, with at least 500 feet of leached capping known to exist, and more presumably once present, it is apparent that most of the present supergene orebody could have evolved from protore of the same tenor. Higher grade veins and fractures control of the enriching solutions were probably responsible for the resulting high-grade lenses which occur in the enriched zone.

Granite Mountain porphyry: A rather unusual feature of the Ray orebody is the fact that only a very small percentage of the ore occurs in the quartz monzonite porphyry itself. This ore may contain chalcocite, chalcopyrite and molybdenite as ore minerals and is usually found near the margins of the intrusive bodies in the Pearl Handle Pit, under Ray Hill, and east of Mineral Creek. Internal portions of these intrusives are usually very low-grade or barren.

Diabase: Almost the opposite can be said of the diabase. Whereas ore intercepts in diabase were at one time dismissed as unreliable or deleted from ore reserve calculations, the diabase is now recognized as having been the most important primary host in the district. In the Pearl Handle Pit and areas east of Mineral Creek primary chalcopyrite ore occurs in diabase near Granite Mountain porphyry intrusives or important pre-mineral faults, although none may be found in adjacent schist or quartzite. It is not uncommon for a drill hole to pass through two or more bodies of ore-grade diabase with the intervening material virtually barren of copper mineralization.

Supergene enrichment in the diabase is negligible, although in the shallower portions of the orebody copper silicates and oxides are found (Slide 14). Some are of this type also occurs in the Apache group quartzites and porphyry. A pilot plant is presently under construction to investigate methods of treating the silicate ore.

Tenor of ore within a diabase sill or series of sills exhibits a vertical gradation. The grade in any given sill is generally highest at the top and decreases gradually with depth. Where a series of diabase bodies occur in a vertical column, the uppermost will contain the highest grade mineralization, the next somewhat lower grade, and so on dropping off to only trace amounts of copper in the lowest.

ALTERATION

The predominant alteration types associated with the ore are quartz veining, silicification, biotitization, sericitization, and argillization. These are dependent upon the character of the host rock. For example, biotitization is expecially intense in the diabase and parts of the schist as well as the porphyry. Sericitization and argillization, believed to be largely supergene in origin are heaviest in areas of secondary sulfide enrichment in schist and porphyry and, where the original pyrite content was high, in diabase.

Silicification is heaviest in the rocks which had a fairly high silica content originally and is most obvious in the Apache group shales and quartzites, Granite Mountain porphyry, and schist in ore areas. There is no silicification in diabase which is commonly, however, reticulated with quartz veinlets.

The areas of sulfide enrichment were overlain by capping heavily stained with limonite and, occasionally, copper oxides. Remnants of this capping can be seen on Emperor Hill and the north wall of the Pearl Handle Pit. Other supergene alteration products are calcite (in diabase), alunite, and gypsum, as well as the oxide copper minerals mentioned previously.

MINERALIZATION RELATED TO STRUCTURE AND LITHOLOGY

The structural framework mentioned above played an essential part in the deposition of hypogene minerals and, to some degree, has influenced supergene enrichment.

Although there are several fault systems in the district which predate the intrusion of the Granite Mountain porphyry, the Porphyry Break, apparently a very deep seated structure, is most closely associated with it. The Porphyry Break's surface expression is very subtle and it shows only as an intensely shattered zone intricately intruded by very irregular masses, as well as small dikes and sills of porphyry, all having very erratic contacts with the country rock. The general northeast strike of the porphyry intrusive bodies was altered somewhat in the Mineral Creek-Ray-Diabase Fault zone, where it spread out in the direction of these structures.

The hypogene mineralization which followed the crystallization of the Granite Mountain porphyry used its contact zones as conduits, mineralizing fluids traveling along the porphyry contacts and the intersecting major structures. The fluids also migrated along the upper contacts of the diabase sills. To a lesser degree, they traveled through the Calumet Breccia Pipe depositing minor amounts of copper and molybdenum sulfides in the interstices of the breccia. Father away from the center of mineralization they formed sulfide veins.

Some of these faults had definitely limiting effects upon the mineralization. Copper values terminate abruptly near the West End (Slide 15) and North

End Faults at the western end of the orebody and in a similar manner at the eastern end of the district. In the latter case, as will be shown on a cross-section, diamond drilling has indicated a north-south striking intrusion of Precambrian granite in the Pinal schist. There seems to be a relation between the copper values in the overlying rocks and this contact, which is roughly perpendicular to the regional schistosity. It may be that the granite to the east acted as a barrier to the mineralizing fluids or it may have simply limited the extent of the fracturing in that direction.

Although it is generally conceded that a genetic relationship exists between the Granite Mountain porphyry and the mineralization, very little ore is found in the porphyry itself, and then usually only near the margins of the intrusion. Similarly, very little primary ore occurs in the Pinal schist, protore rarely containing more than 0.2% copper, and secondary enrichment was necessary to make the mineralization economic.

As I have already mentioned, structure was important in the secondary enrichment process as well. The most obvious example is the Emperor Fault (Slide 16, 17). Rocks in the hanging wall have been completely oxidized and leached of all sulfides, whereas those in the footwall contain high grade supergene enriched ore. The Bishop Fault, which cuts the Emperor, has carried the oxidation as well as the supergene enriching solutions to a greater depth. This has resulted in a high grade zone of steely chalcocite replacing pyrite in veins several inches across. Assays as high as ten percent copper have been obtained in this area and small amounts of native silver have also been observed. (Slide 18)

By far, the most important host rock in the district has been the diabase. Whereas at one time ore intercepts in diabase were dismissed as "unrealistic" or "unreliable", they are now known to be more extensive in the primary zone than in any other rock. The sill-like masses of diabase which extend for miles to the north, south, and east of Ray are, however, intensely mineralized within the district. The grade of copper mineralization in them is higher near the porphyry contacts and major structures previously mentioned and decreases outwardly. As in the other rock types, a pyritic halo extends for a considerable distance outside the copper mineralization.

