

STORY OF THE MORENCI OREBODY

The Morenci Branch of the Phelps Dodge Corporation has averaged a production of approximately 295 million pounds of copper per year for the last five years. In 1950 it produced the amazing total of 309,353,406 pounds. This production is all the more impressive when one realizes that it equals the planned production four years hence from the five new major Arizona developments, San Manuel, Lavender Pit, Copper Cities, Silver Bell and Bagdad.

The Morenci orebody, from which this copper has been taken, is located in the Eastern part of Arizona, about fifteen miles from the New Mexico border, and 70 miles by road from Lordsburg. Though the Morenci mine has produced some ore from rich fissures that traverse the deposit, it was essentially a distinct deposit of low grade ore which was recognized as such as far back as 1904. Development work pushed spasmodically, increased the tonnage of known ore, but the average copper content was only a little above 1 percent, or 20 lbs. per ton, exploitation was not attempted. In 1929 when Mr. Cates resigned from Utah Copper to accept the presidency of the Phelps Dodge Corporation, his experience with the Utah Copper enterprise and the Ray Mine block caving development, naturally prompted him to push the exploitation of the Morenci orebody. Here was a problem worthy of his great abilities.

Early History of the District

Rickard, Joralemon and Parsons have written interesting accounts of the early history of the Clifton-Morenci mining district wherein the Morenci orebody is located, and much of this story was gleaned from their writings. The district was first of the southwestern copper camps to become important. Spanish and Mexican explorers had reported the presence of copper in the precipitous mountains north of the Gila River early in the nineteenth century. In 1864, Henry Clifton and a group of prospectors from Silver City, New Mexico, rediscovered the rich copper carbonate ore, but the district was so remote they made no attempt to locate the mines. Six years later, a prospector named Isaac Stevens, together with Bob Metcalf and six others, found striking outcrops of beautiful green copper carbonates near the top of the limestone cliffs two thousand feet above the bed of Chase Creek. They located the first claims in 1872 and founded the town of Clifton in the deep canyon where Chase Creek and the San Francisco River came together.

A little one-ton adobe furnace was built by the Leszinsky brothers who organized the Longfellow Copper Company in 1873, to smelt the 20 percent ore from the Longfellow mine. They later built a larger blast-furnace plant at Clifton.

The first concentrator was built in 1886, but the ores were principally oxidized, and direct smelting ore still supplied most of the production. As early as 1893, the mining of somewhat leaner porphyry ores, containing copper in the form of sulphide mineral, chalcocite, was commenced; but these still were of comparatively high grade and the concentrators were plants of only 100 to 400 tons daily capacity. The backbone of operations was still the production of rich oxidized ores for direct smelting. They assayed 10 to 15 percent copper and the sulphide milling ores assayed 3 to 4 percent. Although the concentrating ore was typical of that in the Porphyry group of mines, except for its richness, Morenci can hardly be claimed to have been the pioneer in large-scale operations on lean copper ores, which honor unquestionably belongs to Jackling at Utah.

The Longfellow was the nucleus for the group that was subsequently acquired by a syndicate of capitalists who organized the Arizona Copper Co., Ltd., in 1884. The Humboldt and Morenci mines were included in the Company's holdings.

William Church, who came to Joy's Camp (now Morenci) in 1874, obtained an option on four patented claims, including the Copper Mountain, and organized the Detroit Copper Mining Co., with Capt. E. B. Ward and some friends from Detroit. By 1880, enough ore was developed to warrant a smelter on the San Francisco River, three miles below Clifton. Indians frequently interfered with the hauling of ore from mine to smelter, so later a 20-in. gauge railroad was built, using the first locomotive ever operated in the Territory of Arizona.

The year 1882 marked the entry of Phelps Dodge company into the Clifton district. On the recommendation of James Douglas, the Phelps Dodge Company advanced \$50,000 toward the building of a new smelter by the Detroit Copper Co. and acquired a half-interest in the property. By 1883 a railroad was built from Clifton to Lordsburg, through which the Southern Pacific had been extended westward from El Paso. Early in 1886 Church built and operated the first copper concentrator in Arizona, treating oxidized ore averaging 6.5 percent copper, which at that time was not suitable for smelter feed. The recovery was only 55 percent and the concentrate averaged 23 percent copper. The plant had a capacity of 50 tons per day and consisted of a jaw crusher, a set of rolls, three revolving trommels and six jigs.

James Colquhoun, a young Scottish engineer, who was sent to America by the Scotch capitalists who had a big investment in the Arizona Copper Company, had watched this experiment with considerable interest because the ore on his property had also declined in copper content. A few months after Church's plant started to operate, Colquhoun built another and larger concentrator for his company on the same principle and with the same gratifying results.

