IC 8789

Bureau of Mines Information Circular/1979

Providing New Sources of Mineral Supply

UNITED STATES DEPARTMENT OF THE INTERIOR

Information Circular 8789

Providing New Sources of Mineral Supply

By John Paul Gries

UNITED STATES DEPARTMENT OF THE INTERIOR
Cecil D. Andrus, Secretary

BUREAU OF MINES
Roger A. Markle, Director

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.

This publication has been cataloged as follows:

Gries, John Paul

Providing new sources of mineral supply / by John Paul Gries. [Washington] : U.S. Dept. of the Interior, Bureau of Mines, 1979.

42 p. : ill., diagrs. ; 27 cm. (Information circular • Bureau of Mines ; 8789)

Includes bibliographical references.

1. Mines and mineral resources • United States. I. United States. Bureau of Mines. II. Title. III. Series: United States. Bureau of Mines. Information circular • Bureau of Mines ; 8789.

TN23.U71 no. 8789 622.06173

U.S. Dept. of the Int. Library

☆ U.S. GOVERNMENT PRINTING OFFICE : 1979 O—287-091

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

Stock Number 024-004-01941-7

CONTENTS

ILLUSTRATIONS

PROVIDING NEW SOURCES OF MINERAL SUPPLY

by

John Paul Gries [1]

ABSTRACT

This Bureau of Mines study outlines the history of 11 major metal ore deposits or districts that are relatively new discoveries. The oldest operation is the White Pine mine, where major exploration was initiated in 1929. Discovery (delineation of ore bodies) dates range from 1948 to 1976. All but two of the deposits, Quartz Hill in Alaska and Flambeau in Wisconsin, are or shortly will be in major production.

INTRODUCTION

The Old Prospector

The popular image of an early-day prospector is that of a bewhiskered old man, accompanied by a jackass laden with pick and shovel, gold pan, bed roll, and grub sack. Actually, most of our early western prospectors were young men, discharged from the army after the Civil War or one of the Indian campaigns. They were footloose, untrained, and temperamentally not ready to settle down to a regular job. They enjoyed the independence of being on their own, walking the streams and inspecting the rock outcrops for gold or other valuable metal. Those who stuck with it, and survived, eventually became the bewhiskered characters of popular fancy. Many ended up as barflies in the smaller towns, trading drinks for tales of lost mines, big nuggets, or of the claim jumpers who stole their bonanza discoveries.

If a prospector arrived in a new area at the start of a "rush," he probably was looking for a placer deposit, where a stream had concentrated gold or other heavy materials into rich pockets. Some placers occur in the beds of present-day streams, others are in ancient channels above the present courses of the streams. In practice, the prospector would dig down to bedrock, scoop out a shovelful of gravel, and concentrate it by panning until only a small quantity of the heavier minerals remained in the pan. If he saw "colors" of gold, he would continue his efforts; if not, he would move on to another

[1] Consultant, Intermountain Field Operations Center, Bureau of Mines, Denver, Colo.; also professor emeritus of geological engineering, South Dakota School of Mines and Technology, Rapid City, S. Dak.

location. If it were a dry gravel bar, he and the jackass would tote a few shovelfuls to the nearest water to pan them. If a rich spot of placer ground was found, he would stake a claim, build a sluice box or rocker, and go into the one-man mining business.

If the promising placer ground was all staked prior to his arrival, our prospector would patiently work his way up the stream, panning as he went, in an effort to locate the rocky mother lode from which the placer gold had been liberated by slow erosion. Frequently, the gold particles became coarser and less worn as the source was approached. When he reached the point on the stream where the last gold was found, he would start examining rock outcrops on the adjacent hillsides. He would crush and pan samples that appealed to him, looking for vestiges of gold or other evidence of mineralization. If he found what appeared to be ore, he probably would take samples to the nearest assay office for analysis; if the prospect looked promising, he would stake one or more claims and record his find at the courthouse or nearest land office.

To prove the value of his lode discovery, trenching, tunneling, or shaft sinking on the bedrock might be necessary. At this point, he probably would need financial backing. If he were already being grubstaked by a local grocer, banker, lawyer, barkeeper, or other affluent person, that individual probably would provide additional help in the purchase of the necessary tools and dynamite. Otherwise, the prospector probably would sell part interest in his discovery to such an individual to obtain funds for development. Or if he wished to continue prospecting, he might sell the whole claim and head back to the wilds in search of a bigger bonanza.

Today's Prospector

The modern prospector may be an individual, working for himself or for a company, or he may be a member of an exploration team. He has access to fast transportation, good maps, aerial photographs, and satellite imagery, plus a number of sophisticated geophysical and geochemical techniques. But now as always, it takes the genius of one individual to select the prospect area, to sell management on providing support for the appropriate exploration techniques, and to recognize a potential discovery ahead of the competition.

Aerial photographs and satellite imagery enable the geologist to view large areas and to see geological relationships not apparent on the ground. Suggestive alinements of known mineral deposits may be projected to provide new prospect areas, or areas of discolored rocks may suggest mineralization in a heretofore unsuspected territory.

Geophysical methods depend upon the difference between normal rock and mineralized rock with regard to electrical, magnetic, radioactive, or gravitational properties. Abnormal values may give a clue to what lies beneath the surface. Many geophysical surveys can be made from aircraft, so that it is possible to run reconnaissance surveys over large areas and to outline favorable areas for more detailed prospecting. Skillful interpretation of geophysical anomalies may pinpoint areas for further work and suggest the need for more detailed mapping, additional geophysical or geochemical work, or deep drilling.

Geochemical surveying is a modern version of the old prospector's hunting for the mother lode by tracing gold upstream from placer deposits. In a geochemical survey, samples of water, stream sediment, soils, or bedrock are taken at regular intervals over large areas and laboratory tested for minute traces of copper, molybdenum, lead, zinc, or other metals. Plotting these minute values on a map often reveals concentrations or haloes of these trace elements, which may suggest the presence of a deeply buried mineral deposit.

Despite all the new technology, the time required to develop metal mines varies greatly (fig. 1). At the Carlin gold mine in Nevada, development time was unusually short. Claims were staked in late 1961, and by 1967, Carlin was the second largest gold mine in the United States. At the Kalamazoo copper deposit in Arizona, claims were staked and some drilling was done in 1946. The property then was inactive until 1965, when major exploration was initiated. An ore body was discovered in 1967, and development was initiated the following year. The property, however, is still undergoing development in 1978, and production is not anticipated until 1979 or 1980. Figure 1 is a

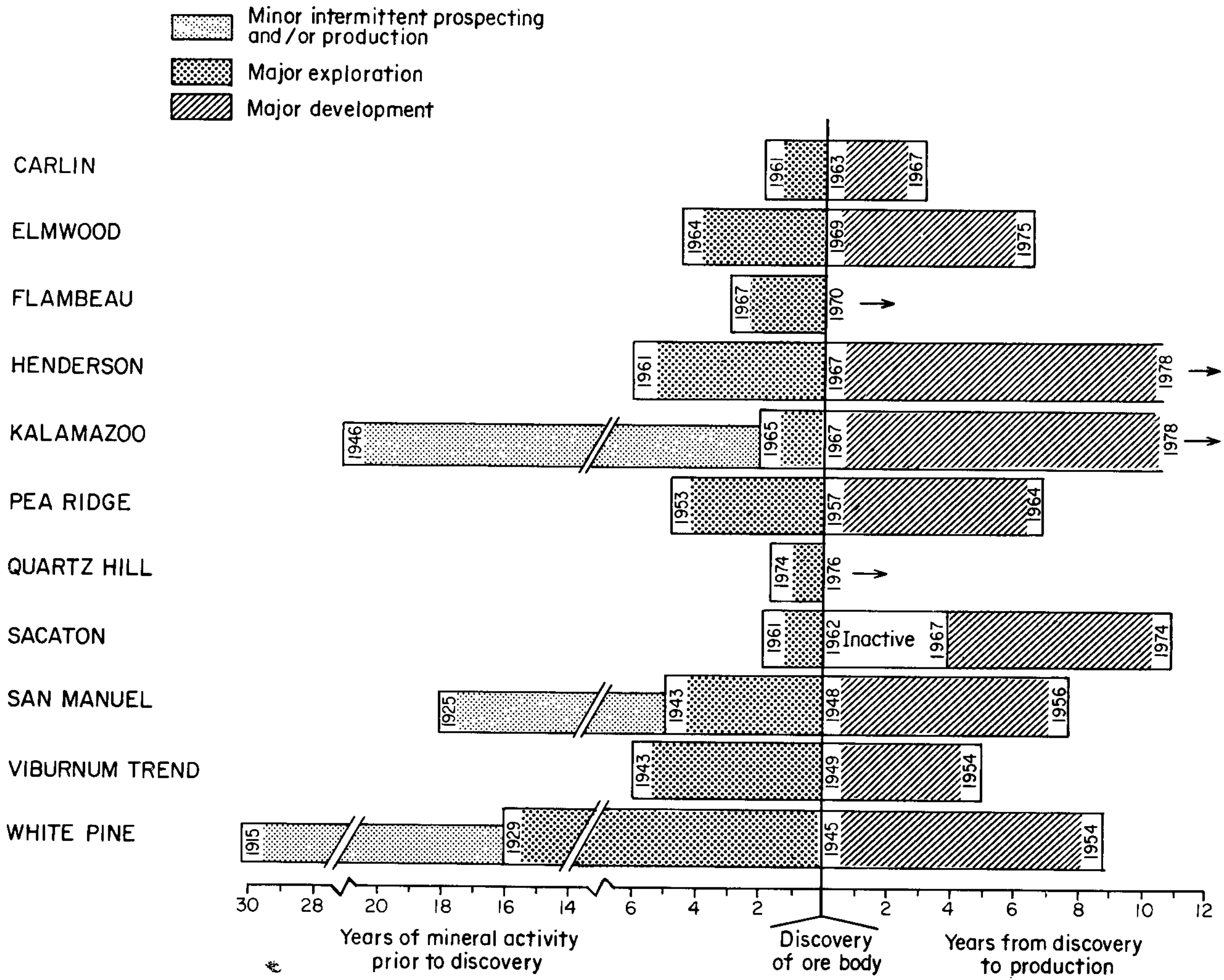

FIGURE 1. - Approximate time required to develop certain metal mines.

generalized graph that depicts approximate time requirements for mine development of the various deposits discussed in this report. Periods of idleness occurring between major exploration and major development are shown only if they are significant, as in the case of Sacaton. For example, the transition period at Kalamazoo, 1967 to 1968, was included in development on the graph.

Let us then become acquainted with some of the individuals and the techniques responsible for several of the more important mineral discoveries of recent years.

CARLIN GOLD DEPOSIT, NEVADA

The Carlin mine is located at an elevation of 6,300 feet in the Tuscarora Mountains of north-central Nevada (fig. 2). It is 20 miles north of Carlin and 40 miles northwest of Elko, Eureka County. An aerial view of the Carlin property is shown in figure 3.

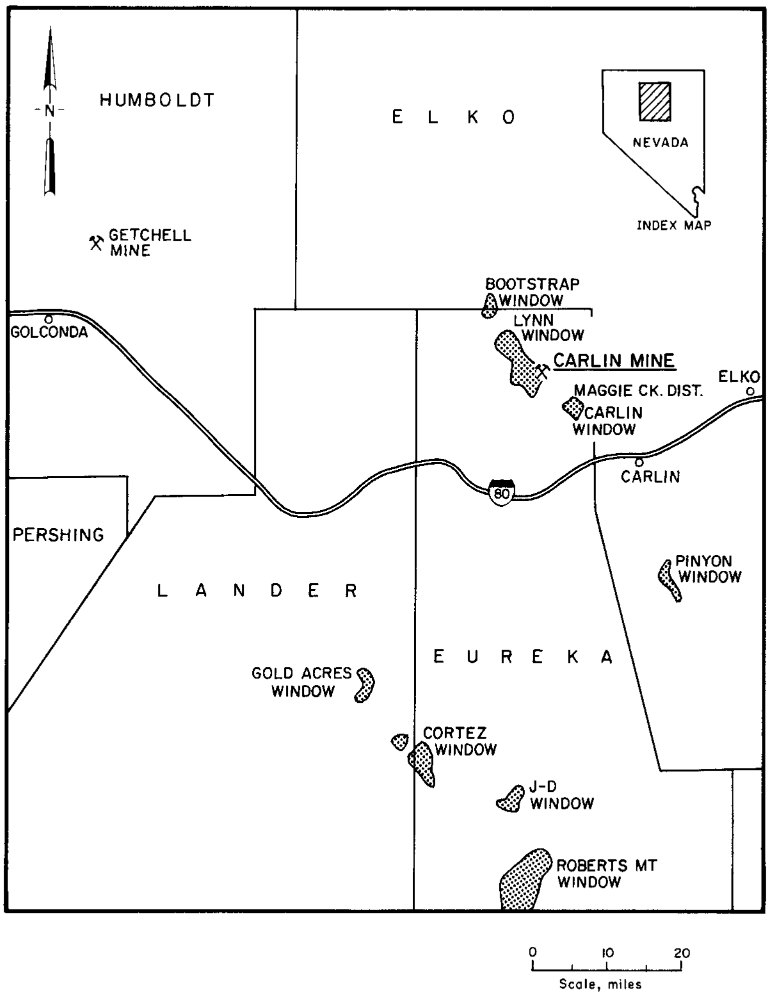

FIGURE 2. - Location map, Carlin gold mine, Eureka County, Nev. (Adapted from Ore Deposits of the United States, 1933-1967, AIME, New York.)

Occasionally, under great compressive forces within the Earth's crust, one mass of rocks will ride up over another, creating what geologists call a thrust fault. The overriding movement may be measured in miles or tens of miles. Later, the entire sequence of rocks may be locally domed up and eroded, exposing "windows" of the underlying rocks. Since 1870, many millions of dollars worth of gold, silver, lead, and zinc have been mined from rocks within such windows in northern Nevada.

To summarize work done during a long mapping program in that area, R. J. Roberts of the U.S. Geological Survey (USGS) published an article in 1960 that called attention to the concentration of ores in these windows, which had not previously been considered significant. He also pointed out the

FIGURE 3. - Mining operations at the Carlin gold property, Eureka County, Nev.
(Courtesy, Carlin Gold Mining Co., Newmont Mining Corp.)

apparent alinement of these windows along definite trends. Roberts suggested that certain old limestone rock units in the known or yet-to-be-recognized windows in the area be explored further.

Roberts' paper came to the attention of Newmont Mining Corp.'s manager of exploration, Bob Fulton, and to John Livermore, a Newmont geologist at Ruby Hill, Nev. Both men recognized the value of the window concept as a way of restricting their prospecting efforts to areas of better than average mineral potential. In gambling-conscious Nevada, no one overlooks a chance to improve his odds! By this time, also, exploration geologists seeking new gold deposits had taken a cue from the copper miners and were looking for very large, lower grade deposits rather than the bonanzas that had lured early prospectors. Fulton and Livermore took their exploration ideas to Plata Malozemoff, president of Newmont, who authorized an exploration program directed at the known windows in Eureka and Lander Counties, Nev.

A joint field conference was arranged among USGS geologists, including Roberts, and two Newmont geologists, Livermore and J. A. Coope, to examine particularly interesting areas near Battle Mountain and Carlin. Newmont subsequently laid out a prospecting program that covered the Marigold and Buffalo Valley areas near Battle Mountain and selected areas in the Lynn Creek and Carlin windows northwest of Carlin.

At a meeting of company officials in Carlin in October 1961, it was decided to stake claims on certain open lands within the Lynn window. Geologic mapping, trenching, and sampling were started immediately and continued until winter weather closed the field season. Early the following spring, fieldwork was resumed, and some additional land was acquired on a short-term option. A drilling program was inaugurated, starting on the optioned land, and the third hole to be drilled cut 80 feet of rock carrying over 1 ounce of gold per ton! The top of the mineralized rock extended upward to within 10 feet of the surface. No gold was visible to the naked eye, but it was shown to be present as disseminated, submicrometer particles of native gold.