As regards the vertical configuration, grade is highest at the top of the diabase intrusives and gradually diminishes with depth. Where several diabase sills occur in a column, the uppermost sill will generally carry the highest grade ore, those below gradually decreasing in grade. The intervening material, whether it be quartzite, schist or porphyry, is virtually barren of copper. A drill hole in such an area might, for example, collar in diabase bearing copper oxides and then pass through a section of Dripping Spring quartzite containing only pyritic mineralization. Upon entering a deeper diabase sill, it would show a marked increase in chalcopyrite as well as pyrite content which might render assays as high as two percent copper (a very high grade area!), decreasing with depth. Upon penetrating this diabase sill, entering a say, Pioneer shale, the copper content would immediately drop off, as would the pyrite, until a second diabase sill was encountered. Assays in the upper portion of this second diabase body might run, for example, one percent copper and again decrease with depth, until this sequence was interrupted by penetration of the diabase sill, our hypothetical drill hole then entering more shale or, perhaps, Pinal schist (Slide 19). This material would show only pyritic mineralization with very minor, or trace amounts, of chalcopyrite. Upon entering a third diabase body at still greater depth, copper values might jump to seven or eight tenths percent, again gradually decreasing with depth to two-tenths percent and less.

Thus it appears that not only was the diabase much more reactive to the mineralizing fluids by precipitating out greater amounts of chalcopyrite than the adjacent rocks, but it must have been more permeable as well. The fluids must have traveled not only vertically through the diabase, but laterally along the upper surfaces of these sills for a greater distance than in any of the other rocks.

SUMMARY

The many and varied geologic events and processes which have taken place at Ray necessarily give it some features that appear to be unique among porphyry coppers. Noticeable are the irregularity of the quartz monzonite porphyry intrusives and the fact that they contain so small a percentage of the orebody. The largest outcrops of the Granite Mountain porphyry occur outside the district and are essentially barren. Another singular feature is the importance of the diabase over any other host rock; the analogy might well be drawn, however, between the diabase and a favorable limestone bed in a mineralized area. Factors related to the formation of the copper silicates east of the Diabase Fault are unusual, if not unique. Structurally it is one of the most complex of the porphyry coppers.

In many ways, though, Ray is very similar to other porphyry copper deposits. The importance of old, recurrently active geologic structures, and the obvious genetic relationship of the ore to quartz monzonite porphyry fall right into line with the other deposits. This structural framework was essential in controlling the intrusion of the phorphyry and providing conduits through which the later mineralizing fluids could be disseminated through the host rock. With the exception of the diabase, however, most of the primary mineralization is sub-economic. As in most of the other deposits, supergene enrichment was necessary to make mining practicable.

LIST OF ILLUSTRATIONS.

R E F E R E N C E S

1. Dunning, C. H., and Peplow, E. H., Jr., Rock to Riches, p. 406, Southwest Publishing Company, Inc., Phoenix, Arizona.

2. Metz, R. A., and Rose, A. W., The Geology of the Ray Copper Deposit, University of Arizona: The Porphyry Copper Deposits of the Southwest.

3. Parsons, A. B., 1959, The Porphyry Coppers in 1956, AIME, New York.

4. Peterson, N. P., 1962, Geology and Ore Deposits of the Globe-Miami District, Arizona: U. S. G. S. Professional Paper 342, p. 151.

5. Ransome, F. L., 1919, The Copper Deposits of Ray and Miami, Arizona: U.S.G.S. Professional Paper 115, p. 192.

6. ____________, 1923, Geologic Atlas of the United States, Ray folio, Arizona: p. 24.

7. Thomas, R. W., 1929, Mining Practice at Ray Mines, Nevada Consolidated Copper Company, Ray, Arizona: Department of Commerce, Bureau of Mines Information Circular 6167.