But six years later, copper prices dropped to ten cents on the New York market, and Church's firm was obliged to shut down. The situation of Colquhoun's company was just as grave. The cessation of Church's ore shipment on the A. C.'s railroad to Lordsburg caused a serious loss of revenue, and production in its own mines declined as the dumps of low-grade ore were exhausted. The company treasury sometimes did not have enough cash to pay wages, and no hope at all seemed to exist for income to meet interest due on the million dollar mortgage. The mine appeared doomed.

As a last resort the Directors in Edinburgh asked Colquhoun to become general manager of the company. Fortunately, the new manager had an idea. The jigs on his concentrator worked well enough with six percent ore, but the only ore now available was the low-grade oxidized porphyry near the surface which could not be successfully treated by the old mechanical means alone. Fooling around with a forty-gallon barrel and a can of sulphuric acid, Colquhoun proved to his own satisfaction that the tailings could be leached. Unable to get financial backing for his idea, he built a plant with funds obtained by cutting into the slender reserves of high-grade ore.

It was one of the most extraordinary plants ever erected under the direction of a mining engineer. The foundation was an old slag dump; the engine was an old machine from the mines; the copper for barrel ends came direct from the

blast furnaces; mine timbers served as lumber; and iron and steel fittings were fashioned at a blacksmith's forge. When finished, the plant cost a hundred thousand dollars and had a capacity of a thousand tons a year. Extraordinary or not, it worked. Within a short time, production was increased forty percent, and the cost of copper reduced by two cents a pound.

By 1895 the company was not only able to meet payments on its mortgage, but declared a small dividend, the first in its history.

Under the management of James Colquhoun, the Arizona Copper Co. paid more than twenty million dollars in dividends. After World War I, the company was faced with the expenditure of several million dollars to allow the treatment of still leaner ore, and it sold out to Phelps Dodge Corporation for a large stock interest. The Phelps Dodge Company had purchased Captain Ward's Detroit Copper in 1895. All of these transactions by Phelps Dodge had been made on the recommendation of James Douglas. Clifton became for many years the greatest copper district in the Southwest.

In "Mineral Industry" for 1900, Dr. Douglas wrote regarding the outlook for copper mining in Arizona, as follows:

"On the solution of the problem of how to handle economically the very large bodies of very lean aluminous and siliceous ores which exist in the southern counties of the Territory depends in great measure her future position as a copper producer. In Graham, Gila, Pinal and Pima Counties, and in fact throughout the whole of southeast and southwest Arizona, there are large areas of copper stained rock resulting from the decay of sulphide ores in a feldspathic gangue These lean surface carbonates all represent sulphides in depth. Experience heretofore tends to show that the average copper contents of the sulphide ore is low, but, being capable of concentration, a comparatively lean average may be economically valuable. The iron of such concentrates supplies a flux to a limited extent for handling the siliceous and aluminous carbonates, and, when roasted, an acid solvent. There is no field where metallurgical skill could be better applied than in handling these vast quantities of very low-grade ore with which large areas of the rocks of this territory are permeated.

The new enterprises which the high price of copper has tempted Eastern Capital to invest in, have as yet increased the Territory's production to a very insignificant extent. Most of them, it is fair to assume, will never do otherwise. Those that have some substantial basis for existence will, before they become profitable, confirm the experience of all those who have had to do with copper mines, that an outlay of money, worry and experience that finds no place in the promoter's prospectus, will have to be made before returns, in cash, balance expenditures."

When in 1897, Dr. Douglas became president of the Detroit Copper Co., he put Charles E. Mills in charge of operations at Morenci. An era of expansion and improvement at both properties commenced under the direction of Mills and Colquhoun. When it became necessary to exploit the leaner sulphide ores,

Colquhoun constructed No. 6 concentrator, first operated in August, 1906. The two companies continued their separate existence, though in 1917 the Detroit Copper Company had come to be called the Morenci Branch of the Phelps Dodge Corporation. In 1922 the A. C. Company was absorbed by Phelps Dodge, and virtually the entire district came under a single control. Included also were the properties of the Shannon Copper Co. at Metcalf, which had been acquired by the A. C. Company in 1918.

From 1907 to 1931 the mines now includedⁱⁿ the Morenci Branch produced 953,500 tons of smelting ore and 31,100,000 tons of concentrating ore, with a yield of 1,222,200,000 lbs of copper in the form of blister. They had been profitable ventures. But the greatest era of production lay ahead, in the Morenci ore-body. To the engineers this deposit offered a most fascinating problem. It was possible to mine it with power shovels or even by underground methods. It also offered two methods of treating the ore: either by concentration of the ore and smelting of the concentrate, or by leaching and the production of pure electrolytic copper near the mine.