Encouraged by this initial success, Newmont acquired more land, and drilling was started on a systematic, 100-foot-square grid pattern. By the end of 1963, an ore body estimated at 11 million tons averaging 0.32 ounce of gold per ton had been blocked out. By that time, $350,000 had been spent by Newmont for land acquisition, drilling, and mapping. Newmont's dream of a large-scale, low-grade, open pit mining operation was now to become a reality.

Gold in ore near the surface was readily recoverable by the standard cyanide process, but where overlying rocks had protected the gold-bearing rock from oxidation, the gold was in an organic form not amenable to cyanide treatment. Research metallurgists at the U.S. Bureau of Mines and at Newmont's Danbury Laboratory began to work on this problem.

Development of the mine and construction of the cyanide mill started in the spring of 1964; Newmont announced the completion of the project on May 27, 1967. Approximately $10 million had been invested in exploration, development, and construction at the site of the Carlin mine before the first bar of gold was poured. By yearend, Carlin was the second largest gold mine in the United States, next only to the Homestake mine in the Black Hills of South Dakota.

By early 1971, the metallurgical problems associated with the carbonaceous ores had been solved, and a second mill was built to process those gold ores that had been held in reserve during initial mining operations.

Bibliography

1. Hausen, D. M., and P. F. Kerr. Fine Gold Occurrence at Carlin, Nevada. Ch. in Ore Deposits of the United States, ed. by J. D. Ridge. American Institute of Mining, Metallurgical, and Petroleum Engineers, New York, v. 1, 1968, pp. 908-913.

2. Ramsey, R. H. Men and Mines of Newmont, a Fifty-Year History. Octagon Books, New York, 1973, pp. 274-279.

ELMWOOD ZINC DEPOSIT, TENNESSEE

In 1969, New Jersey Zinc Co. announced the discovery of its Elmwood zinc deposit, located at a depth of 1,300 feet in the rolling bluegrass country of central Tennessee. It was the culmination of an exploration program conceived in the early 1960's and actually embarked upon in 1964. The approach was unique, one which could be undertaken only by a company with large financial reserves and an exploration staff dedicated to supporting the program to its completion. Cooperation of management at all levels was vital.

Elmwood is a small community about 50 miles east of Nashville, and the Elmwood deposit is near the axis of the Nashville dome (fig. 4). The crest of the dome is a topographic basin (the Central Basin), which is bounded to the east and west by the Highland Rim, a wide topographic shelf below the Cumberland Plateau on the east.

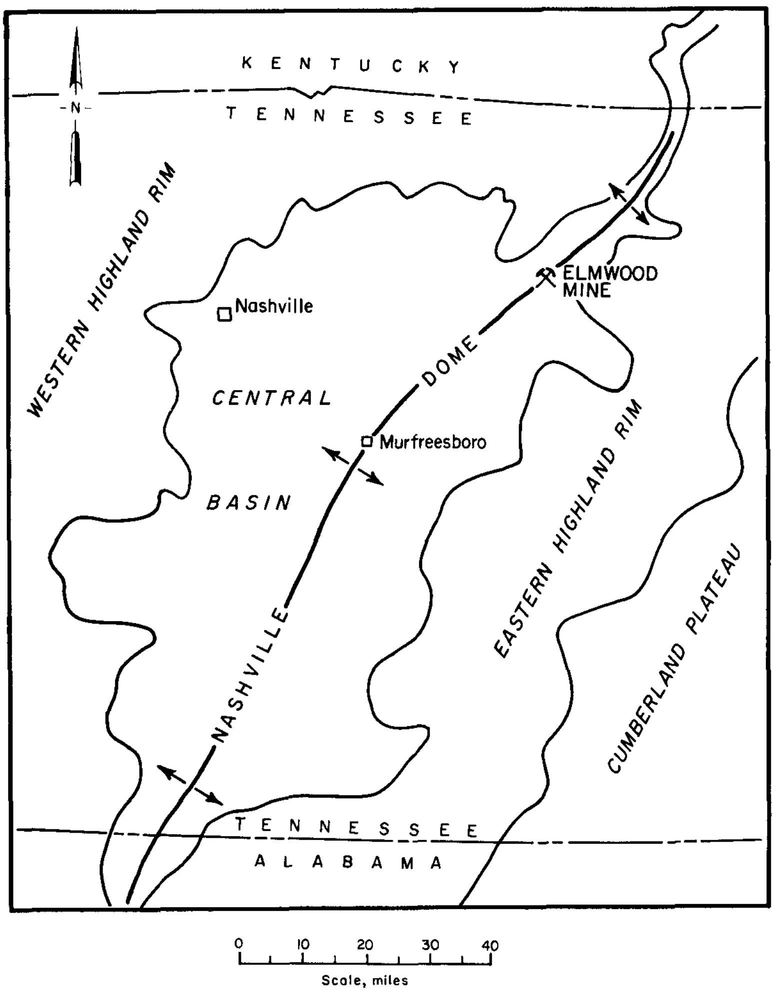

FIGURE 4. - Location map, Elmwood zinc deposit, central Tennessee. (Adapted from W. H. Callahan, Econ. Geol., v. 72, No. 7, 1977.)

To understand the theory behind the program, we need a bit of geology. In temperate and subtropical areas of the earth's surface where thick limestone strata lie at the surface, a unique topography often develops. Because limestone is slowly water soluble, rain soaking into the ground dissolves minute amounts of the limestone, enlarging crevices and forming caverns. Ultimately, the caverns collapse, sinkholes form, and all but the major streams flow underground. European geologists named such areas "karst," and the term is applied to such areas in Florida, central Kentucky, Missouri, and elsewhere. Karst topographies developed in earlier geologic times and buried beneath younger rocks are called buried or fossil karsts, and the contact between the karst surface and the overlying rocks is called an "unconformity."

Geologists have been aware in recent years that many of the known ore deposits in limestones are related to broken and cavernous rocks below an unconformity. The best known, perhaps, are the lead deposits in the old Tri-State district of southwestern Missouri. Less well known ore bodies are found in southwestern Wisconsin, Pennsylvania, Virginia, and eastern Tennessee. Because of their abundance in the Central United States, they generally are referred to as Mississippi Valley-type lead-zinc deposits.

As early as 1937, William H. Callahan, a New Jersey Zinc Co. geologist working on an ore deposit in limestone at Friedensville, Pa., began to develop his belief that various structures associated with buried unconformities were ideal hosts for ore deposition. He read all available literature as it was published, visited numerous areas where such deposits could be examined, and gradually conceived the idea that unconformities within certain, relatively porous limestones of Lower Ordovician age seem to be an ideal host for commercial accumulations of lead and zinc ores in particular. Since his company was already active in eastern Tennessee, his thoughts turned first to that State. In central Tennessee, south and east of Nashville, is a large area where the older rocks have been arched upward, and many of the overlying strata have been removed by erosion. Geologists call it the Nashville dome. Many oil and gas test wells have been drilled in the dome over the years, so that considerable information is available regarding the nature and distribution of the underlying strata. An unconformity was known to overlie the Knox Dolomite, the host rock for the eastern Tennessee zinc deposits. In the Nashville area, the unconformity lay at a depth of 900 to 2,000 feet, covering an area of 7,000 square miles. A score of small, zinc-bearing, mineral veins had been found in the surface rocks, well distributed over the prospect area. In at least four oil tests, the zinc mineral sphalerite (zinc sulfide, ZnS) had been reported in the target zone at the top of the Knox Dolomite. Here, then, was a prospective target area where geological conditions were favorable and drilling depths were within reason.

How could Callahan and his associates go about finding such a hypothetical deposit? No clues could be found by detailed mapping of the surface rocks. At the anticipated depth, such disseminated ore probably would not be recognized by any type of geophysical survey. Blind drilling on this scale had never before been attempted. Could it be justified?

Perhaps statistical analysis could answer the question. Suppose that the hypothetical deposit had the same areal extent and density as those in eastern Tennessee or in the Tri-State district. Could those deposits have been found by totally random drilling without investing a sum equal to their value before hitting ore? The Tri-State district was chosen as a model. The statistical answer seemed to be that the odds were in favor of discovery at an acceptable cost.

Could such a proposition be sold to management? Fortunately, the top management of the New Jersey Zinc Co. was exploration-minded at the time. The president, R. L. McCann, was a mining engineer who recognized that the company needed new discoveries to offset a decline in known ore reserves. S. S. Good, vice-president for exploration and mining, was a geologist with previous experience in similar zinc deposits at Austinville, Va. The manager of mines,

W. T. Pettijohn was an experienced production geologist. Johnson Crawford and A. D. Hoagland, geologists, were thoroughly familiar with this type of zinc ore deposit. In September 1963, Hoagland and Fred Fischer presented the proposal to top management. The risks were understood to be great, and the importance of giving the program a fair-if-expensive trial was accepted. It was approved.

Callahan, as manager of exploration, became the liaison man between top management and the exploration team, which consisted of Hoagland, Ray Gilbert, Alan Stag, and Fred Fischer, plus many technically trained assistants. It was Callahan's job to see that management was fully informed, and that enthusiasm for the project did not lag as successive dry holes were drilled.

Exploratory drilling started in May 1964, as soon as sufficient leases could be acquired. The plan was to drill holes 5 to 6 miles apart at random over the entire prospect area. At the peak of the project, the company held more than 5,000 leases covering 900 square miles and was simultaneously running 20 core rigs in central Tennessee and adjacent south-central Kentucky.

In 1966, before any sort of success had been achieved, New Jersey Zinc Co. was merged with Gulf + Western Industries, Inc. New Jersey Zinc Co. retained its management team and the project continued as planned.

The first encouragement came in February 1967. At a depth of 1,300 feet in hole No. 79, 5 feet of ore assaying 6.5 percent zinc was discovered. Up to this time, over $600,000 had been invested for property control, staff, drilling, and overhead.

Random drilling continued with high enthusiasm, while property was acquired around No. 79. One year later, another hole was drilled 100 feet north of No. 79. Only weak mineralization was encountered. Had the original hole been drilled 100 feet to the north, the weak showing would have been ignored, and the Elmwood ore body would not have been found! The next four holes were drilled in an approximate circle around No. 79, each about 1-1/2 miles away. Each hole hit thin streaks of highly mineralized rock, but none of such thickness as to be deemed commercial. Then, hole No. 106, located 1,000 feet west of No. 79, was found to contain 17 feet of 18 percent zinc! The decision was made to drill the area surrounding hole No. 106 on 1,000-foot centers. After 89 more holes had been put down, the data thus acquired were fed into a computer, along with various assumptions about grade and thickness. Results were sufficient to justify a third phase of exploration.

The choice was between drilling another 100 closely spaced holes or sinking an exploratory shaft to 1,325 feet and driving 10,000 feet of exploratory drifts. The latter approach was selected, and the shaft was started in July 1969. Drifting and underground drilling followed, and phase 3 was completed in February 1972. The total cost to that date was $2.9 million.

The decision was made to develop the discovery as a mine but to keep initial costs as low as possible until further development warranted expansion. Rather than build an entirely new mill, the company decided to incorporate parts of two dismantled mills from other areas. Mine production started in August, and milling, in September 1975. Between the start of the initial exploratory drilling and the start of production, 11 years had elapsed and approximately $15 million had been expended.

Public announcement of the discovery was made in January 1969. Rival companies flocked to the area. Competition for leases and drill rigs became intense, and at the height of the play, 69 drill rigs were in operation on the Nashville dome. Discoveries by other companies were not made public, but by mid-1977, no other company had started any form of development work.

Bibliography

1. Callahan, W. H. The History of the Discovery of the Zinc Deposit at Elmwood, Tennessee, Concept and Consequence. Econ. Geol., v. 72, No. 7, 1977, pp. 1382-1392.

FLAMBEAU COPPER DEPOSIT, WISCONSIN

Geologically, northern Wisconsin is a southern extension of the Canadian Shield, a vast area of low-lying, ancient rocks generally concealed by lakes, muskeg, or a mantle of stony clay left by glaciers. In Canada, these ancient rocks are known to contain many deposits of gold, silver, lead, zinc, copper, iron, and uranium.

In the gently rolling terrain of north-central Wisconsin, there are few rock outcrops; most of the area is covered with a thick mantle of glacial clays and gravels. When pioneers first saw the area, it was covered with a dense hardwood forest. Intensive lumbering started in the 1850's, leaving a cutover land of little value to anyone. Now, about half of the area is second-growth timber and the other half, cleared land devoted to dairying. The iron mines of Minnesota lie 150 miles to the northwest, the copper deposits of the Keweenaw Peninsula are 150 miles to the north, and the old Wisconsin lead-zinc district lies 180 miles to the south. Very few people considered the area a potential mining district.

Yet, in this central area, Kennecott Copper Corp. started prospecting in 1950 for rocks similar to those which enclose massive sulfide ore bodies far to the north, in Canada. Its interest had probably been whetted by a 1914 note published by the Wisconsin Geological Survey concerning an intensely altered copper-stained rock encountered in a 30-foot, hand-dug well in southern Rusk County. In 1966, geologist J. S. Phillips, working in Rusk County for Bear Creek Mining Co., a Kennecott subsidiary, found three small outcrops of ancient and severely altered volcanic rocks with abundant iron pyrite, which he believed might be the proper host rock for massive sulfide deposits.

Phillips outlined three prospect areas within a few miles of one another. One, the so-called Schoolhouse prospect, was selected in 1967 for diamond core drilling. The drill encountered an abundance of the iron sulfide, pyrite (fools' gold), but no base metal values. The presence of the pyrite was sufficiently encouraging to justify an airborne geophysical survey in May of the same year. The survey employed an electromagnetic method of prospecting and covered a 220-square-mile area embracing the three prospects. The survey did not reveal the previously outlined prospects but did pinpoint a fourth area of possible interest. Geologists who interpreted the anomaly believed it to be an area of unusual structural complexity. They recommended detailed ground surveys, using the newly introduced Slingram-Ronta electromagnetic method. The survey was started as soon as the ground was frozen. Subsequently, a belt of very strong conductivity was discovered 1-1/2 miles southwest of the town of Ladysmith and only a few hundred feet from the east bank of the Flambeau River. The anomaly was interpreted as possibly due to a narrow belt of massive sulfides completely concealed by glacial drift. Diamond drilling was employed next, and on November 6, 1968, the bit cut massive copper sulfides at a depth of only 199 feet. Land acquisition along the trend of the geophysical anamaly was completed early in 1969.

The years 1969 and 1970 saw additional geophysical exploration, which was carefully integrated with an extensive drilling program carried out by Kennecott subsidiaries around the newly named Flambeau prospect. One hundred and thirty-three diamond core drill holes were put down, both vertically and on a slant. The deepest hole bottomed at over 800 feet below the surface. At the conclusion of this exploration program, the company had outlined a long, nearly vertical ore body 55 feet wide, 2,400 feet long, and up to 800 feet deep. Chemical analyses of the cores indicated that the overall ore body averaged 4 percent copper but that a zone of enriched ore was present in the upper 100 to 200 feet of the deposit.

Kennecott made a public announcement of its copper discovery late in 1970, and other companies rushed into the area with their own exploration programs. At one time or another, over two dozen companies entered the search for additional ore bodies. Despite the competition, Kennecott continued both airborne and ground studies in the area. A small geophysical anamaly northwest of Ladysmith was tentatively interpreted by Kennecott geophysicists as a cultural feature, induced by the close proximity of two fence lines, a railroad, and a powerline. However, geologist Ned Eisenbrey was curious enough to make a field check and found massive sulfide in volcanic rocks cropping out in the Thornapple River at that point. A series of 20 to 30 drill holes confirmed the presence of a relatively small ore body capable of producing 1,000 tons of ore per day for 10 to 14 years. Unlike Flambeau, it contained a recoverable quantity of zinc with the copper.