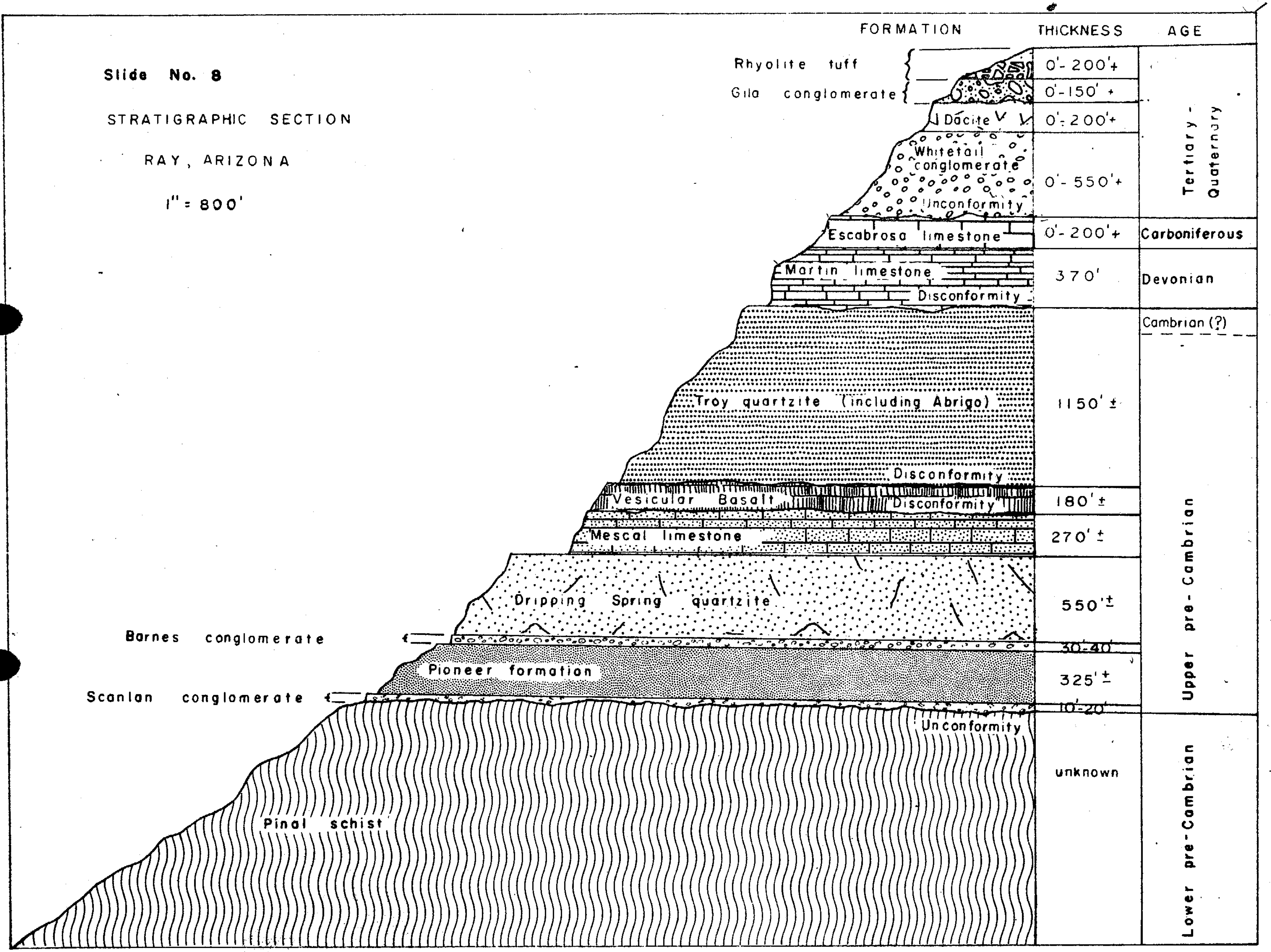
8. Wilson, E. D., 1962, A Resume of the Geology of Arizona, Arizona Bureau of Mines Bulletin No. 171, p. 140.

Slide No. 8

STRATIGRAPHIC SECTION

RAY, ARIZONA

1" = 800'



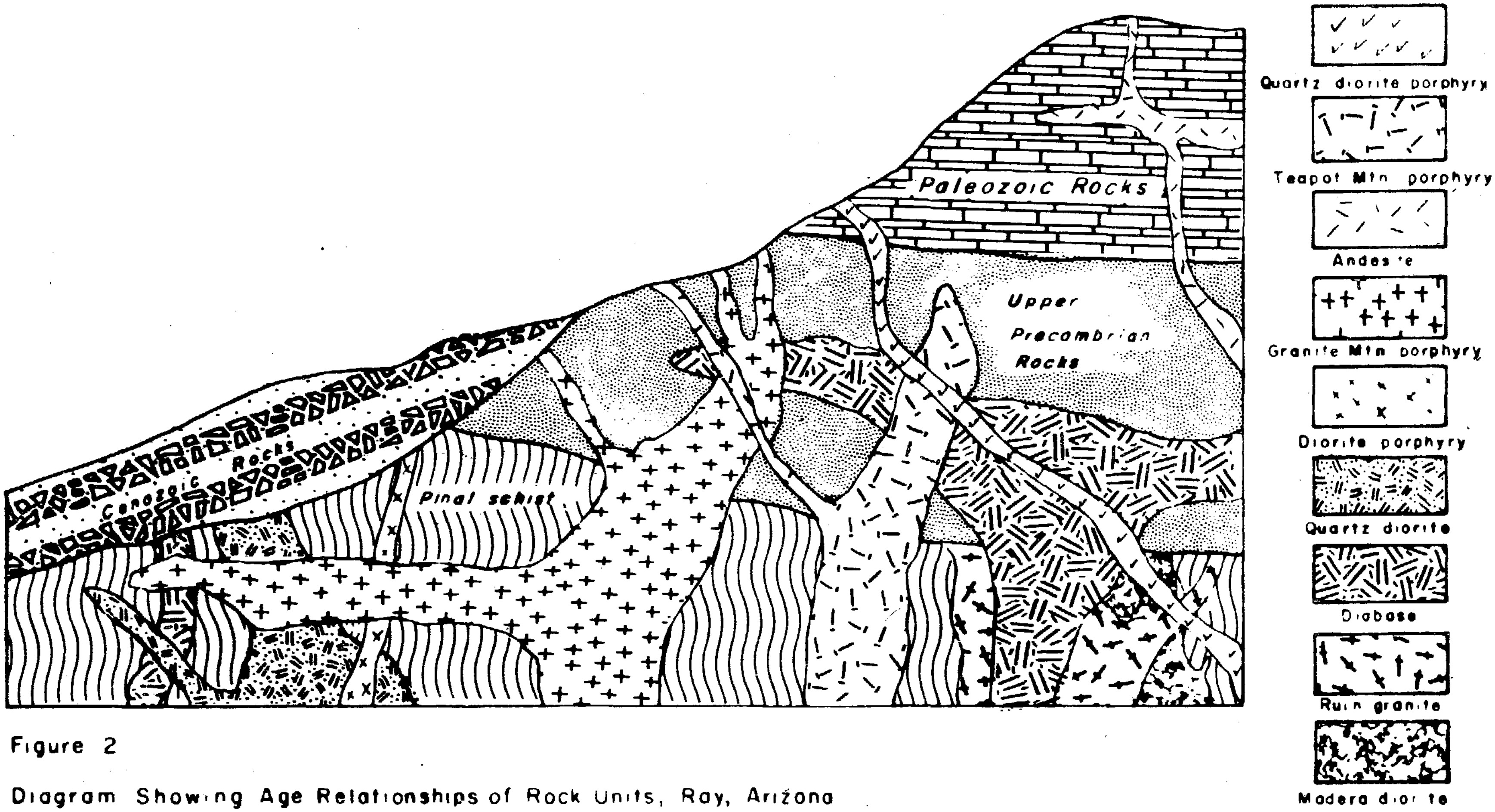
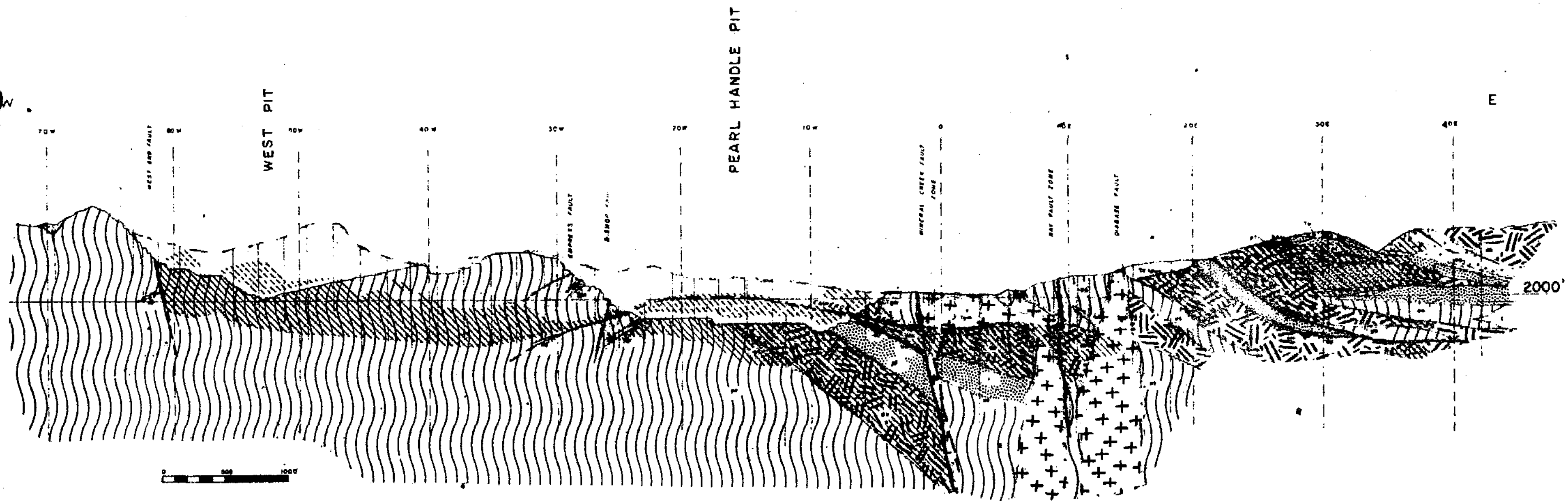