From 1929 to 1942 when regular production from the Morenci open pit commenced in January, Mr. Cates directed a thorough program of testing and development which culminated in the construction of a 25,000-ton concentrator and a smelter to handle its product at the mouth of Morenci Canyon 2 miles from the open pit. A more fortuitous date for starting this operation could not have been chosen, for it was the year of World War II, and Uncle Sam had need for every pound of copper he could get his hands on. In 1943, the Phelps Dodge Corporation in combination with the Defense Plant Corporation prepared for a daily production of 45,000 tons of copper ore, which was the designed capacity of the combined P. D. and Defense Corp. concentrators. The present capacity is 50,000 tons daily.

As may well be imagined, the long period of experimentation and planning, between 1929 and 1942, was marked by many failures and changes of plans. While the big problem was the choice of open-pit or underground mining, and leaching or regular concentration methods, there were many other worries facing the company. By no means the least was the uncertain future of the copper industry during the long depression period. Metallurgical problems, involving the choice of the proper equipment to use after the selection of the method of concentration, included the necessity for large-scale practical testing, and the choice was not an easy one. Then there was the smelting problem, for the character of the concentrates made by the mill naturally varied with the modifications of the crushing, grinding and concentration processes.

Description and Geology of the Morenci Ore Deposit*

The Morenci open-pit mine is on the southwest side of Chase Creek and north of the area that had been most productive in the past - namely the Copper Mountain - Longfellow area. The ore body, as now defined has a maximum length of 4,400 feet and a maximum width of 2,800 feet. The mine is entirely within the quartz monzonite porphyry body, which is highly altered and fissured throughout the mineralized area. Different parts of the ore body have been

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From a paper presented to the A.I.M.E. at Tucson, November 1-3, 1938, and Lindgren's Professional Paper A 3, 1905, U. S. Geol. Survey.

developed by different methods. Some of the earliest openings followed the more prominent fissures for hundreds of feet. Later areas were developed by underground openings, and the latest developments were by churn drill.

The primary mineralization, as shown in the deep levels, is quartz, pyrite, chalcopryrite and sphalerite veins with most veins containing much pyrite. Outcrops over the ore are largely leached of both iron and copper. Below the leached caprock, which has a maximum thickness of 500 feet, the ore consists of secondary chalcocite that has replaced pyrite extensively in the ore and decreasingly with increased depth or decreased permeability of the rock.

The mineralized body, in common with other disseminated deposits, can be separated into three parts or zones: (1) the upper or surface zone, which has an average thickness of 216 feet; (2) the ore zone, which is a network of fissures composed mainly of quartz and pyrite, the latter coated and replaced by varying degrees of chalcocite. The thickness of the ore body is irregular, but over much of the area is 500 to 700 feet; and (3) In depth many drill holes show a rather sharp drop from near 1 percent to $\frac{1}{2}$ percent, there is no general record of the copper content of the underlying material. In this low grade material the copper is probably chalcopryrite.

The Morenci Orebody Development and Exploitation

When development of the low-grade ore body was first under consideration, careful estimates were made to determine whether it would be advisable to use underground methods or an open-pit. Thorough drilling and sampling were done to check the tonnage and grade. With underground mining, it would be necessary to confine operations to a smaller tonnage of the better grade of ore. In an open-pit a much larger tonnage of lower-grade material could be profitably extracted. After consideration of all of the factors it was decided to make use of an open-pit.

Following parallel tests between a small pilot concentrating plant and leaching plant, it was decided to adopt the concentration method.

To mine by open-pit methods required the removing of a large amount of waste capping. This was estimated to require nearly five years of preparatory work before uncovering enough ore to make possible a steady production of 25,000 tons per day. Also, plans were made for constructing a concentrator, smelter and power plant, and providing the many other necessary facilities required to take care of this large production.

Louis Cates and the Directors of Phelps Dodge had to have courage to launch a \$76,000,000 enterprise, and they made sure that this, the first major copper development in Arizona in 30 years, would be as well planned and well equipped as human ingenuity, experience and determination could make it.

It was fortunate that the Morenci enterprise had such exhaustive attention paid to every detail of its design for before the new smelter poured its first copper in April 1942, the W.P.B. called on Phelps Dodge for an 80 percent expansion in output. Even this had been anticipated, and the plans were ready. Morenci quickly expanded its production, increasing each year until in 1947 it attained one hundred percent expansion. This expansion program took another tremendous expenditure of many millions of dollars, provided by the Defense Plant Corporation, which leased the new sections of the concentrator

to Phelps Dodge to operate. Thus it may be stated that it took over \$76,000,000 to open up, develop and equip Morenci. Subsequently, the Defense Plant Corporation facilities were purchased by Phelps Dodge Corporation.

Mining

Pit benches, which are all carried at a uniform height of 50 feet, have been established at even elevations above sea level, the top bench being at elevation 5500. The ultimate range of mining is estimated to be slightly in excess of 1,300 feet. The economical thickness of the orebody is 850 feet. When fully developed, the pit will be 5,800 feet long and 4,000 feet wide, and the final excavation will cover 350 acres.