Following the Thornapple discovery, exploration appeared to lag, but in 1974, Noranda Exploration Co., after geological work by Carl G. Schwenk, announced discovery of its Pelican River copper-zinc deposit. It lay southeast of Rhinelander in Oneida County, nearly 100 miles east of Ladysmith. Preliminary drilling indicates a deposit 1,000 feet long, 50 feet wide, and 600 feet deep, containing 2 million to 3 million tons of ore. The rock averages 4.5 percent zinc and 1 percent copper.

Farther east, near the town of Crandon in Forest County, a geophysical anomaly had been recognized by several companies, but, because of drilling problems (300 feet of glacial drift), it was not considered a prime target.

The Exxon Corp. finally acquired the necessary rights and put the Crandon prospect as the last item on their northern Wisconsin exploration program. If nothing was developed, Exxon was prepared to drop its entire program and move to more promising areas. But the drills did encounter sulfides--one hole cut ore within 417 feet of the surface. Thus in May 1976, Exxon topped all previous discoveries in the area with the announcement of a 60-million-ton, zinc-copper ore body. Subsequent drilling has raised the estimate to 75 million tons of ore averaging 5 percent zinc, 1 percent copper, and small values in gold, silver, and lead. As now defined, the ore body is 5,000 feet long, a few hundred feet wide, and 2,500 feet deep. It is believed to be one of the 10 largest massive sulfide ore deposits in the United States.

The three major discoveries lie in a rough east-west line extending a total distance of 110 miles (fig. 5). Kennecott Copper Corp., with a combination of basic field geology, up-to-date geophysics, and corporate teamwork, thus made the opening discovery of what will become a major new copper- and zinc-producing district in North America.

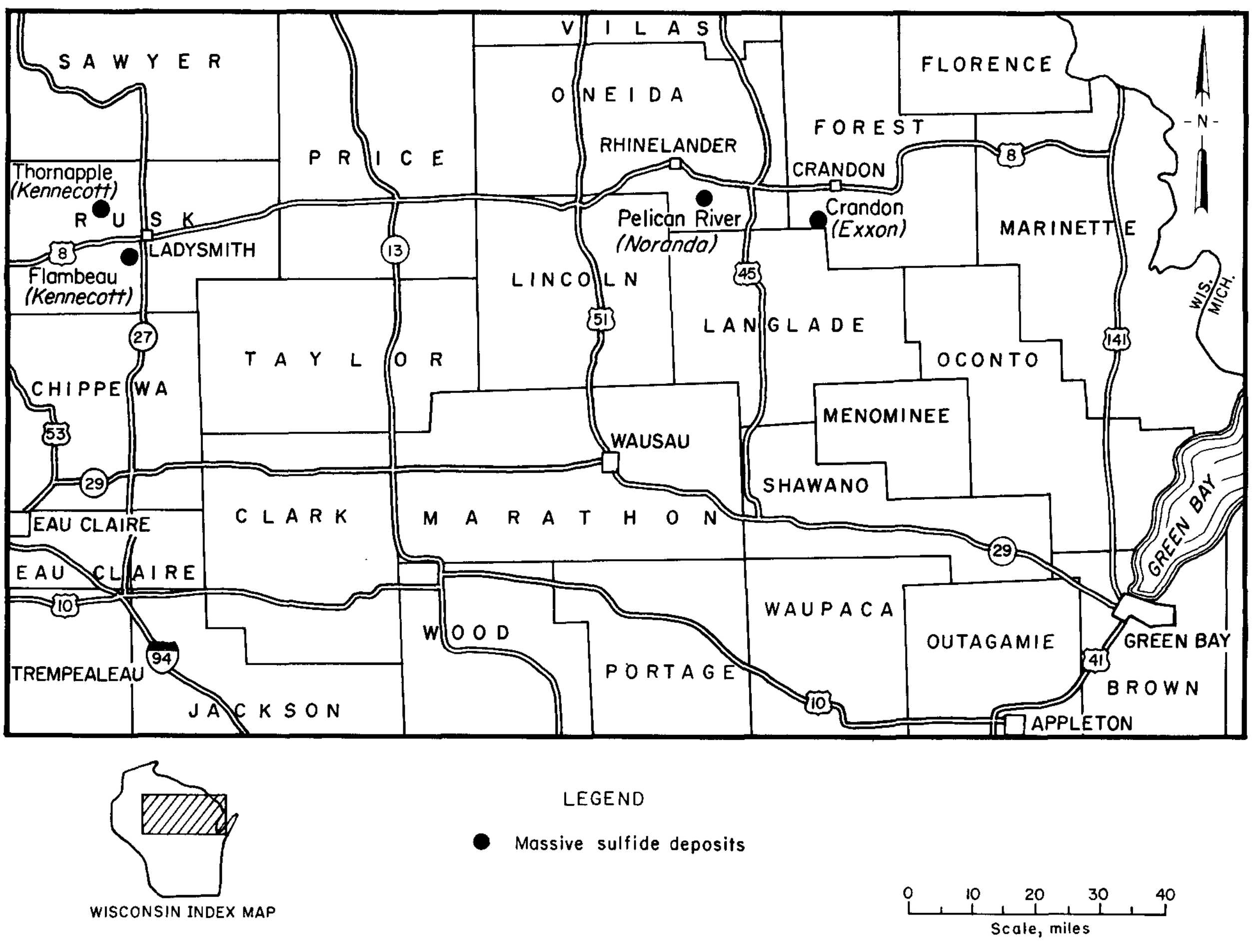

FIGURE 5. - Location map, massive sulfide deposits of northern Wisconsin.

Environmental impact studies were started as early as 1970. A preliminary report on Ladysmith was presented to the State of Wisconsin in June 1974, and an addendum followed in February 1975. Flambeau Mining Corp. plans to mine the upper 285 feet of the deposit by means of a small open pit operation with a life of 11 years. If economic conditions permit, the company will shift to underground mining for an additional 11 years.

Pending additional environmental studies, the depressed price of copper, and some local maneuvering to assure the counties a reasonable share of the State's revenues from mineral development, the area was at a virtual standstill in early 1978. Kennecott is continuing environmental monitoring at Ladysmith, and Exxon is going ahead with developmental drilling.

Bibliography

1. Dutton, C. E., and W. S. White. Copper Resources of Wisconsin. Geosci. Wis., v. 1, 1977, pp. 8-9, 30-31.

2. Kennecott Copper Corp. Facts About Proposed Flambeau Copper Mine. July 1975, 4 pp.

3. May, E. R. Flambeau--A Precambrian Supergene Enriched Massive Sulfide Deposit. Proc. 50th Ann. Meeting, Minn. Sec., AIME, Duluth, Minn., Jan. 12-14, 1977, pp. 11-4--11-28.

4. Mudrey, M. A., Jr., and M. E. Ostrum. Massive Sulfide Deposits in Wisconsin. University-Industry Resource Newsletter, University of Wisconsin, Madison, Wis., v. 11, No. 3, 1977, pp. 2, 31.

5. Schwenk, C. G. Discovery of the Flambeau Deposit, Rusk County, Wisconsin--A Geophysical Case History. Geosci. Wis., v. 1, 1977, pp. 27-42.

6. Skillings' Mining Review. AIME Annual Meeting. V. 65, No. 15, Apr. 10, 1976, pp. 9-11.

7. _____. Flambeau Mining Seeks Permit for Copper Mine. V. 63, No. 28, July 13, 1974, p. 6.

8. Wisconsin Department of Revenue, for the Upper Great Lakes Regional Commission. Wisconsin Mining Impact Study. 1977, pp. 74-78.

HENDERSON MOLYBDENUM DEPOSIT, COLORADO

The Henderson molybdenum mine of American Metal Climax, Inc. (AMAX), lies close to the Continental Divide, about 50 miles west of Denver, Colo. The discovery of ore in 1965 is a tribute to sound intuitive reasoning based on very detailed geological studies, the building of a geological model for certain types of molybdenum deposits, and the subsequent application of that model to other areas where similar geological conditions occur.

287-091 O - 79 - 2

The story really begins back at AMAX's Climax molybdenum mine in the Tenmile Range, 80 miles to the southwest of Henderson. Although some limited mining had been done during World War I, the history of molybdenum mining in Colorado starts in August 1924. By that time, sufficient uses had been developed for the newly recognized wonder metal molybdenum to justify mining operations in a peacetime economy. As mining operations progressed and as exploratory drilling ahead of mining gave additional information, it was realized that the Climax deposit was indeed very complex. Deeper ore bodies were discovered and developed and, by the 1950's, the deposit was considered to be a huge, irregular cylinder of ore with a barren rock core. The ore itself was in light-colored porphyry amid surrounding ancient granites and schists. These rocks had been intensely fractured and healed by thin, closely spaced veinlets of the lead-colored mineral molybdenite (molybdenum sulfide, MoS_2). Geologists call the cross-veined rock "stockwork" (fig. 6).

Many of the interesting sidelights on development at the Climax and Henderson mines have come from the writer's interviews and correspondence with Stewart Wallace of Denver, Colo. Stewart Wallace joined the geological staff at Climax in 1955 and was advanced to chief geologist by 1958. Wallace and his assistants continued exploratory drilling and remapped many of the old workings in an effort to clarify geological anomalies not explained by the cylinder theory. They were encouraged at every step by Robert Henderson, a

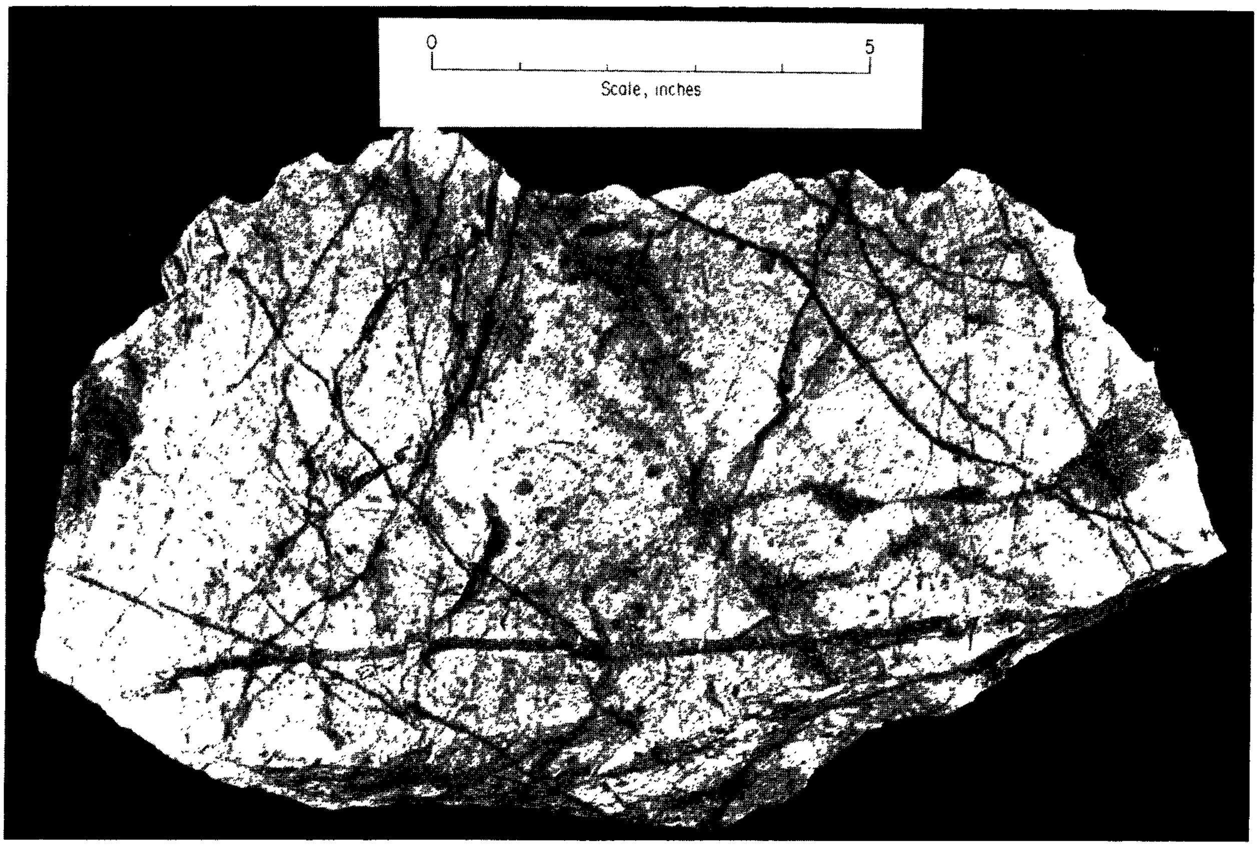

FIGURE 6. - Slab of ore showing typical stockwork of crisscrossing veinlets of molybdenite in gangue rock.

long-time Climax veteran and, at that time, vice-president in charge of western operations. A new geological model for the Climax deposit was developed over the next few years that was much more complicated than the original but capable of answering most of the questions raised by the cylinder theory. Basically, the new theory postulated three separate intrusions instead of one, each successively deeper than its predecessor and, with each, the formation of a cap-shaped ore body in the overlying rocks. At Climax, most of the uppermost ore body is eroded, the intermediate ore body crops out on the mountainside, and the third ore body lies 800 to 1,600 feet below the surface.

Red Mountain, far to the northeast, probably was prospected thoroughly during the latter third of the 19th century, but, because no gold or silver prospects were uncovered, interest in the area waned. The yellow molybdenum mineral, ferrimolybdite, was recognized in several shallow opencuts made on the mountainside in the early 1900's, but no market existed and the area again was neglected. The Primos Chemical Co. started a small mine and milled 70,000 tons of 1-percent-MoS_2 ore between February 1918 and June 1919, but the market dwindled after peace was restored in Europe. The property then was acquired by the Vanadium Corp. of America in 1921, but no development followed. In 1941, the Molybdenum Corp. leased the property from the Vanadium Corp., opened up the old mine, and, with Government assistance, built a 200-ton-per-day mill to process the ore. This phase of activity lasted from June 1944 to June 1946 when economic conditions again became unfavorable. Molybdenum Corp. continued to drill out a large block of low-grade ore, but apparently nothing of promise developed, and eventually the company allowed the lease to expire. American Metal Climax, Inc., negotiated a lease with right-to-purchase option from the Vanadium Corp. in 1961.

Bob Henderson immediately authorized Stewart Wallace and two assistants, W. Bruce McKenzie and Robert G. Blair, to start field mapping at Urad on Red Mountain as time and weather conditions permitted. They also were to design a diamond core-drilling program to outline the known Urad deposit, permit study of geological conditions around that ore body, and look for indications of other associated ore bodies. Preliminary shallow (less than 1,500 feet) drill holes and the attendant mapping convinced Wallace and his associates that the rocks and general geological setting at Red Mountain were, in many respects, similar to those at Climax. If the geologic model at Climax was valid, possibly additional ore was underlying the Urad deposit on Red Mountain.

Finally, the last drill hole of the initial exploration program was started in the spring of 1963. The proposed depth of 1,500 feet was reached with no signs of ore, but the rocks "looked right" and the hole was continued to a depth of 3,000 feet. Within this unscheduled 1,500-foot extension, the drill cut 600 feet of rock carrying 0.2 to 0.3 percent MoS_2. This clearly was not part of the Urad ore body and it meant that the drillers were in or very near to a new molybdenum deposit!

On the strength of the evidence from this one hole, Bob Henderson received full support from Wallace McGregor, president of Climax, and Frank Coolbaugh, chairman of AMAX, to continue the drilling program to verify the new prospect. With the coming of summer, Wallace moved his drill crew outdoors and, starting near timberline at an elevation of 10,800 feet, drilled an inclined hole to cross the line of the previous hole within the 600-foot mineralized interval. At about 3,000 feet, this hole cut 400 feet of 0.3-percent-MoS_2 ore. It was estimated that if the original hole had been located even 100 feet farther west, it would have missed the ore body; without this drill intercept, the program probably would have been terminated, and the Henderson would not have been discovered.