Figure 2

Diagram Showing Age Relationships of Rock Units, Ray, Arizona



GEOLOGIC CROSS SECTION
1200 North

Similar to Slide No. 18

LEGEND:

Original Surface

Copper Mineralization

Copper Mineralization above present surface

A BRIEF HISTORY OF THE RAY DISTRICT

The Mineral Creek Mining District, which includes the Ray area, was organized by silver prospectors in 1873. In 1880 the Mineral Creek Mining Co. built a five-stamp mill, then in 1883 the Ray Copper Co. took over and built a 30-ton copper furnace. The ore of the area was described as principally native copper. There was little activity until 1898 when the claims were purchased by the Globe Mines Exploration Company, (Ltd.), of London. The following year the ground was acquired by the Ray Copper Mines, (Ltd.), another British Company.

During the first year of its existence the new company founded the town of Kelvin and erected a 250-ton mill there. Ray and Kelvin were connected by a 7 mile narrow gauge railroad, various shops and offices were erected, and a 344 ft. shaft was sunk at Ray. Supplies were transported by steam traction engine 43 miles from Red Rock, the nearest shipping point on the railroad. There was no mining activity between 1901 and 1905.

D. C. Jackling was attracted to the district in 1906. The Ray Copper Co. and Gila Copper Co. were organized to acquire the English Company's holdings; they were merged as the Ray Consolidated Copper Co. in 1910. Other companies to become active in the district in 1906 and 1907 were the Arizona Hercules Copper Mining Co., Kelvin Calumet Mining Co. and Ray Central Mining Co.

The properties of all these Companies were acquired by the Ray Consolidated Copper Co. through the years. A mill was placed in operation at Hayden during 1911 and production started from the mines at Ray. In 1912 a smelter was built by A.S.& R. at Hayden. In 1924 Ray Consolidated Copper acquired the Chino Copper Co. in New Mexico. In 1926 the Nevada Consolidated Copper Co. absorbed the Ray Consolidated holdings and these holdings were later absorbed by Kennecott Copper Corp.

Mining methods underground and metallurgical processes at the mill underwent a slow but constant improvement. The Ray Mines were the first underground operation to produce 8000 tons of ore per day by the block caving method.

There was a brief shut-down of mining operations in 1921. Operations were again shut down during the depression between 1933 and 1937.

In 1938 the first unit of a modern precipitating plant was placed in operation. The plant has now expanded to six units which handle 2000 gallons of solution per minute, from underground workings and waste dumps.

During 1948 it was decided to mine the remaining ore by open pit methods. The Isbell Construction Company stripped waste from the Pearl Handle Pit under contract from 1948 to 1952. First ore was mined by open pit methods in 1950. The capacity of the Mill at Hayden was increased to 15,000 tons a day. A new Crushing Plant was built at Ray to handle the pit ore. Ore from the pit was gradually increased and from the underground mine decreased, until February 1, 1955, when underground mining was discontinued.

To increase recovery of non-sulphide copper in the ore, a Leach-Precipitation-Flotation Plant (L-P-F Plant) has been built at Hayden at a cost of over $5,000.000. This involves a special flotation section for recovery of previously rejected pyrite. This is roasted to produce sponge iron and sulphuric acid. The acid is used to leach the ore in the Mill feed and remove the soluble copper which is then precipitated on the sponge iron and recovered by flotation.