During the early stages of the Morenci development, trucks, because of their flexibility, were best suited for the preparation of the mining benches. These operations included dumping of the waste rock in the deep rough canyons to be utilized later in the construction of track roadbeds. Soon most of the material was handled by standard gauge locomotives and dump cars. Diesel-electric and combination trolley-diesel locomotives are used. The track section between the pit and the crushing plant has been electrified.

On the established benches drilling for primary blasting is done with electric churn drills using 9-in and 12-in bits. Loading equipment has been more or less standardized, all units being of the 5 cu. yd. revolving type shovels using electric power at 2300 volts. Ore is delivered to the crushing plant, about $2\frac{1}{2}$ miles from the pit, in trains made up of eight 40 cu. yd. cars. Traffic on the main haulage system is regulated by means of both hand-operated and automatic signal systems controlled from a central tower at the pit entrance. Established at 100-ft. intervals, each waste disposal dump serves two benches. A portion of the waste loaded in trains of eight 40-yd cars, moves in the opposite direction from the ore movement. Average hauling distance is about $2\frac{1}{2}$ miles.

Crushing, Grinding, Concentration and Smelting

Primary and secondary crushing plants and concentrator are situated at the northern end of the plant site, where a natural slope provided adequate fall through these units. A level section extending to the south contains the smelter and bedding plant, power house, machine shops, warehouse and tailings dewatering plant. The entire system is a masterpiece of engineering design. The crushing plants and concentrator are almost entirely automatic in operation. The major buildings are accessible by rail and truck, and cranes available on the different floor levels, as well as elevators, facilitate secondary handling of materials, supplies and equipment. Treatment involves three-stage crushing, single-stage grinding, flotation, regrinding, cleaning, thickening and filtering concentrate. The first stage of crushing is a 60-in gyratory. Reduction of the gyratory product is accomplished by 7-ft standard cone crushers followed by 7-ft short-head cone crushers. The final stage is a grinding operation in 10 x 10 ft. grate mills, using 2 in and 3 in grinding balls. Each mill operates in closed circuit with spiral classifiers.

Concentration is done by flotation in mechanical flotation machines. The tailings go to traction thickeners from which the thickened pulp goes to the tailings dams, and the overflow water is pumped back to the head-water tanks for re-use. The concentrates are given a re-treatment in additional flotation machines, called cleaners, which produce a suitable smelter feed. The tailings

from these cleaning machines are reground in $8\frac{1}{2}$ x 12 ft. overflow type ball mills, and returned to the primary rougher machines. The final flotation concentrates are thickened, filtered, and transported to the smelter bedding plant by a belt conveyor.

The smelting plant consists of a bedding plant, crushing plant, sampling tower reverberatory furnaces, converters, anode-casting furnaces and an anode casting wheel. All equipment including the dust collecting system, is the last word in mechanical design.

The towns of Clifton and Morenci are up to date in every respect, with fine homes built by the Company for its employees. There is a modern hospital, fine club houses, churches and excellent tax-supported schools. According to the 1950 census the population of Clifton is 3,466 and Morenci 6,541. There are approximately 2,500 workers on the Morenci Branch Phelps Dodge payroll. The economic existence of both towns is entirely dependent upon the Morenci enterprise.

Total production from the Morenci Orebody from 1939-1951, incl. was as follows:

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| Total tons ore mined | 127,326,400 |
| Total lbs. copper recovered | 2,354,391,000 |
| Total ounces gold | 66,050 |
| Total ounces silver | 4,197,000 |

A total of approximately \$76,500,000 has been expended for the purchase, development, capital additions and improvements on the Morenci enterprise to the end of 1951.

Although Mr. Louis S. Cates is acknowledged to be the guiding spirit that brought the Morenci enterprise to fruition, he very modestly gives all the credit to teamwork. Mr. Cates made the following remarks in the May, 1942 issue of Mining and Metallurgy:

"Modern technical and mechanical progress has made the Morenci achievement possible. Hard and loyal efforts of many men have made it a reality to the officers, engineers, miners, construction gangs, and all who have labored on this task sincere appreciation and thanks are given. Modern industry requires teamwork, of which all that has been done at Morenci is a conspicuous example.

Much help and valuable information have been secured from many sources, but notably from our two chief competitors. Over a long period the mining industry has maintained a most liberal attitude toward the exchange of technical data. To this attitude, I am sure, can be attributed much of the remarkable progress that has taken place in the last generation.

Through the kindness of Cornelius F. Kelly we were able to secure, as chief designing and construction engineer, Wilbur Jurden, head of the engineering department of the Anaconda organization. To Mr. Jurden and to the Phelps Dodge engineering department, which he built up to design and construct the new reduction works, can be credited the efficient arrangement, convenience and economy