When winter set in, the drill crew again moved underground. In the spring of 1964, when deepening two previously drilled, shallow, underground holes, the crew encountered long intervals of mineralized rock carrying less than 0.1 percent MoS_2. The two drill holes were straddling the ore body. The next hole, planned to test the space between the two previous drill holes, was authorized by Bob Henderson, by then seriously ill but still wholeheartedly behind the project. Bob Henderson died in May 1964, only a few days before the drill penetrated 900 feet of 0.5-percent-MoS_2 ore, thus establishing the possibility of an ore body.

After about 100,000 feet of exploratory drilling had been completed and evaluated, a decision was made to start development of the mine and mill in 1967. Application of the model developed at Climax had paid off! Company officials determined to name the mine the Henderson in honor of Bob Henderson whose encouragement and support throughout the exploration program assured its final success. By 1976, drilling and development had outlined about 300 million tons of proved and probable ore averaging 0.49 percent MoS_2, and drilling continues to add to the known reserves.

Mining at Red Mountain was planned so that the Urad mine could be depleted and phased out as the Henderson mine went into production. This was the third period of mining the Urad ore body, and most of its production came during the years 1967 to 1974 when the mine was operated at a rate of more than 5,000 tons per day. Personnel and equipment were transferred from one mine to the other without interruption. Buildings were removed from the site at Urad, the dump covered with surface material removed from the Henderson site, and revegetation was initiated.

The shafts for the Henderson mine are, of course, at the foot of Red Mountain, but still they lie at an elevation of 10,400 feet above sea level (fig. 7). For ecological reasons, the mill is located 14 miles to the west, in the broad valley of the Williams Fork on the west side of the Continental Divide. A 9.6-mile-long tunnel under the divide connects the mine and mill. The tunnel was driven from both ends and took 4-1/2 years to complete. It is a triumph to modern engineering and laser beam surveying that, when the two tunnels met at 7:50 a.m., on July 15, 1975, they alined within 5 inches horizontally and 1 inch vertically.

Climax Molybdenum Corp. will have spent over $500 million on the project before the mine and mill reach full capacity of 30,000 tons of ore per day in 1980.

From the initiation of the Henderson project, the AMAX engineers have worked very closely with State and private environmental groups to assure minimal environmental impact without unreasonable delays in putting the mine into

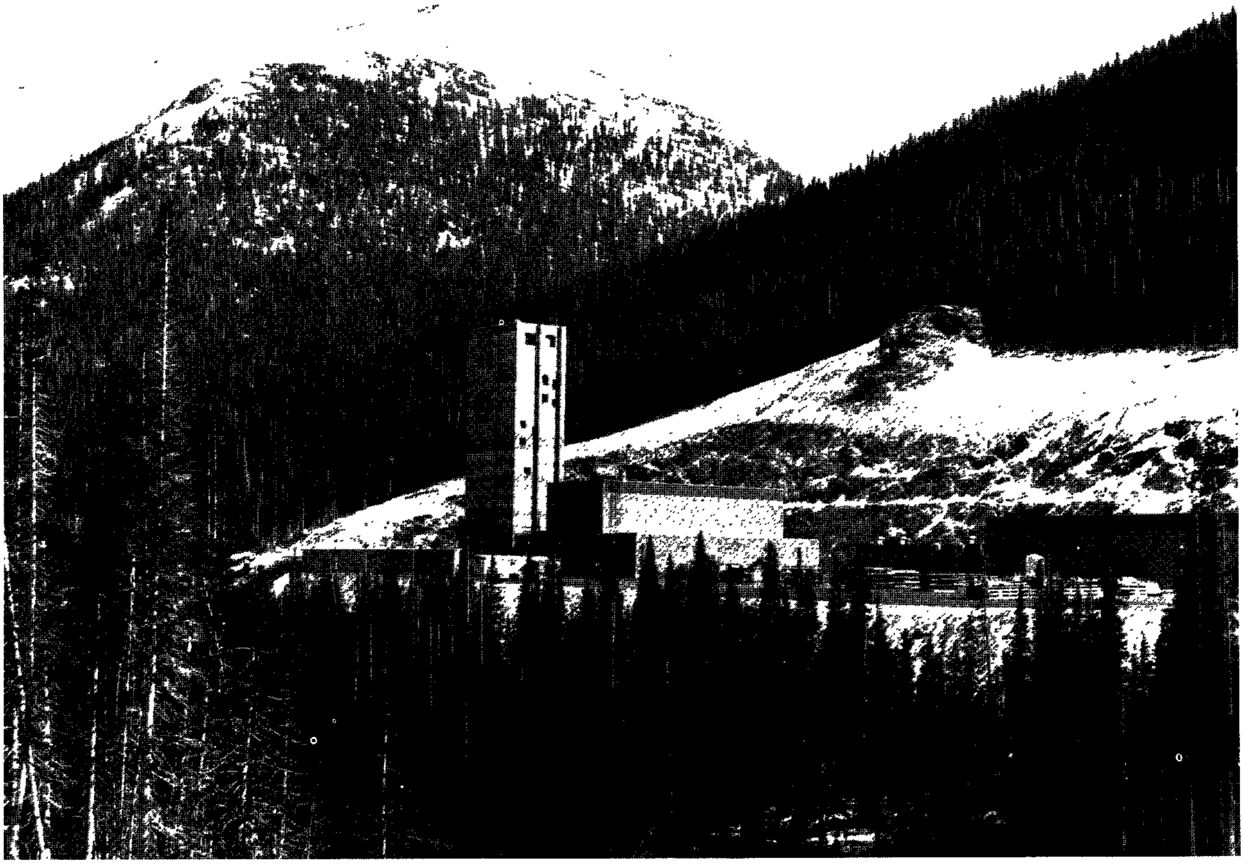

FIGURE 7. - Surface plant at the Henderson molybdenum mine located 9 miles west of Empire, Colo. *(Courtesy, AMAX, Inc.)*

production. Primarily as a result of this wholehearted cooperative planning, the Henderson project was selected by the United States Government as the subject for a case history presentation in an international symposium on "Environmental Accomplishments to Date: A Reason for Hope" held in conjunction with the 1974 World's Fair in Spokane, Wash.

Bibliography

1. Skillings' Mining Review. Haulage Tunnel Holed Through at AMAX's Henderson Mine. V. 64, No. 32, Aug. 2, 1975, pp. 10-11.

2. Wallace, S. R. The Henderson Ore Body--Elements of Discovery, Reflections. Trans. Soc. Min. Eng., AIME, v. 256, 1974, pp. 216-227.

3. World Mining. Henderson and Cuajone--Two Examples Prove Why Costs of New Mine Development Are Frightening. V. 21, No. 10, September 1976, pp. 82-83.

4. _____. Henderson Output 2,000,000 Pounds MoS_2 Per Month. V. 30, No. 9, August 1977, pp. 81-82.

5. _____. Henderson Tunnel Holed Through at Climax Molybdenum. V. 28, No. 10, September 1975, p. 35.

KALAMAZOO COPPER DEPOSIT, ARIZONA

The Kalamazoo mine lies in the cactus-studded Sonoran Desert, about 7 miles east of Oracle, in Pinal County, Ariz. (fig. 8). Unlike its sister property, San Manuel, there was no direct surface evidence of the presence of the Kalamazoo ore body. Its discovery was the result of sound intuitive reasoning, based upon the geological factors revealed during the development of the San Manuel mine.

Drilling at San Manuel showed that the upper surface of the ore body was a gently undulating, nearly flat surface sloping to the southwest at about 25°. Geologists agreed that the upper portion of the original ore body must have been sheared off and displaced by a low angle fault, but there was no agreement as to the direction or how far the missing upper segment had been shifted.

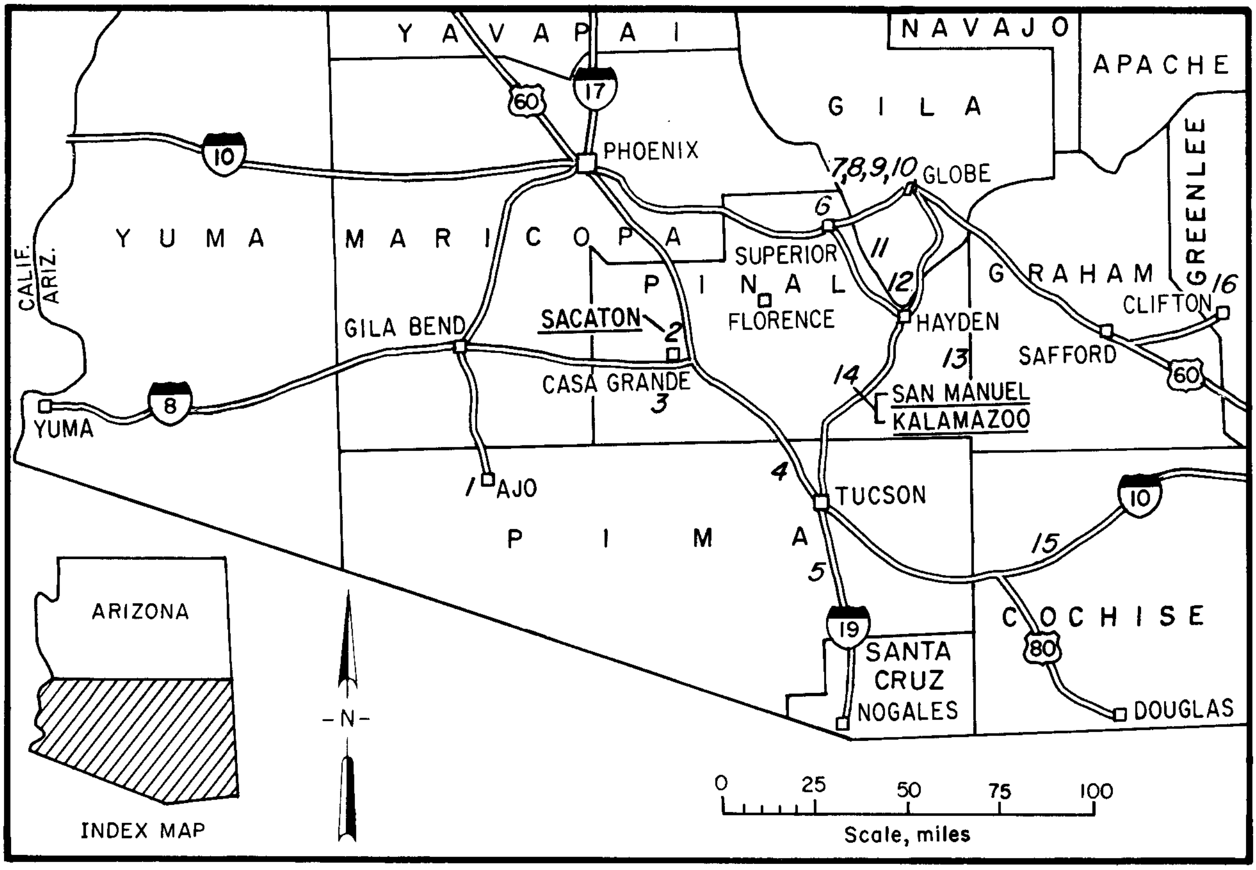

FIGURE 8. - Location map, major copper producers in southern Arizona: *1*, New Cornelia mine, open pit; *2*, Sacaton mine, open pit; *3*, Lakeshore mine, underground; *4*, Silver Bell mine, open pit; *5*, Mission, San Xavier, Twin Buttes, Pima, Esperanza, and Sierrita mines, open pits; *6*, Superior mine, underground; *7*, Pinto Valley mine, open pit; *8*, Blue Bird mine, open pit; *9*, Inspiration mines; open pits; *10*, Copper Cities mine, dump leach; *11*, Ray mine, open pit; *12*, Christmas mine, open pit; *13*, Old Reliable mine, in situ leaching; *14*, San Manuel and Kalamazoo deposits, underground block caving; *15*, Johnson mine, open pit; and *16*, Morenci and Metcalf mines, open pits. (Adapted from Arizona Copper Capital, U.S.A., Arizona Mining Association, Phoenix, Ariz., 1975.)

In 1946, four individuals from nearby Mammoth, Ariz., staked claims immediately to the west of the San Manuel property. Martha Purcell took an option on the claims that same year, and between 1947 and 1958 drilled seven cable tool test holes ranging in depth from 1,400 to 2,950 feet. No ore was encountered during this program, but fortunately the logs, drill cuttings, and assays were saved for future study.

The area then stood idle until 1965 when Quintana Minerals Corp., an affiliate of Quintana Petroleum Corp., became interested in locating a copper property. The firm retained J. David Lowell of Tucson as its geologic consultant. Lowell reviewed all known information, published and otherwise, on the San Manuel ore body, and reconstructed an image of that ore body before faulting took place. He postulated a hugh vertical cylinder, consisting of concentric zones or shells. In the center was a low-grade zone, 2,600 feet in diameter, containing only 0.3 percent copper. Wrapped around this core was the ore zone, roughly 600 feet thick; outside of that another shell of marginal ore; and surrounding the entire copper-bearing body, a rind 1,000 to 1,500 feet thick, rich in pyrite but averaging only 0.03 percent copper. Some of the silicate minerals in these zones had been altered during geologic time, so that zones of alteration also could be detected by microscopic study of the rocks.

Lowell postulated that in successive stages, this huge cylinder of copper-bearing minerals was tilted to the northeast until it lay at about a 20° angle from the horizontal. He further visualized it as being sheared through the core by a fault, as a segment of a log might be cleaved by an axe. The lower half represented the ore body in the present San Manuel mine. The upper, displaced half would represent the ore body he was seeking--the yet-to-be-discovered Kalamazoo. Schematic cross-section drawings are shown in figure 9.

Lowell relates the difficulties associated with restudying the cuttings

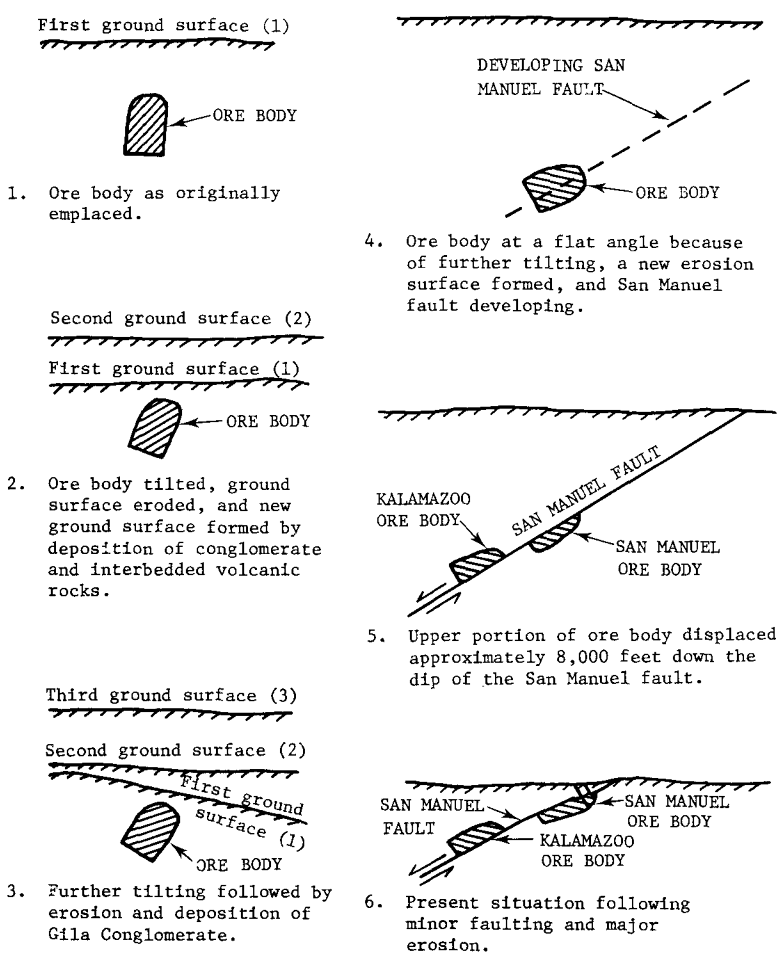

FIGURE 9. - Schematic cross-section drawings showing possible origin of Kalamazoo ore body. (Adapted from Lowell, Econ. Geol., v. 63, No. 6, 1968.)

saved and stored by Martha Purcell. The samples had been stored for many years in an old adit with a wooden door. When Lowell tried to open the door, he discovered that a swarm of bees were in residence on the inside surface of the door. He persuaded a local beekeeper in Oracle to collect the bees, but then found that water had dripped from the back of the adit and made one solid mound of the hundreds of paper bags full of drill cuttings. However, by using archaeological dig techniques with a putty knife and a whisk broom, Lowell was able to identify and salvage most of the samples.