During 1956, work was started on an expansion program to increase production capacity to 22,500 tons of ore a day. A new Smelter is being constructed at Hayden to treat the concentrates which have previously been treated by the American Smelting and Refining Company.

Reference: Ransome - U.S.G.S. Professional Paper #115 1919, 1923

Notes from Mr. Leroy Hoyt

O Carrol - Kennecott
Hoyt - sec AIME - Ariz Sect.

The Ray Orebody

Foreword.

The geology of the area was first described by Ransome in 1919, later revised by him in 1923 in U.S.G.S. Professional Paper #115. It is a wonderful piece of work that still remains essentially correct. Valuable contributions to the Ray geology were later made by Spurr and Cox (private report, July 1909), C. L. Hoyt (private report, 1938) and Otis M. Clarke, (Arizona Geological Society Guidebook, 1952).

In the present work, the constant supervision of Mr. Donald D. Smythe, his continued advice and personal study of the deposit have largely increased our knowledge on the major structures with, as a result, a substantial increase in ore reserves.

The progressive policy observed by Mr. A. P. Morris, General Manager, keeps pace with the geological work by a well-planned and systematic drilling program, well worth mentioning.

Location.

Ray is located at the foothills of the Dripping Spring Mountains on Mineral Creek which flows South into the Gila River.

Geology. 1. Stratigraphy

The Stratigraphic sequence is first reviewed and the most important rocks are here briefly described. The basement consists of the Pinal Schist, old pre-Cambrian in age and contemporary to the Vishu Schist in the Grand Canyon. The formation generally shows a northeast-southwest schistosity, dipping to the NW from 30 to 60 degrees. Many local folds are observed in this formation which is composed of metamorphosed sedimentary rocks, generally showing an alternation of shaly and quartzose layers, and of intrusive rocks like rhyolite and what is locally called "amphibolite-schist".

The color of the Pinal Schist is generally gray with a bluish hue outside of the mineralized area turning naturally into different shades of brown within it.

The Apache group unconformably overlies the Pinal Schist and is also pre-Cambrian. The lower part of it is mainly composed of the Pioneer formation, generally a shale, the Barnes conglomerate, and the Dripping Spring quartzite. These rocks show in the vicinity of Ray a regional trend slightly east of north with a low dip, 10 to 20 degrees eastward.

The Pioneer formation, the Dripping Spring quartzite, and the Pinal Schist are at times quite difficult to differentiate, be it in the field on the surface geology, or in the examination of drill-core.

The tan-colored Mescal limestone is next in the sequence and is often seen in conjunction with dark brown basaltic flows that covered it.

The Troy quartzite, Cambrian in age, follows.

All these formations are abundantly found East of Ray.

The Martin, Escabrosa and Naco limestones of Paleozoic age occur only on the top of the Dripping Spring Range and do not appear near the orebody.

Long before Laramide time, heavy faulting occurred and incompetent rocks such as the Dripping Spring quartzite, were broken and fractured. Diabase was intruded shortly after, lifting the separate masses of quartzite and filling all existing fissures.

A specific fracture trending NNW and SSE with a dip of 45 degrees to the East has been filled with diabase: it is now conspicuously visible in the pit. To the East of Mineral Creek there is considerable diabase, some existing as sills between members of the Apache group and other portions underlying the whole series as an extensive mass. Another series of irregular fractures exhibit the same trend but they occur more vertically; in this group we have the Ray fault and the Mineral Creek fault.

Porphyry next intruded the area. The Teapot Mountain porphyry came first, exhibiting well formed felspar and quartz phenocrysts, and it was followed by the Granite Mountain porphyry. It appears that this latter porphyry forced its way through fractures that trend in an opposite direction to those previously noted;

it is found along a NE-SW trend irregularly intruded but it also shows here and there as small stocks.

One interesting observation is the fact that the Teapot Mountain porphyry occurs North of an East-West line passing approximately through the pit, while the Granite Mountain porphyry definitely shows South of that line. Copper mineralization occurred simultaneously or slightly after the intrusion of the Granite Mountain porphyry.

After a presumably long interval of time, during which erosion and also secondary enrichment occurred, the country was covered by tertiary flows, tuffs, and conglomerates: Whitetail conglomerate, dacite flow, Gila conglomerate, then tuffs and volcanic breccias.

These are the main formations that we encounter in and around the Ray orebody.

2. Structure.

A major fault zone, particularly complex near Ray, extends along Mineral Creek exhibiting a Northwest-Southeast trend. It seems to show an en-echelon pattern with successive downthrows to the East, almost all steep.

The movement along this major fault area has been estimated by Ransome, Cox and Spurr, to amount to 1500 ft. and even 2000 ft. It started before Laramide time with a relative downthrow of the east block, later alternated with an upthrow and finally with a renewed and important downthrow again of the eastern area.

Recent Tertiary movement is well shown by the conspicuous offset observed in the dacite flow: some remnants occur on the Teapot Mountain to the Northwest at 4400 ft. elevation while a larger mass of dacite occurs near town (best seen at the bridge) at 2050 ft. elevation and more. Another obvious indication of this large offset is obtained from a look at the geologic map. It shows a solid area of Pinal schist west of the fault zone without any of the later sediments. This contrasts with later sediments found to the east, ranging from the Cambrian up to the Tertiary.

It is worth mentioning that while the west block has been disturbed relatively little, the eastern one shows a broken assemblage of formations that Ransome justly calls a mosaic. It is fortunate that stratigraphy can partially assist in deciphering this jumble; the Barnes conglomerate is of particular help here as a faithful and conspicuous marker.

The orebody, and particularly its limits, is largely controlled by structural factors. To the west, the West End fault appears definitely to indicate a structural termination. To the north the situation may be similar. The southern limit seems to be indicated by a rather sharp fade-out. Similarly to the east we are inclined to believe in a gradual fade-out beyond the fault zone.

The orebody can thus be represented roughly on a map by an irregular ellipsoid 8000 ft. long and 1500 ft. wide elongated along a direction east-west. This does not mean that this is a solid ore body: for instance, between the old Pearl Handle pit and the West pit the intervening hill, that is now being gradually stripped away, is almost all waste. The west block contains three major coordinate faults almost at right angle. Whenever they cut through the ore body there is no large offset in the latter.

It will be difficult for a long time to determine for certain which are the faults that pre-date or post-date mineralization; most of them probably antidated mineralization then recurrence of movement during and/or after mineralization blurred the whole picture.

Without any doubt the later fault movements have influenced the supergene orebody: for instance, the oxidation zone in the eastern block is much deeper than in the western zone because the water-table has followed the downward movement of that bloc.

A major structure observable in the pit is an over-thrust fault oriented N20W, dipping 15 degrees East. This truncated the main diabase dike, displacing its upper body toward the west; no remnant of the upper body has been found yet as it is probably all eroded. The lower body has been dragged close to the fault and extends irregularly toward the west as an elongated tongue.

The westward displacement along this thrust fault is indicated in section by an offset (known from drill-hole data) of parts of the porphyry mass existing east of the pit. The amount of displacement might amount to a few hundred feet.

3. Mineralization.

The three formations seen in the pit are the diabase, a dark-gray color, the schist ranging from a light pink to a reddish brown and the porphyry often lighter in color.

Hypogene mineralization occurs more conspicuously in the diabase under the form of chalcopyrite and pyrite. The rock is fractured and broken, although fine-grained and dense. It is hard to break, hard to drill and hard to crush; however it crumbles easily by disintegration after a few months of exposure in the air. A hammer blow breaks it along pre-existing fractures and each new blow breaks it along more tiny fractures all of which are mineralized. This mineralization does not extend far away from the fracture, perhaps a tenth or 2 tenths of an inch. It is not truly disseminated therefore, and it could better be called reticulated for example, as E. N. Pennebaker labeled it (verbal communication).

It is difficult to distinguish chalcocite in this dark rock and the amount of supergene enrichment is now well known.

The schist in the pit usually shows chalcocite as copper mineral either as tiny specks or as veinlets. This is understandably secondary because we are still in the supergene zone.

In the schist also, we can detect the same "reticulation" in mineralization as noticed in the diabase.

The porphyry in the pit shows chalcopyrite, pyrite and secondary chalcocite; much of the chalcopyrite and the pyrite have indeed been already replaced.

Gold and silver in minute quantity accompany the copper minerals with some molybdenum.

Native copper has been one of the copper minerals frequently found in the Ray ore zones. Cuprite sometimes under the form of chalcotrichite with its delicate hairlike crystals, is also abundant in places.

4. Alteration.

Little hydrothermal alteration as such seems to have affected the diabase. The schist, on the other hand, exhibits much more alteration although less than at other mines, such as Chino, etc. Sericitization is the main phenomenon and it occurs generally along with mineralization; it is well displayed in the whole western portion of the Pearl Handle Pit. Some silicification mainly along faults also shows at places. It has been repeatedly observed in field specimens from the pit and outside, that a small bleached zone of sericitization occurs on either side of pyrite veins but the phenomenon does not occur along quartz veins.

Another type of alteration connected with thermal metamorphism is seen in the pit west of the diabase: this is the occurrence of larger masses of a siliceous rock quite sericitic, grayish and fine-grained, occasionally still showing remnants of schistosity. It breaks, however, like diabase with a similar occurrence of mineralization, often then having a darker grayish color.

Two such occurrences have been found. One shows in the diabase, near its underface, north of the pit, where it looks more like a stoped mass of schist in the diabase. The other, quite extensive, shows on the west side of the pit below but adjacent to the diabase. The occurrence seems in this case to be more of a transitional type. The color is generally light gray, sometimes whitish gray showing a marked contrast with the dark diabase to the east and the brown reddish schist further west. Thin sections made from this rock showed it to be a sericitized quartzite.

The porphyry, mainly found east of the pit, displays some alteration mainly in the plagioclase felspars. It has a pinkish appearance and shows well-formed biotite books, shiny and well crystallized. Here too, we see that along pyrite veinlets there is a bleached sericitized band on either side. These bands are wider here than in the schist, often 1 or 2 inches wide in total. The color becomes creamy-tan.

To the south of the pit we also find a transitional zone between schist and porphyry this time where the two rock characteristics have been blended together.