Upon microscopic restudy of the cuttings saved from Martha Purcell's drill holes, Lowell and his associates were able to recognize both the mineral zone and the alteration zones which the drill had penetrated. The four holes had entered the outer pyritic zone at depth, and at least one hole had actually encountered the marginal ore zone. Working from the geometry of these showings, and assuming that the fault movement had been southwestward down the fault plane, Lowell postulated the position of the missing ore body. A geochemical survey of surface soils, showing high copper and molybdenum traces above the hypothetical location of the ore body, gave further credence to his hypothesis.

On the strength of Lowell's reasoning, Quintana moved very rapidly and acquired control of the necessary ground. The very first exploratory hole drilled by Quintana passed successively through the types of rocks Lowell had predicted and entered ore-grade rock at about 2,500 feet! Because the ore body was believed to lie along a northeast bearing, a grid system of 25 holes on 600-foot centers was laid out in that direction but centering on the discovery hole. Every hole drilled in the project intersected the ore body. Quintana, with experience gained in oilfield drilling, used a conventional oilfield rotary drill. Holes were drilled rapidly with a conventional bit to about 3,000 feet. As soon as chemical analyses of cuttings reached 0.2 percent copper, core drilling was started, and continued to the bottom of the ore zone at 3,000 to 5,000 feet.

Drilling outlined an ore body the shape of an overturned canoe, precisely as predicted by Lowell. Here, in 1967, was a new ore body, awaiting a name. Lowell related how Corbin Robertson, the president of Quintana, named it. Robertson was a great admirer of the music of bandleader Glenn Miller, who disappeared on a flight over the English Channel during World War II. Robertson was in the habit of naming his properties, oilfields or mines, after favorite Glenn Miller selections. One of his favorites was Miller's rendition of "I've Got a Gal in Kalamazoo," and for it the Kalamazoo mine was named.

Further drilling established that the missing half of the ore body had been shifted horizontally for 8,000 feet and dropped about 3,500 feet vertically. The ore body was estimated to contain 565 million tons of sulfide ore averaging 0.72 percent copper. Clearly this forecast a very large scale, underground operation. The tremendous task of developing and equipping a mine and mill for such a vast copper deposit was beyond the financial and technical resources of Quintana Minerals. Magma Copper, with facilities and know-how already developed at neighboring San Manuel, was approached, and after extended negotiations, Kalamazoo was purchased by Magma for $27 million in cash and stock equivalent in March 1968.

Mine development started in November 1968, and the first production is anticipated in 1979 or 1980. It was thus 21 years from the time the first claim was staked until ore was discovered in 1967, and it will be at least 12 years from ore discovery to full-scale operation.

Bibliography

1. Burgin, L. B. Time Required in Developing Selected Arizona Copper Mines. BuMines IC 8702, 1976, pp. 44-46.

2. Joralemon, I. B. Copper. Howell-North Books, Berkeley, Calif., 1973, pp. 339-341.

3. Lowell, J. D. Geology of the Kalamazoo Orebody, San Manuel District, Arizona. Econ. Geol., v. 63, No. 6, 1968, pp. 645-654.

PEA RIDGE IRON DEPOSIT, MISSOURI

The Pea Ridge iron deposit lies on the north flank of the Ozark uplift near Sullivan, Washington County, Mo. (fig. 10). It is 60 miles southwest of St. Louis and 40 miles northwest of the Bonne Terre lead mining district.

In 1929, the Missouri Bureau of Geology and Mines initiated a program for reconnaissance mapping of the intensity of the earth's magnetic field within the State. Fieldwork got underway in 1930. Geophysicists with portable magnetometers established stations at widely spaced intervals along major roads and highways and determined local values of the magnetic field. This pioneer project was completed in 1932 with assistance from Federal Works Progress Administration (WPA) funds, and two large magnetic anomalies were found. This initial survey missed Pea Ridge because of the wide spacing of magnetic stations and the inaccessibility of the area where it later was discovered. The magnetic maps of Missouri finally were published in 1943.

In 1943-44, the Bureau of Mines of the U.S. Department of the Interior drilled four test holes, ranging in depth from 1,800 to 2,400 feet, on the Bourbon prospect in Crawford County. Cores revealed a medium-grade iron ore body consisting of magnetite and quartz in the basement rocks. The tenor of the ore was too low to be of interest to the iron industry at that time.

In 1950, a newly developed type of airborne magnetometer was flown over the Sullivan-Bourbon area through cooperation of the U.S. Geological Survey, the Missouri Bureau of Geology and Mines, and private companies, foremost of which was St. Joseph Lead Co. (St. Joe). This survey revealed an additional large anomaly at Pea Ridge. Many facts relating to subsequent exploration and development at Pea Ridge have been related to the writer by two longtime St. Joe geologists, Richard Wagner and Jack Emery. When a land check was made, St. Joe found that it owned a block of land directly over the anomaly. The way this piece of good fortune came about was related by Dick Wagner, retired exploration geologist for St. Joe. When St. Joe was drilling the Indian Creek area for lead in 1948, its personnel badly wanted to option two 40-acre tracts held in an estate. Executors for the estate, over the years, had sold most of

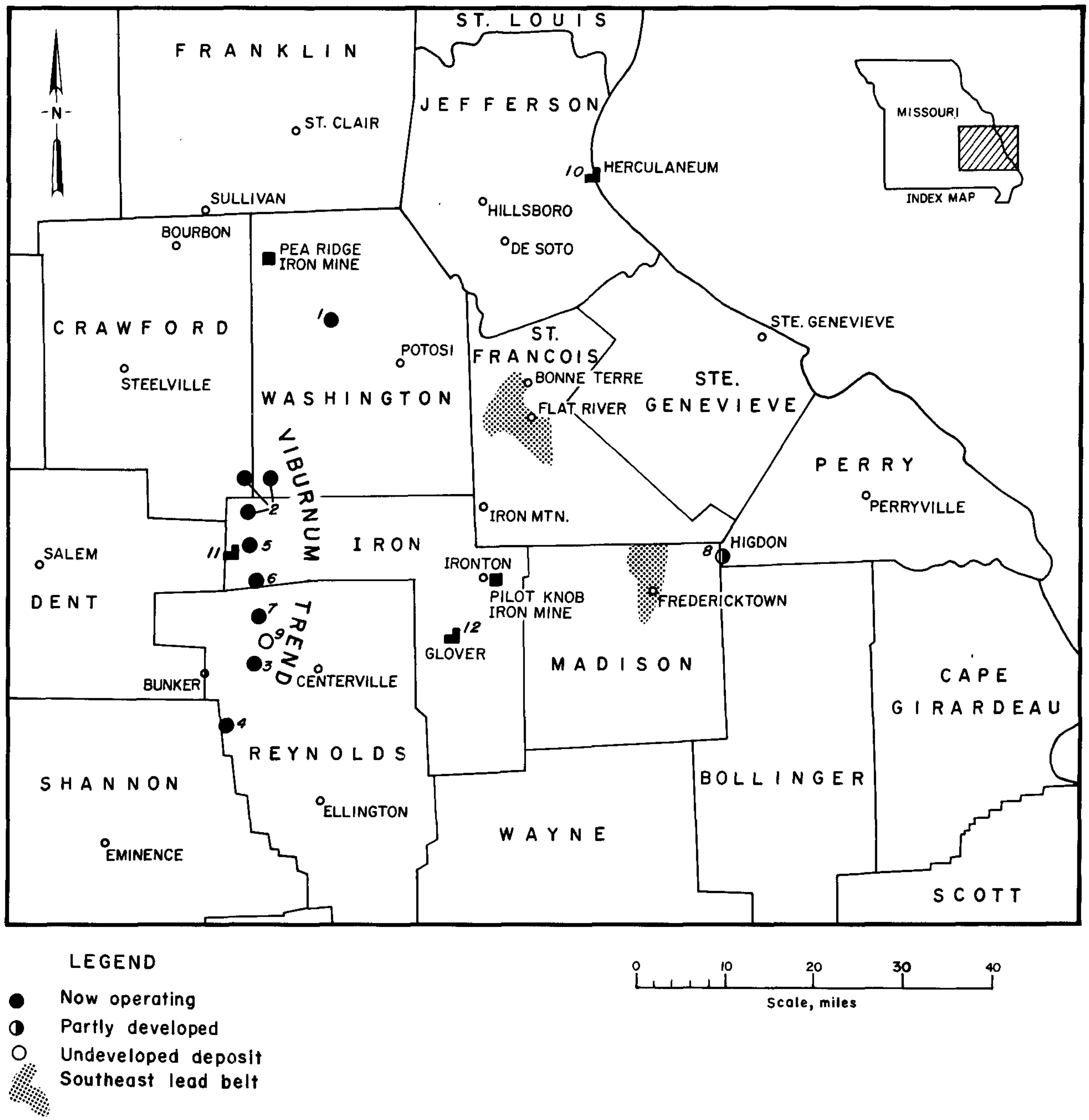

FIGURE 10. - Map showing lead deposits and operations in the southeast Missouri lead district. Lead-zinc-copper operations: *1*, St. Joe Minerals Corp. Indian Creek Div. mines and mill; *2*, St. Joe Minerals Corp. Viburnum Div. mines and mill; *3*, St. Joe Minerals Corp. Fletcher Div. mine and mill; *4*, Sweetwater mine and mill, Ozark Lead Co., subsidiary of Kennecott Copper Corp.; *5*, Magmont mine and mill, Cominco American Inc. and Dresser Industries Inc.; *6*, Buick mine and mill, AMAX-Homestake (AMAX Lead Co. of Missouri and AMAX-Homestake Missouri lead complex); *7*, Brushy Creek Div. mine and mill; *8*, Higdon mine, the Bunker Hill Co. and NL Industries, Inc.; *9*, West Fork deposit, American Smelting and Refining Co. (ASARCO). Lead smelters: *10*, St. Joe Minerals Corp. Herculaneum Div. plant; *11*, AMAX-Homestake Buick smelter; *12*, ASARCO Clover plant. (Adapted from the Viburnum Trend Guidebook, Missouri Department of Natural Resources.)

the desirable pieces of land, and only scattered tracts totaling 7,000 acres remained. The lawyers handling the estate refused either to option or to sell the two 40-acre tracts separately, but would deal only with the entire unsold acreage. After some dickering, the estate lawyers made the following proposition: "If you were to option the entire 7,000 acres for the customary 3-year period at $1 per acre, you would spend $3 per acre or $21,000. Give us $4 per acre and we'll sell you the entire 7,000 acres in fee." St. Joe accepted the offer and bought the residue of the estate for $28,000. It turned out that the two 40-acre tracts they originally sought contained no minerals of value, but the company continued to hold the entire purchase against future exploration developments.

Detailed ground magnetic surveys were implemented in the three areas, more closely outlining the limits of the potential ore bodies. In 1953, St. Joe started drilling all three prospects. It became apparent that Pea Ridge was the most promising, and by 1957, the company completed 19 test holes ranging in depth from 1,800 to 3,200 feet. This program outlined an ore body directly beneath the buried Precambrian surface at 1,000 to 1,300 feet below the surface. The ore body appeared as a nearly vertical, dikelike mass 3,000 feet long, up to 700 feet wide, and of undetermined depth. The long axis of the ore body extended in a N 60° E direction.

On the strength of this drilling, the St. Joseph Lead Co. and Bethlehem Steel Corp., in December 1957, formed the Meramec Mining Co. to mine and process the Pea Ridge ore. One shaft was started, and the millsite was cleared by the end of the year. The company decided to build a mill and pelletizing plant capable of producing 2 million tons of iron concentrate pellets per year and to design a mine to produce the requisite ore. A second shaft was started in 1958, together with a 28-mile railroad spur to the Missouri Pacific main line at Cadet, Mo. By 1961, the service shaft had been completed to a depth of 2,505 feet and the main hoisting shaft, to 2,491 feet. Exploratory drilling soon was being carried on from underground drifts. A 10-inch waterline brought in mill water from the Meramec River 4 miles away.

Mining and milling started in February 1964, producing pellets of 68 percent iron content. By 1965, the mine and mill were in full operation, mining on five levels between 1,395 and 2,275 feet and turning out the rated 2 million tons of pellets per year, respectively. The total cost of the joint venture, prior to startup, was reported to be $52 million. A total of 1,000 men was employed, 500 in the mine and 500 in the surface operations. Meramec Mining became the biggest taxpayer in Washington County. Figure 11 is a photograph of the Pea Ridge surface plant.

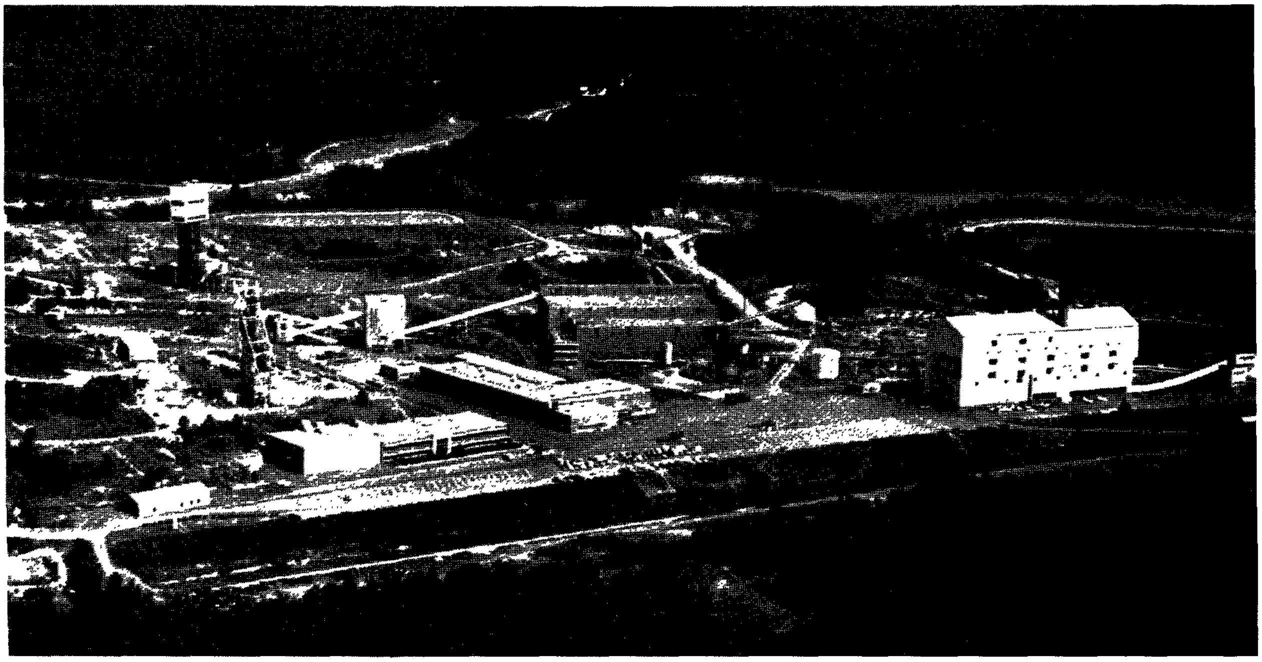

FIGURE 11. - Surface plant, mill, and pellet plant at the Pea Ridge iron mine, Washington County, Mo.