---

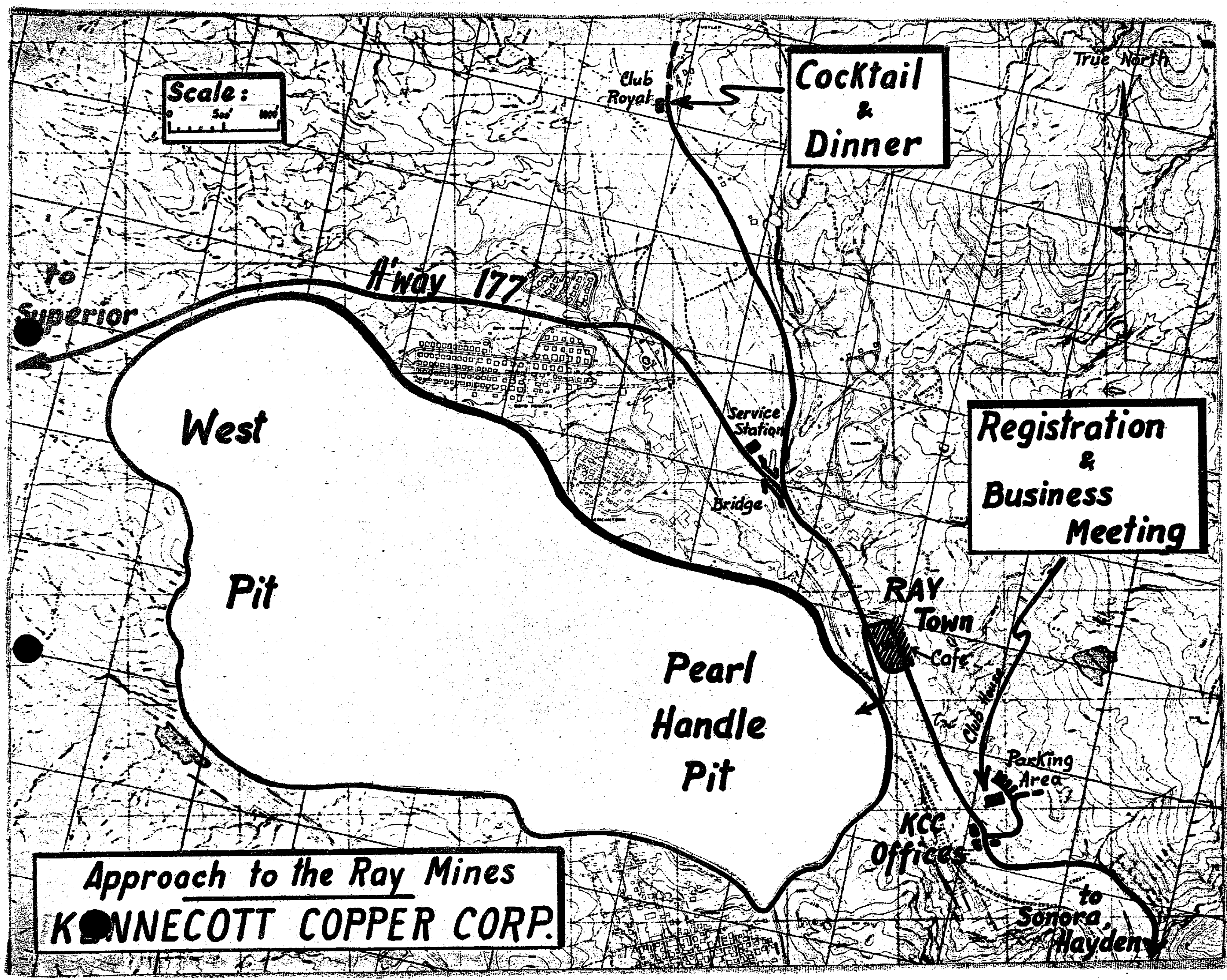
5. <u>Origin of the Ore</u>.

There is much speculation about this question. It appears, however, that one of the small stocks of Granite Mountain porphyry is much more broken and shattered than others; it is located east of the present pit and on the Ray fault within the ore body.

A well shattered porphyry stock in the middle of a heavy fault zone, accompanied by a general rustiness of the rocks in the area, seems a valid criteria for good porphyry copper. The presence of diabase, as is seen in other mines of the vicinity, is an additional favorable factor influencing the orebody.

J. Wertz

(Paper presented at the Spring Meeting AIME, Geology Division, Ray, Arizona on April 12, 1958).



Approach to the Ray Mines
KENNECOTT COPPER CORP.

Mr. Courtright

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

July 10, 1950

MEMORANDUM FOR MR. WILSON

MINERALIZATION EAST OF RAY
Pinal County, Arizona

On July 1st a brief examination of the subject area was made for the purpose of determining how far significant mineralization extends east and southeast beyond the productive area where both open pit and underground porphyry copper mines are now being operated by Kennecott's Ray division.

The chalcocite orebodies of the Ray district occur in a west-northwesterly trending zone of disseminated sulphide mineralization and associated alteration, about 2½ miles long and three-fourths of a mile wide. This zone, for the most part in Pinal schist, is marked by buff to brownish, or rusty colored outcrops, in sharp contrast to the various shades of gray in the unaltered rocks outside its borders. The dark maroon limonite (after chalcocite) occurs as narrow veinlets and minute specks in the leached rock. Where this material is more abundant, the outcrops display darker color tones with less of the yellow-brown, as is characteristic of the leached capping over enriched porphyry copper deposits. Westerly, the principal zone of mineralization narrows gradually and feathers out. Easterly, the zone widens and terminates in an irregular fashion along a northerly trending border (see map) suggesting a possible genetic relationship with the major fault zone which has guided the erosion of the Mineral Creek drainage basin in a general way.

Due to the generally brownish color tone of the quartzite, the principal rock type east of the Mineral Creek, this easterly border of the zone of disseminated sulphide mineralization does not stand out as sharply by color contrast as does the margin of the zone elsewhere - in schist mainly. Viewed at a distance, mineralization appears to continue easterly and be diffused through the quartzite for several miles along the flanks of the Dripping Springs range. However, a closer view disclosed evidence of a comparatively well defined margin not much over a thousand feet east of Mineral Creek. As observed in traveling up Poorman Gulch, a very definite change in the appearance of the diabase coincides with a significant, but hardly noticeable change in the quartzite. The diabase, which occurs as dikes and sills in the quartzite, is far more susceptible to hydrothermal alteration than the quartzite and consequently affords in visible effects a better gauge of relative intensities of alteration. Strongly altered diabase, a light gray mass of sericite and clay containing veins and grains of residual limonite, gives way within a hundred feet or so to almost black, unmineralized rock with the original texture clearly evident. The quartzite adjacent to the altered diabase is strongly fractured, with residual limonite in numerous veinlets; adjacent to the fresh diabase the quartzite is devoid of veinlets, but still shows "rusty" hues, due principally to thin films of transported iron and manganese oxides.

Here, as in many other porphyry copper deposits, copper stain, usually chrysocolla, is most conspicuous around the periphery of the zone of disseminated mineralization where less altered rocks, being more reactive, precipitate the copper

July 10, 1950

Memorandum for Mr. Wilson

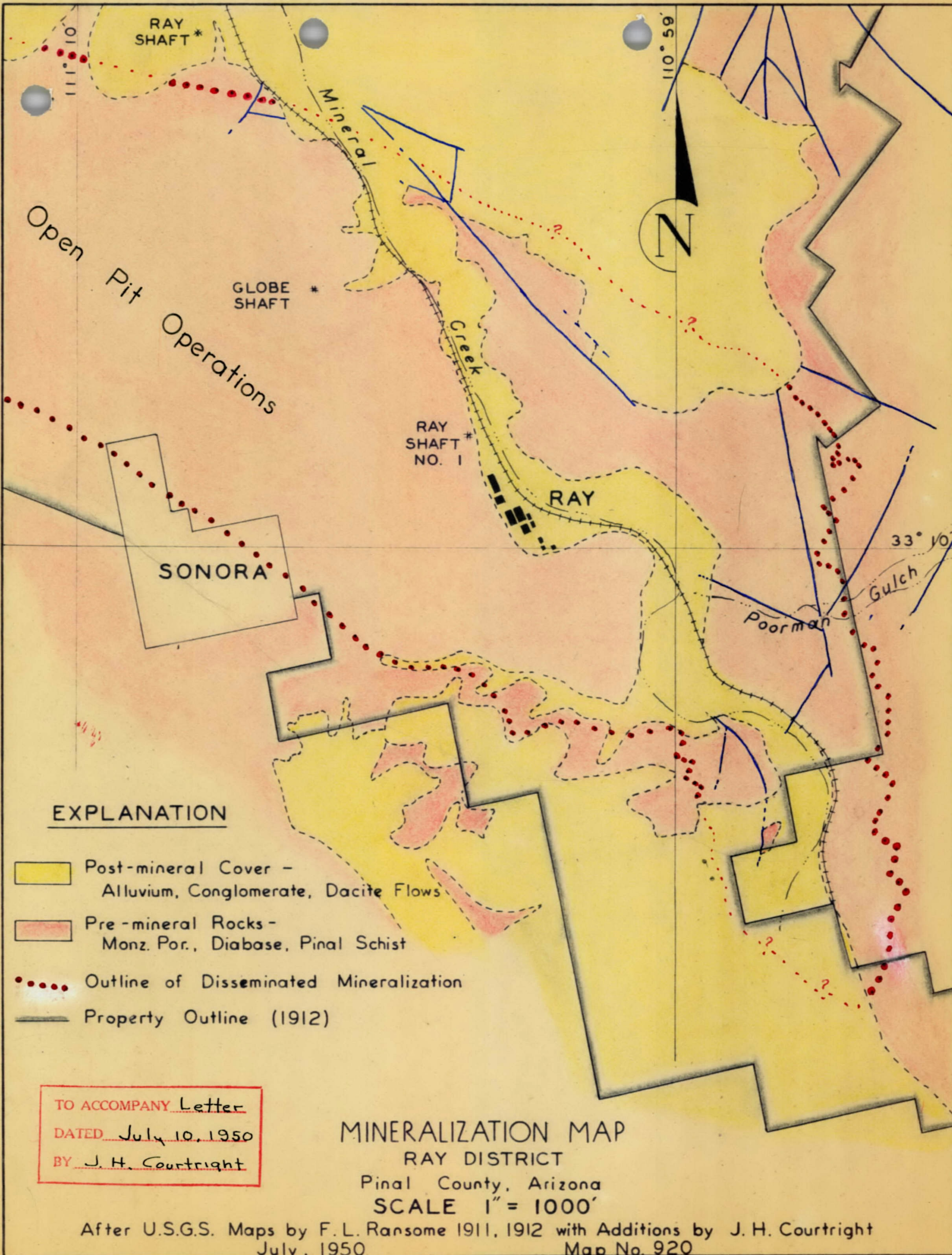
from the groundwater. This condition is particularly well displayed along the margin (indicated by red dots on the attached map) some 2,000 feet south of the town of Ray. Here, the strongly altered schist, light gray and sericitic, contains considerable residual limonite, some after chalcocite, but no copper stain. This grades within a few feet into a greenish, chloritic, weakly altered schist, liberally splashed with blue-green copper minerals.

In conclusion, it is considered that the approximate limits of the zone of porphyry copper mineralization and alteration at Ray are evident in the existing outcrops of pre-mineral rocks, and that these limits serve to confine exploration possibilities to nothing more than minor extensions of the known ore-bearing area.

JHC:ar

J. H. COURTRIGHT

Attachment: Map


RAY SHAFT *
111° 10'
110° 59'
Mineral
Creek
Open Pit Operations
GLOBE SHAFT *
RAY SHAFT NO. 1 *
RAY
SONORA
33° 10'
Poorman
Gulch
?
?
?
?
N
EXPLANATION
Post-mineral Cover - Alluvium, Conglomerate, Dacite Flows
Pre-mineral Rocks - Monz. Por., Diabase, Pinal Schist
Outline of Disseminated Mineralization
Property Outline (1912)
TO ACCOMPANY Letter
DATED July 10, 1950
BY J. H. Courtright
MINERALIZATION MAP
RAY DISTRICT
Pinal County, Arizona
SCALE 1" = 1000'
After U.S.G.S. Maps by F. L. Ransome 1911, 1912 with Additions by J. H. Courtright
July, 1950
Map No. 920

REGIONAL GEOLOGY
AREA SOUTH AND WEST OF RAY
PINAL COUNTY, ARIZONA
BY
RICHARD G. BOGUE
APRIL, 1949
AMERICAN SMELTING & REFINING CO.,
TUCSON, ARIZONA
SCALE 1" = 1 MILE

MAP NO. 776