(Courtesy, St. Joe Minerals Corp., St. Joe Lead Co., Iron Ore Div.)

Bibliography

1. Emery, J. A. Geology of the Pea Ridge Iron Ore Body. Ch. in Ore Deposits of the United States, 1933-1967, ed. by J. D. Ridge. American Institute of Mining, Metallurgical, and Petroleum Engineers, New York, v. 1, 1968, pp. 359-361.

2. U.S. Bureau of Mines. Minerals Yearbooks, 1956-65, Area Reports: Domestic. Chapter on the Mineral Industry of Missouri.

3. Weigel, W. W. The Inside Story of Missouri's Exploration Boom. Eng. and Min. J., v. 166, No. 12, 1965, pp. 81-83, 161-162.

QUARTZ HILL MOLYBDENUM DEPOSIT, ALASKA

Southeastern Alaska is that portion of the State lying along the Pacific Coast west of British Columbia. It consists of countless offshore islands and a narrow, deeply dissected strip of mainland on the west flank of the rugged Coast Range, Juneau lies near the northern end, and Ketchikan is the principal city in the southern area. Much prospecting was done in this part of Alaska in the late 1890's and early 1900's. Numerous mineral claims were recorded, but very little in the way of mineral resources was subsequently developed. Significant discoveries of copper in the Canadian portion of the Insular Belt just south of Alaska and on the east flank of the Coast Range in British Columbia stimulated interest in southeastern Alaska by a score of U.S. and Canadian companies in the late 1960's and into the early 1970's.

The United States Borax & Chemical Corp. became interested in the mineral potential of rocks along the boundary between the intrusive rocks, which form the crest of the Coastal Range, and the country rock along the western flanks of the mountains. During the winters of 1971-72 and 1972-73, Jackie E. Stephens, a company geologist, thoroughly reviewed the literature and unpublished reports, and plotted all reported mineral occurrences on an overlay of army base maps of the area. On the basis of these compilations and his own fieldwork on a copper prospect on nearby Prince of Wales Island, Stephens proposed a field examination and geochemical survey along streams flowing down the west side of the range in the general vicinity of Ketchikan. The plan was submitted to Robert C. Munro, manager of exploration for United States Borax, in November 1973. The plan was approved and an exploration budget established for the following summer field season.

FIGURE 12. - Exploratory drilling operations at the Quartz Hill deposit in the Tongass National Forest, southeastern Alaska. *(Courtesy, United States Borax & Chemical Corp.)*

In June 1974, a boat was obtained for use as a base camp, with facilities for a small, two-man helicopter to land on the roof of the cabin. Four geologists, a cook, and the pilot comprised the field party. Lance E. Senter, then a summer student trainee, was designated as project geologist. Each day when flight was possible, the geologists individually were flown inland and dropped off two to a party on a ridge or stream, to work their way down toward tidewater during the long Alaskan summer days (fig. 12). Insects were a constant annoyance, and there was always a chance of encountering an unfriendly bear. In the evenings, the geologists were picked up individually and flown back to base camp. Field reconnaissance was made on either side of the traverse as far as practicable, and rock chips, soil samples, and stream sediments were collected for geochemical analysis every quarter of a mile. Samples were shipped to the company's research laboratory in Anaheim, Calif., for study and analysis. Every week or so, the boat would be moved northward to another cove as the field work progressed slowly up the coast.

By late September, with the field season for the students drawing to a close, laboratory reports indicated an anomalous area with relatively high traces of molybdenum (up to 168 parts per million) in the Wilson Arm area. Jackie Stephens and Bob Kistler, chief geologist for United States Borax, flew back up to the anomaly, which they called the Quartz Hill prospect. The helicopter first landed in the cirque area of the Quartz Hill Basin, about 2 miles upstream from the best showing of molybdenum. The rocks were highly silicified, but no molybdenum mineralization could be seen. At the second landing point, the geologists found molybdenite (molybdenum sulfide, MoS_2) in the float rock. At the third point at which the pilot set the helicopter down, the geologists saw molybdenite in a solid outcrop, and at the fourth landing place on top of Quartz Hill, they found the whole hilltop marked by the classifical cobwebbing quartz stockwork characteristic of molybdenum deposits. The prospect area lay entirely within the Tongass National Forest so a decision was made quickly to stake claims over the area. On a crash program, working under miserable weather conditions, Stephens and a nine-man contract crew from Ketchikan built a log cabin from materials at hand and staked 161 claims during the month of October. They later learned that nearby Ketchikan had recorded 42 inches of rain during that 30-day period. The crew was finally snowed out by the end of October.

Three months later, in January 1975, four company geologists, including Jackie Stephens, returned to the site, which by then was buried under 25 to 30 feet of snow. They dug down to the cabin and established a temporary camp beneath the snow. During a week of near-zero weather, they set up a small portable drill on a windswept outcrop, and put down the first 100-foot hole in the mineralized rock.

In the summer of 1975, under supervision of Lance Senter, who had become a full-time employee of the company, mapping, sampling, and further shallow drilling with a portable Winkie drill[2] continued to define the molybdenite-rich area. A few additional claims were staked as dictated by the results of the drilling. It soon became obvious that an access road would be needed to gain ingress to the prospect. An outside consulting firm was retained to gather the necessary data for an environmental impact statement during the fall and winter months. A draft impact statement was submitted to the Forest Service in the early spring. Finally, in March of 1976, the United States Borax & Chemical Corp. made a public announcement of the discovery of an important deposit of molybdenum ore in southeastern Alaska.

Further mapping, deep drilling, surveying of claims, and other attendant operations have continued during the summers of 1976 and 1977.

---

[2]Reference to specific equipment does not imply endorsement by the Bureau of Mines.

A news note in Skillings' Mining Review (March 27, 1976, p. 18) states that the United States Borax prospect covers nearly 1 square mile. It lies at an elevation of 2,000 feet, is 45 miles east of Ketchikan, and is 5 miles from tidewater (fig. 13). A further statement was made that drilling at that time had outlined 100 million tons of ore running from 0.3 to 0.35 percent molybdenite (MoS_2) and that the ore is close enough to the surface so that it may be recovered by open pit mining. Skillings' Mining Review placed the cost of exploration to that date at more than \$1 million and estimated that the cost of a 30,000-ton-per-day operation, including mine, mill, and dock facilities, might exceed \$250 million before the first concentrate is shipped.[3]

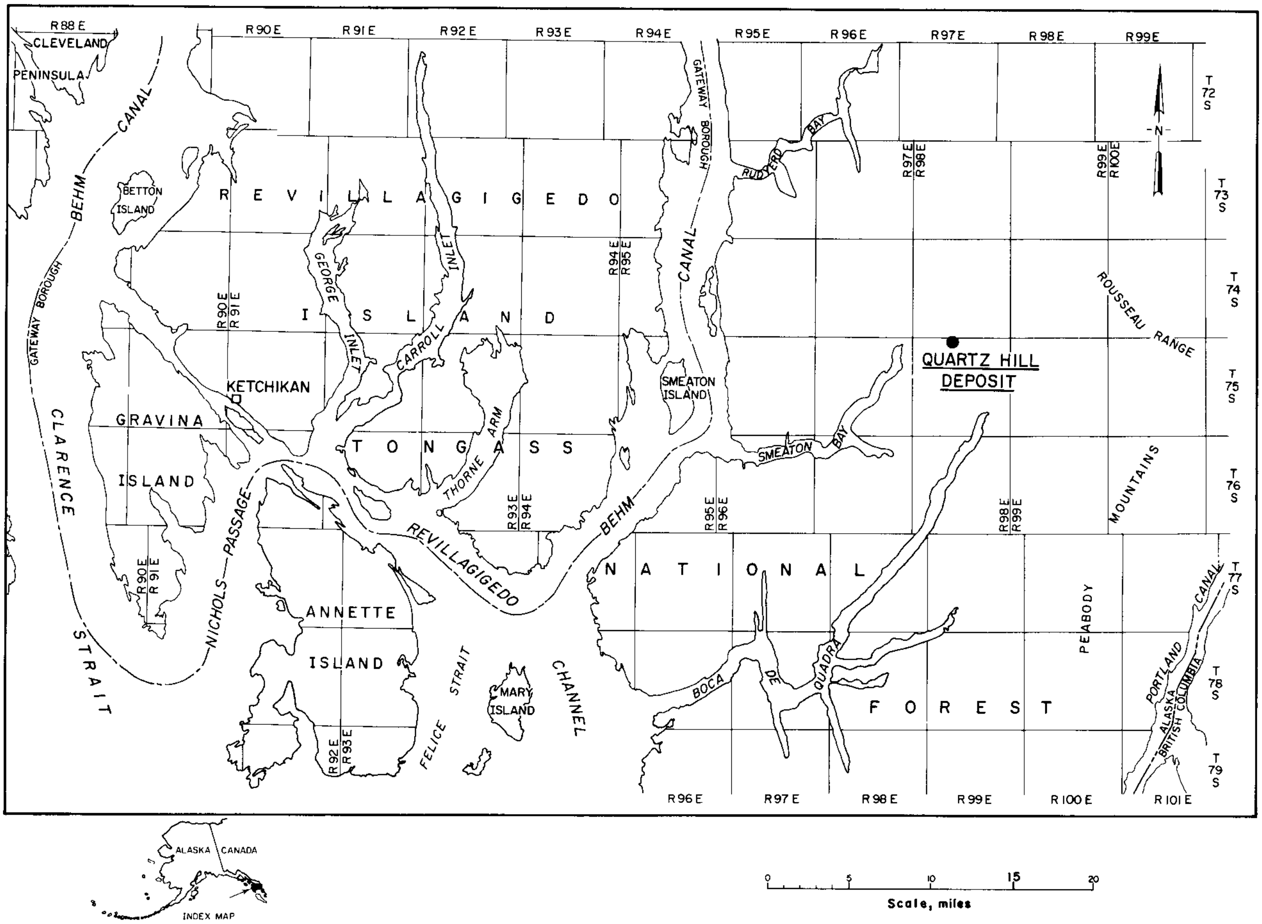

FIGURE 13. - Map showing approximate location of Quartz Hill molybdenum deposit, Tongass National Forest, southeastern Alaska.

[3]The above exploration narrative is based primarily on company information supplied to Sheldon Wimpfen, chief mining engineer for the Bureau of Mines, by Jackie E. Stephens, now northwest regional manager, United States Borax & Chemical Corp., Spokane, Wash.

SACATON COPPER DEPOSIT, ARIZONA

Long before satellite imagery made easy the recognition of major fracture zones in the earth's crust, geologists had recognized that ore deposits frequently are distributed along regional trends or lineaments, and substantial ore accumulations often were developed at the intersection of two crosscutting lineaments.

Early in 1961, geologists of the American Smelting and Refining Co. (ASARCO), holding a "skull session" in their regional office in Tucson, Ariz., were reexamining the area for likely localities upon which to concentrate their exploration activities. The southwest trending Superior-Miami trend was well established by development of several famous older copper properties. ASARCO geologists hypothesized a less well defined trend extending northeast through the Casa Grande area. A projection of the two trends crossed just south of the Sacaton Mountains, 5 miles northwest of the cotton-raising town of Casa Grande (fig. 8). The group agreed that this intersection, about 20 miles west of the nearest copper production, might be a good area to prospect.

Examination of a U.S. Geological Survey topographic map of the area showe showed that much of the prospect area was a flat desert plain where the bedrock was deeply buried by alluvial gravels. However, a few small knobs and gentle rises might represent points where resistant bedrock stood above the alluvial fill. A field check on February 9, 1961, showed that the first knob visited was indeed a rock outcrop, but it consisted of Pinal Schist that was of no immediate interest. The next "hill," 300 feet in diameter and 30 feet high, consisted of granite cut by a dike of much younger monzonite porphyry, a typical host rock for the Arizona copper deposits. Alteration of the rock and iron staining suggested that sulfide minerals had been leached from the surface outcrop but still might be found at depth.

On the strength of this small showing, the ASARCO land department was asked to secure exploration leases on State land in the immediate area and to obtain options on the intervening private land surrounding the prospect area. Geophysical surveys were used to obtain clues to what might lie beneath the thick accumulation of surface gravels. Electrical and magnetic methods were used in an attempt to outline areas underlain by concentrations of highly conductive sulfide minerals, and the seismograph was employed to estimate depths to possible ore bodies. These preliminary surveys outlined several anomalies that could be interpreted only by test drilling.

A drilling program was set in motion in September. The first five holes around the original outcrop found encouraging shows of mineralization, and the sixth hole cut rich chalcocite (copper sulfide, Cu_2S) ore. With this inducement, a system of drilling on a regular grid was inaugurated, and a total of 74,000 feet of drill hole was completed by the end of 1962. This program roughly outlined two adjacent ore bodies. The west ore body appeared to be relatively shallow, overlain by an average of only 100 feet of alluvium and barren rock. The top of the east ore body, slightly northeast of the shallow ore, was at least 1,500 to 1,900 feet below the land surface. A major fault appeared to separate the two deposits.

The relatively low price of copper at that time delayed further exploration of the discovery until 1967, when rising prices justified a second and more detailed drilling program. By January of 1969, the company had drilled an additional 38 holes averaging a quarter of a mile in depth and totaling nearly 47,000 feet in all. This program confirmed the economic potential of the two ore bodies. It was established that the west ore body, which is about 1,200 feet in diameter and up to 700 feet thick, could be mined by open pit methods. The east ore deposit, 1,200 feet long by 600 feet wide by 300 feet thick, would be mined by underground methods exclusively. The two together were estimated to contain 47 million tons of ore averaging 0.76 percent copper.

In April 1972, the Board of Directors of ASARCO approved the expenditure of $36 million to develop the Sacaton mine and to build a 9,000-ton-per-day concentrating plant (fig. 14). The concentrates would be shipped to the ASARCO smelter at nearby Hayden, Ariz. Stripping of the west ore body started that same month with leased equipment. By yearend, the company had acquired its own equipment, and stripping was in full swing. Full operation of the mine and mill began in the spring of 1974, 13 years after the initiation of a drilling program.[4]

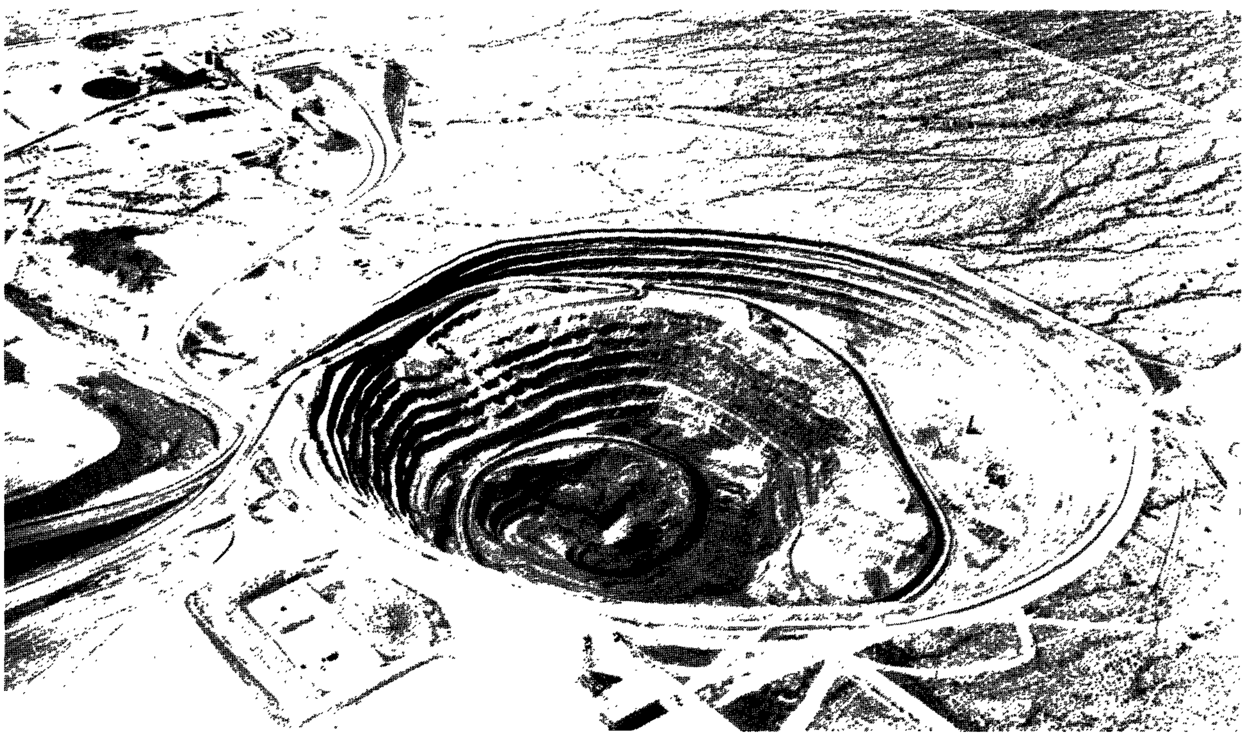

FIGURE 14. - Oblique aerial view of the Sacaton open pit and concentrator near Casa Grande, Ariz.

(Courtesy, ASARCO, Inc.)

[4] Compiled from numerous news items in Skillings' Mining Review, Engineering and Mining Journal, World Mining, Mining Magazine, and the Domestic Area Reports volumes of the Minerals Yearbook.

287-091 O - 79 - 3

The Sacaton discovery gave credence to the geologists' assumption of a northeast-southwest trending lineament. Following this lead, two other substantial finds on the same trend were made about 30 miles southwest of Sacaton. One, by El Paso Natural Gas Co., is known as the Lakeside property; the other, by Newmont Mining Corp., is named for the nearby Vekol Hills. Both are on the Papago Indian Reservation.

SAN MANUEL COPPER DEPOSIT, ARIZONA

Red Hill, which led to the discovery of the San Manuel copper deposit, is an iron-stained rocky knob that stands above the flat gravel surface of the Arizona desert some 45 miles northeast of Tucson (fig. 8). Because of the iron discoloration, the hill reputedly was prospected prior to the Civil War, and the first claims officially were staked in the 1870's. By 1873, interest had shifted about a mile to the north, to a group of mineralized veins around which the Mammoth or Old Hat mining camp was developed. Production at Mammoth started in 1881 and continued intermittently until 1947. Little attention was paid to Red Hill, although additional claims were staked in 1906. Between 1915 and 1917, two cable tool prospect holes were drilled just southeast of Red Hill where some green copper stains were noted on a small outcrop of rock. Prophetically, they were drilled at the instigation of William Boyce Thompson, who was associated with the newly organized Magma Copper Co. The holes penetrated pyritized rock and yielded assays of 0.8 percent copper, about half the value that was considered ore at the time.

Serious prospecting in the Red Hill area started in 1925, when Anselmo Laguna of nearby Superior staked the original San Manuel Nos. 1-5 claims. James M. Douglas, owner of a saloon in Superior, purchased a one-third interest in the Laguna claims in June 1926, and another one-third interest in August 1939. Douglas and R. Burns Giffin, a garage owner and car dealer from Superior, acquired the remaining one-third interest. Another story relates that Laguna, on his deathbed, willed his remaining share of the San Manuel claims to Douglas for his kindness during Anselmo's final illness. In any event, by 1940, Douglas, Giffin, and Victor Erickson, who had just acquired a one-fourth interest in the claims, held title to the San Manuel Group. They offered the property to Magma Copper Co. for $50,000, but after a Magma field engineer examined the property, the offer was declined.

In 1942, at the request of the partners, Henry W. Nichols, an assayer for Magma, examined their property, located some new claims for the owners, prepared a report on the property, and again tried unsuccessfully to interest Magma. For his services, he received a one-fourth interest in the partnership. In October, Nichols submitted an application to the Reconstruction Finance Corp. (RFC) for a $20,000 exploration loan, using his report as supporting evidence of the merit of the area. Although the RFC declined the immediate loan, the application came to the attention of other Government agencies interested in developing copper resources to meet the demands of World War II. Through the persistence of Nichols, the RFC ultimately requested that the U.S. Geological Survey examine the prospect. N. P. Peterson and B. S. Butler of the Geological Survey mapped and sampled the property in mid-March. Butler thought that the pyritized rocks of Red Hill were part of a halo of pyritic mineralization, which often surrounds copper deposits in Arizona. He postulated that the main ore body might lie out under the gravels, which all but engulf Red Hill. Butler's enthusiasm encouraged the U.S. Bureau of Mines to clean out some old prospects and to sample the working faces. In 1943, after drawing up an agreement with the partners, the Bureau started a churn drilling program to consist of five 300-foot holes. These test holes all revealed low-grade copper oxide ore beneath the gravel and conglomerate. After receiving additional funds for the project, in the spring of 1944 the Bureau carried out some deeper drilling and encountered sulfide ore at 685 feet.

It was at this point that John Gustafson, geologist for the Magma mine at Superior, first heard of Red Hill and the drilling program of the Bureau of Mines. On his own initiative, he visited the San Manuel property and was impressed by its potential. He reported his findings to Magma's New York office, and received permission to try to acquire an option on the property from the four partners. At first Nichols was reluctant to deal with Magma, who had rebuffed him on several previous occasions. Finally, however, Gustafson and Nichols worked out a preliminary agreement, and by the end of August, a formal option agreement was signed by Magma Copper and the partners. Under the option, the vendors would get a 5-percent interest in the San Manuel Copper Corp.

With the partner's claims as a nucleus, Magma staked additional claims over the eastern and southern extensions of the ore body. To the north, valid claims were held by Sam Houghton, a local mining engineer, and by members of the Quarelli family, who owned a saloon in nearby Winkleman. The latter had optioned their claims to Houghton. After protracted negotiations, Gustafson and Houghton reached an oral agreement in the early hours of the morning at a bar in Oracle. Under the agreement, Magma was to acquire the best of Houghton's claims and an option on the Quarelli claims. Gustafson promptly wrote out the essence of their agreement and submitted it to a lawyer to rewrite in final legal form. Three days later, Gustafson received a shock when he came back to Houghton with an agreement ready for signatures. According to Ramsay (p. 162):

> Houghton greeted him by handing him a letter from the Chief geologist of International Smelting and Refining, an Anaconda subsidiary, saying that his company agreed to conclude the purchase of Houghton's property on terms that had been proposed previously. To Gustafson's great relief, Houghton stuck by his agreement and signed the papers Gustafson had prepared.

Subsequently, Anaconda acquired the remainder of Houghton's holdings, and it was several years before Anaconda and Magma reached an accord on how to mine the Anaconda interest.

With a viable group of claims under its control, Magma embarked on a protracted drilling program extending from December 1944 to February 1948. Eighty-eight cable tool holes totaling 172,692 feet were drilled; the deepest was 2,755 feet. Anaconda drilled 18 holes on its adjacent claims, and the Bureau of Mines drilled 17 holes totaling 15,839 feet. Their deepest penetration was 1,990 feet below the surface.

In 1948, as a result of all drilling, an ore body 3,000 feet long, 400 to 800 feet wide, and 500 to 700 feet thick was outlined. Distance to the top of the ore body averaged 670 feet; at its deepest point it was 1,900 feet below the desert floor. Magma was now ready to proceed with development of a large-scale underground mine and all necessary adjuncts.

In accordance with a section of the original agreement with the partners, San Manuel Copper Corp. was formed as a subsidiary of Magma in late 1945. By the end of 1946, Magma owned 458,941 shares and Houghton and the early partners owned 56,059 shares in the new company. In 1950, in order to make San Manuel a wholly owned subsidiary, Magma exchanged for the partners' shares 20,000 shares of Magma stock, then worth about $25 a share, or half a million dollars, for their faith in the Red Hill prospect! By 1956, those same shares would be worth $2.5 million.

Sinking of the first shaft was started in March 1948, and it was completed in January 1952 (fig. 15). By this time it was evident that more than

FIGURE 15. - Surface plant, mill, smelter, refinery, casting plant, and townsite at San Manuel copper mine, Pinal County, Ariz.

(Courtesy, Magma Copper Co., Newmont Mining Corp.)

$100 million would be needed to put the mine into production. To obtain such financing for a small company like Magma challenged the ingenuity of A. J. McNab, president and guiding genius of both San Manuel and Magma. The financing is a story in itself; the Federal Reconstruction Finance Corp. (RFC) supplied the bulk of the money at 5 percent interest and supported its investment by agreeing to purchase copper from the company at a specified floor price if it could not be sold at a higher price on the open market. RFC's conditions were as follows: (1) All the Magma Copper property was pledged as a mortgage, (2) Magma was to raise and invest $8 million in addition to the $10 million already spent before drawing on RFC funds, and (3) Magma was to find other financing for a town of 1,000 dwellings as well as attendant utilities, services, and schools. Magma met these conditions to the letter. The venture was so successful that Magma soon obtained private financing for $80 million and repaid the RFC in full.

Major underground development started in January 1953, and the first block of ore was undercut in January 1956. During this development period, Magma also planned and constructed a 30,000-ton-per-day mill, a smelter, a 30-mile branch railroad from Hayden, Ariz., and the completely new town of San Manuel. By December 31, 1956, total capital expenditure at San Manuel, including the railroad but excluding the townsite, was $102,589,445. The first copper anode was poured at the smelter in early 1956, and the operation reached its scheduled output of 33,000 tons of ore per day in October 1957.

Bibliography

In addition to notes in trade journals, the following sources have been freely drawn upon.

1. Burgin, L. B. Time Required in Developing Selected Arizona Copper Mines. BuMines IC 8702, 1976, 144 pp.

2. Joralemon, I. B. Copper. Howell-North Books, Berkeley, Calif., 1973, pp. 337-340.

3. Ramsay, R. H. Men and Mines of Newmont. Octagon Press, New York, 1973, pp. 157-177.

VIBURNUM TREND LEAD-ZINC DEPOSITS, MISSOURI

French voyageurs paddling along the Meramec River in southeastern Missouri in search of furs reported good showings of lead ore as early as 1700. By 1725 surface mining was started at Mine La Motte under French auspices. This was probably one of two lead-mining areas within the limits of the Louisiana Purchase at the time President Jefferson bought that vast territory from Napoleon's government in 1803. Successive discoveries of shallow lead and zinc ore continued to expand the known productive area and to increase the number of modest sized mining operations in the region. The St. Joseph Lead Co. (St. Joe) was formed in New York in 1864 to develop lead-mining properties in St. Francois County, Mo. They started by purchasing the La Grave mine, which was iwthin the limits of the present-day town of Bonne Terre. Gradually, St. Joe acquired other properties, and by 1933 it was the dominant operator in the entire district.

By the close of World War II, known reserves in the old southeast Missouri lead belt were seriously depleted, and it was doubtful whether additional nearby deposits could be found even by intensive prospecting. In 1943, officials of St. Joe decided to embark upon an extensive regional search for new lead resources. A geology department was formally organized under John S. Brown. It was charged with developing a coordinated exploration program based on geology, geophysics, and extensive deep exploratory drilling. As many as 25 geologists participated in the search. The target area was centered on Washington County, where similar geological conditions were believed to be present but at a greater depth than in the old lead belt. The story of the team efforts of this group have been related to the writer by Richard Wagner, who was an active member of the team and is now retired.

A dearth of roads, plus mud and snow in winter and chiggers and copperheads in summer, plagued the exploration crews. Even though the Volstead Act had been repealed, stills were still operating; land men and drill crews had to win the confidence of the operators or stay out of critical areas.

The southeast Missouri lead-zinc ores occur in the nearly flat-lying Bonne Terre Dolomite, which was deposited in shoals in the Upper Cambrian sea. In the early 1950's it had been recognized that the ores were localized in areas of algal growth occurring either as banks or as reefs above or paralleling the shorelines of islands, which stood above an ancient shallow sea. Geological reconstruction of the Upper Cambrian geography thus became a powerful tool in the exploration program. Because some of the Precambrian knobs that stood up as islands were composed of iron formations, it was possible initially to delineate certain prospect areas by the use of magnetic or gravitational surveys. Areas thus localized then were explored by drill holes. As exploration moved westward, the host strata for lead ores became deeper, and domes and other evidences of the old buried topography became less evident. As a consequence, almost random, widely spaced test holes, 1,000 to 2,000 feet deep, became the principal exploration method.

Because it was unnecessary to core drill the broken, cherty strata overlying the Bonne Terre Formation, holes were drilled to the top of that bed with slow percussion or cable tool drills. Casing was set at the top of the Bonne Terre, and core drills were moved on to complete the holes. Because of the slowness of the cable tool drills, it took four cable tools to keep ahead of each diamond drill rig. Much of the time as many as 16 cable tool rigs were required to keep ahead of four core drills. This meant that the geologist had to spot many additional holes before he knew the results of coring on one specific hole. Probably many unneeded holes were drilled.

The general practice in that area was to option private land for possible purchase before drilling and to negotiate a final purchase price for surface and mineral rights when ore was discovered. Most of the land is rough, cutover timberland of limited value so far as surface rights are concerned. During the depression years of the 1930's, much of this cutover land had been bought up by the Federal Government to aid financially distressed owners. It is now administered by the U.S. Forest Service. Here, options for purchase cannot be obtained, claim staking is not permitted, and only limited acreages can be held by any one operator for prospecting permits from the Government. If ore is found on Government lands, an operating lease with production royalties can be negotiated.

In 1948, as a result of a bit of luck, St. Joe first encountered what was to become the Indian Creek ore body. The story was recounted in slightly different versions by W. W. Weigel and by Richard (Dick) Wagner, both retired geologists of that company. On the last hole to be drilled during the 1948 season, under miserable weather conditions, the diamond drill became stuck, and the drill crew wished to salvage what they could and abandon the hole. Had that been done, the exploration option would have been dropped, and the crew would have been moved to another area the following spring. However, Wagner instructed them to try for two more days to free the bit and continue the hole. Unbeknownst to Wagner, Art Sears, the geologist directly in charge of the drill crew, determined to try to bypass the bit by "wedging," or deflecting, the drill past the obstruction. He was successful, and continued to drill the hole to the original target depth. A modest showing of mineralization was found in the bottom of that hole. With this encouragement, B. F. Murphy, the district manager in charge of exploration, authorized acquisition of additional options in the area, and subsequent drilling the following year enabled the company to outline the Indian Creek ore body. Mine development followed, and production at the rate of 2,000 tons per day started in 1954. Although Indian Creek is only 20 miles from older production, its discovery vindicated John Brown's belief that ore could be found in deeper rocks west of the old lead belt.

Word of the discovery resulting from St. Joe's intensified exploration program led other companies into the area. Because of limitations of size of Federal permits which could be held at any one time by any one company, favorable acreage was available for newcomers to capitalize on St. Joe's initiative and persistence.

Following drilling by American Metal Climax, Inc. (AMAX), east of Czar Knob, in which some encouraging but noncommercial showings of lead minerals were observed, St. Joe acquired additional land southeast of Czar Knob. After a few months of drilling along the crest of a supposed ancient ridge, St. Joe encountered rich ore in September 1955 that ultimately became St. Joe's No. 27 mine. Continued drilling in that same area resulted in the discovery of what became the first ore body directly on the Viburnum Trend.

St. Joseph Lead Co. followed its initial Viburnum discovery by finding the Fletcher ore body in the summer of 1958. The company had tried some gravitational geophysical surveys in the Bee Creek area. Results were inconclusive, but Dick Wagner drilled an apparent anomaly consisting of only two stations. The hole encountered modest shows of mineralization. It turned out later that the two stations were in error and no anomaly existed. But Wagner relates how luck played a further part in the Fletcher discovery. Word of a possible find on Bee Creek reached a rival company that held an option on two 40-acre tracts lying in an east-west line about one-half mile west of St. Joe's drill hole. That company drilled a hole along the north-south fence at the east edge of its option, but found nothing. It turned out later that the fence was not on the property line, and the crew had drilled a barren hole on St. Joe ground. They then drilled in the center of their west "40" and found nothing. Discouraged, they dropped the option on the two 40-acre-tracts. St. Joe picked up the option, drilled between the two barren holes, and hit the main ore trend. Following an intensive drilling program, the company authorized the development of a $14 million, 5,000-ton-per-day facility in 1963. Shaft sinking started in the summer of 1964, and the mill began to operate at the end of February 1967.

AMAX, which had been unsuccessful in earlier drilling programs near Palmer and Czar Knob, teamed up with Homestake Mining Co. and in 1960 found an ore body 10 miles south of Viburnum near the small settlement of Buick. The joint venture ultimately outlined an ore deposit at a depth of 1,200 to 1,300 feet, which became the Buick mine. A total of $18.5 million was budgeted for development of a mine and mill capable of producing 50,000 tons of lead per year. In 1973 and 1974, the Buick mine accounted for 28 percent of the U.S. production of lead, and 12 percent of its zinc (fig. 16). Ore reserves were calculated at 50 million tons containing 8 percent lead and 2 percent zinc.

The Montana Phosphate Products Co. and the Magnet Cover Barium Corp., subsidiaries of Cominco American, Inc., and of Dresser Industries, respectively, jointly acquired a block along the Viburnum Trend several miles south of Viburnum and started exploratory drilling in 1960. Following the first encounter with ore in September 1962, the company drilled more than 200 holes (23 miles of core) to establish the presence of an ore body 1,200 feet below the surface. The Magmont mine and mill, named for the first syllable of each company name, now produces and processes 1 million tons of ore per year. Lead concentrates are smelted at the nearby AMAX-Homestake smelter; zinc and copper concentrates are shipped elsewhere for treatment.

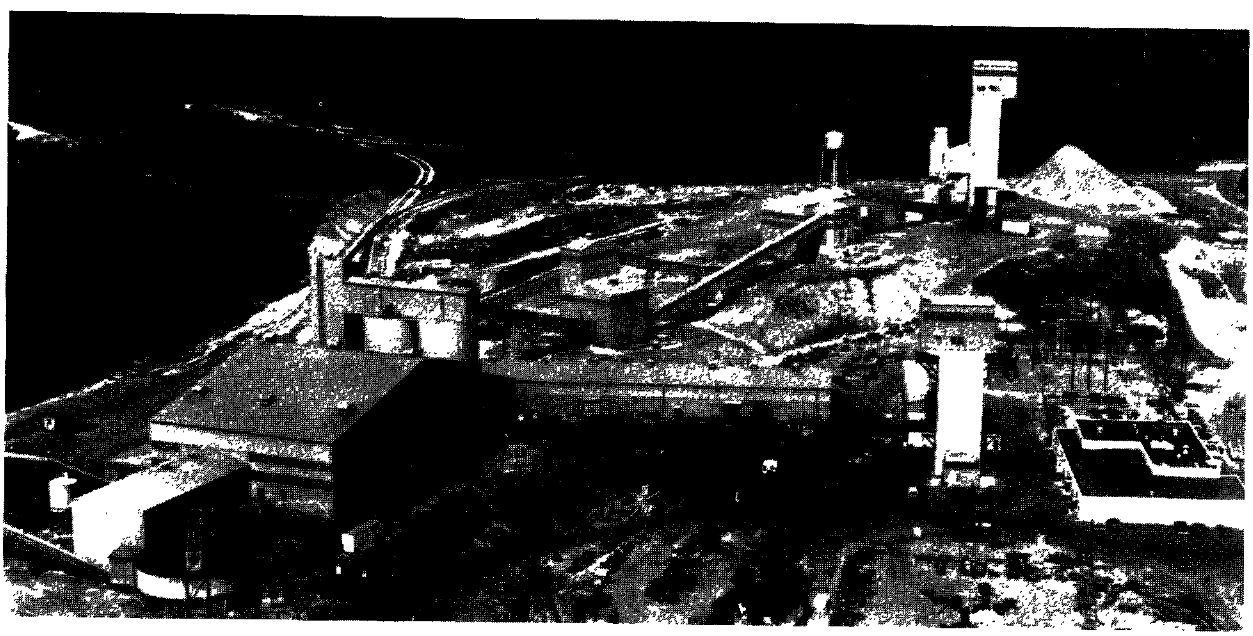

FIGURE 16. - Surface plant, Buick mine, Viburnum Trend, southeast Missouri.

Other discoveries followed once the trend was so clearly defined. The most southern ore body to be discovered so far on the Viburnum Trend, the Sweetwater mine, was found by Kennecott at a depth of 1,250 feet in January 1964. It is operated by a subsidiary, Ozark Lead Co. Mine production started in June 1968.

Thus, in the course of some 19 years following the ore body delineation at Indian Creek, the Viburnum Trend has developed into a producing belt 45 miles long. The width of the ore zone ranges from a few hundred feet to about 2 miles. Seven active mines lie along the trend, and undeveloped ore bodies have been outlined (fig. 10). The Viburnum district is currently the leading lead-producing area in the world.

Weigel estimated in 1965 that the cost of options and drilling in the area from 1944 to 1966 was approximately $50 million, followed by an additional $25 million for acquisition of fee lands. He estimated that capital charges for development of the already discovered ore bodies, including mills, smelters, railroads, and powerlines, would total another $500 million by the year 1976.

Bibliography

1. Economic Geology. An Issue Devoted to the Viburnum Trend, Southeastern Missouri. V. 72, No. 3, May 1977, pp. 337-526.

2. Missouri Department of Natural Resources. Viburnum Trend, Missouri, the Geology and Ore Deposits of Selected Mines. Guidebook, RI 78, 1975, 56 pp.

3. Weigel, W. W. The Inside Story of Missouri's Exploration Boom. Eng. and Min. J., v. 166, No. 11, 1965, pp. 77-86; v. 166, No. 12, 1965, pp. 81-83, 161-162.

WHITE PINE COPPER DEPOSITS, MICHIGAN

White Pine lies a little below the middle of a 160-mile-long copper belt that extends from extreme northeastern Wisconsin, northeasterly to the tip of the Keweenaw Peninsula of northern Michigan (fig. 17). Most of the area is covered with cutover second growth forest. Pulpwood and mining are the principal industries.

The Keweenaw Peninsula has been known for the presence of native copper since the first Jesuit missionary visited the area in 1636. For centuries before that the Chippewa Indians or their predecessors had hammered tools and ornaments from nuggets of native copper found in streams or along the shoreline of Lake Superior or where it had weathered out of the glacial drift. They had traded fragments of the malleable red metal throughout the upper Mississippi and Ohio valleys. Early French traders, using Indian labor, had made strenuous efforts to wrest masses of copper from the native rock; many of the major copper deposits were later found by the presence of abandoned pits of these primitive efforts. Alexander Baxter came from England in 1768 to investigate reports of copper. Douglass Houghton, for whom the principal city on the peninsula is named, gave the first technical description of the copper deposits 7 years before he became state geologist of Michigan in 1837.

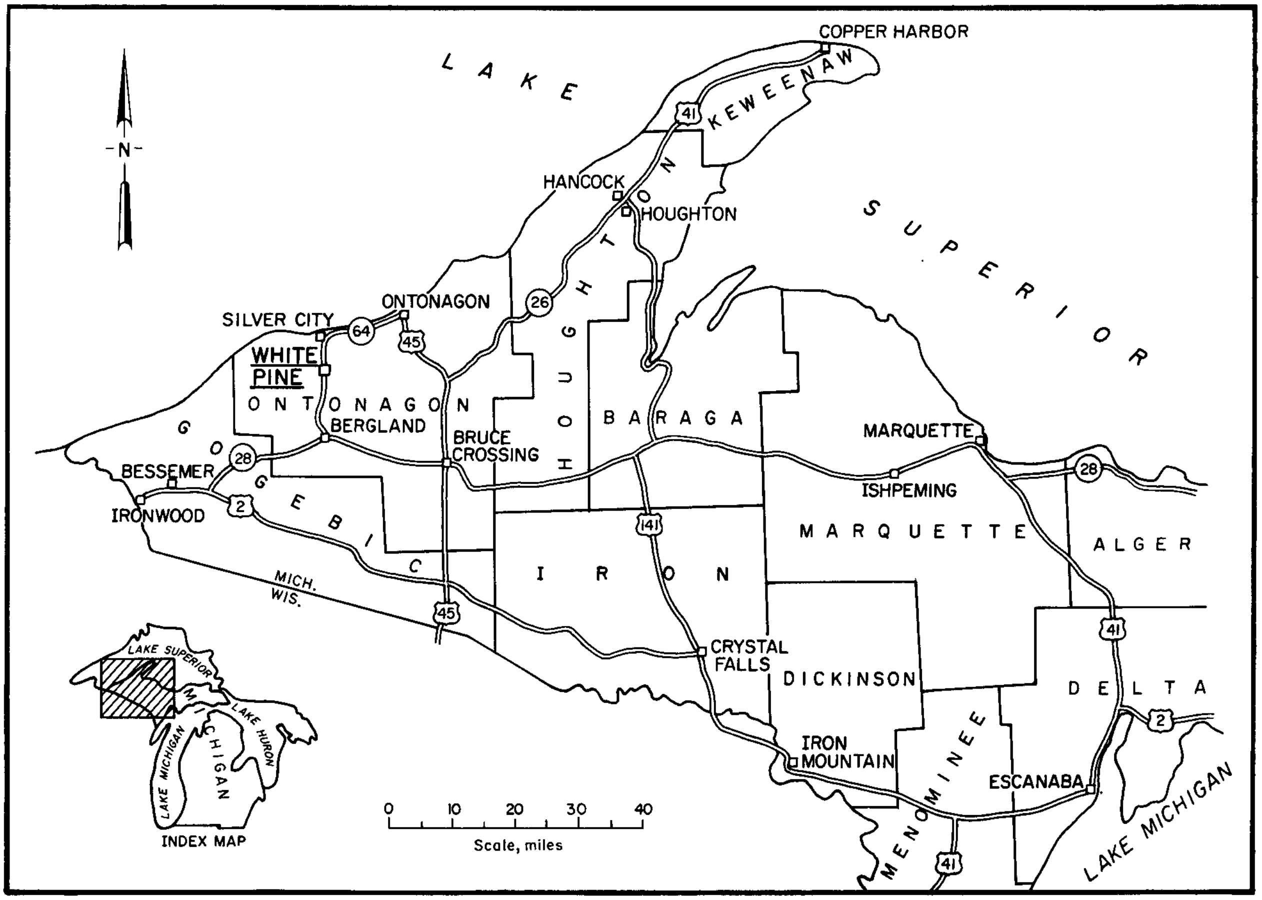

FIGURE 17. - Location map, White Pine copper mine, Ontonagon County, Mich.

The dominant mineral throughout the peninsula was always native copper, cementing together the pebbles of an ancient conglomerate or filling the bubble holes formed by gases trapped in cooling lava flows. Other forms of copper, the sulfides and oxides, were so rare as to be mere curiosities. Uninterrupted mining of the native copper deposits started at the Cliff mine at the northern tip of the Keweenaw Peninsula in 1846.

At the southern end of the copper belt, the copper ore was a sandstone heavily impregnated with finely divided native copper. The large metallic masses typical of the mines to the north were conspicuously absent. The old Nonesuch mine produced 195 tons of copper from sandstone between 1868 and 1885. From 1872 to 1876, this district underwent a promotional boom, which ultimately produced a few tons of silver ore. The White Pine district received considerable attention, and claims were staked for 60 miles to the east and south. But when the silver deposit became exhausted, all interest in the sandstone ores lagged until 1915, when demands of World War I caused the original White Pine Copper Co. to develop a small copper mine along the White Pine fault. Operations ceased in 1921 owing to depletion of the richer ores and a drop in the demand for copper.

Exploratory drilling by Calumet and Hecla crews working outward from the faultline deposit showed low-grade copper in sandstone, and also disseminated, minutely divided copper in shale associated with the sandstone. This persistent, 600-foot-thick shale and sandstone unit had been named the Nonesuch shale from the mine where the potential of the sandstone ore was first recognized. Continued drilling showed that the copper was concentrated in two thin beds a few feet above the base of the formation. Assays were low by standards of those days, and metallurgical test runs indicated that copper recovery would be poor.

Ira Joralemon (1973, p. 345) relates that C. H. Benedict, chief metallurgist for Calumet and Hecla, once told him that they failed to recognize the importance of the finely divided chalcocite (copper sulfide, Cu_2S) which occurred in the shale along with the native copper. In the metallurgical tests they had made no effort to save this mineral, assuming that it was a minor constituent of the ore at White Pine as it was in the huge conglomerate and lava ore bodies farther north. Calumet and Hecla lost interest in the area after mining ceased, and the drilling program was stopped.

William H. (Bill) Schacht is given credit for recognizing the possible importance of the shale as copper ore. A similar deposit in the Mansfield copper shale (kupferschiefer) in East Germany and Poland had long been an important Old World source of copper. Schacht reasoned that similar deposits might be found and exploited in the United States. The Nonesuch shale might well be such a host rock.

In January 1929, Copper Range quietly picked up the White Pine property at a public sale. The price was $119,000. As time and money permitted, they set about to core drill the shale at increasing distances from the original faultline discovery. At first they drilled on 500-foot centers, but because the logs and assays from successive holes were so consistent, they ultimately increased the spacing to 2,000 feet. Eventually, the area proved to be underlain by copper-bearing shale covering more than 20 square miles.

Geologists for Copper Range and the U.S. Geological Survey noted that the copper was concentrated in two bands of 2 to 3 percent ore, each band less than 5 feet in thickness, but separated by 5 to 15 feet of very lean rock. By 1945, the drilling program had delineated a deposit containing 200 million tons of ore averaging 1.1 percent copper, or 22 pounds of copper per ton. The time had come to consider development of this unique deposit.

Two major problems soon confronted Copper Range. First, U.S. miners had limited experience with this sort of copper ore. The widespread, gently dipping seams of ore most nearly resembled coalbeds, and ultimately the equipment and methods of coal mining were adapted to mining the copper-bearing shales. Second, because of the barren rock lying between the two ore beds, dilution of the ore to about 1 percent copper was inevitable. Only after protracted experimentation at the Freda mill of Copper Range did the metallurgists succeed in raising the recovery of copper from the finely disseminated ore to 80 to 85 percent.

Experimental mining was initiated during 1945, and large-scale mining operations commenced during the fall of 1954 following completion of the mill. The initial plans of Bill Schacht and Morris La Croix were to develop a mining operation of modest size. These plans were shoved aside when the Federal Government offered to assist in building an operation designed to mine 10,000 tons per day and produce 75 million pounds of copper annually. With the stimulation of a $57 million loan, awarded under the Defense Production Act, and a guaranteed purchase contract for 243,750 tons of copper at a base price of 25.5 cents per pound, development of the commercial mining operation began in 1952. Construction of the 10,000-ton-per-day mill was completed late in 1954, and large-scale mining operations began.

Bill Schacht died early in the development stage of the mine; the Schacht shaft of the White Pine copper mine was named in his honor. Morris La Croix, too, died before the plant was at full capacity. However, the vision of these two men placed Copper Range in the number one position with respect to copper reserves, all from ore which earlier geologists and engineers had deemed worthless. Figure 18 is a photograph of the surface plant of the White Pine mine.

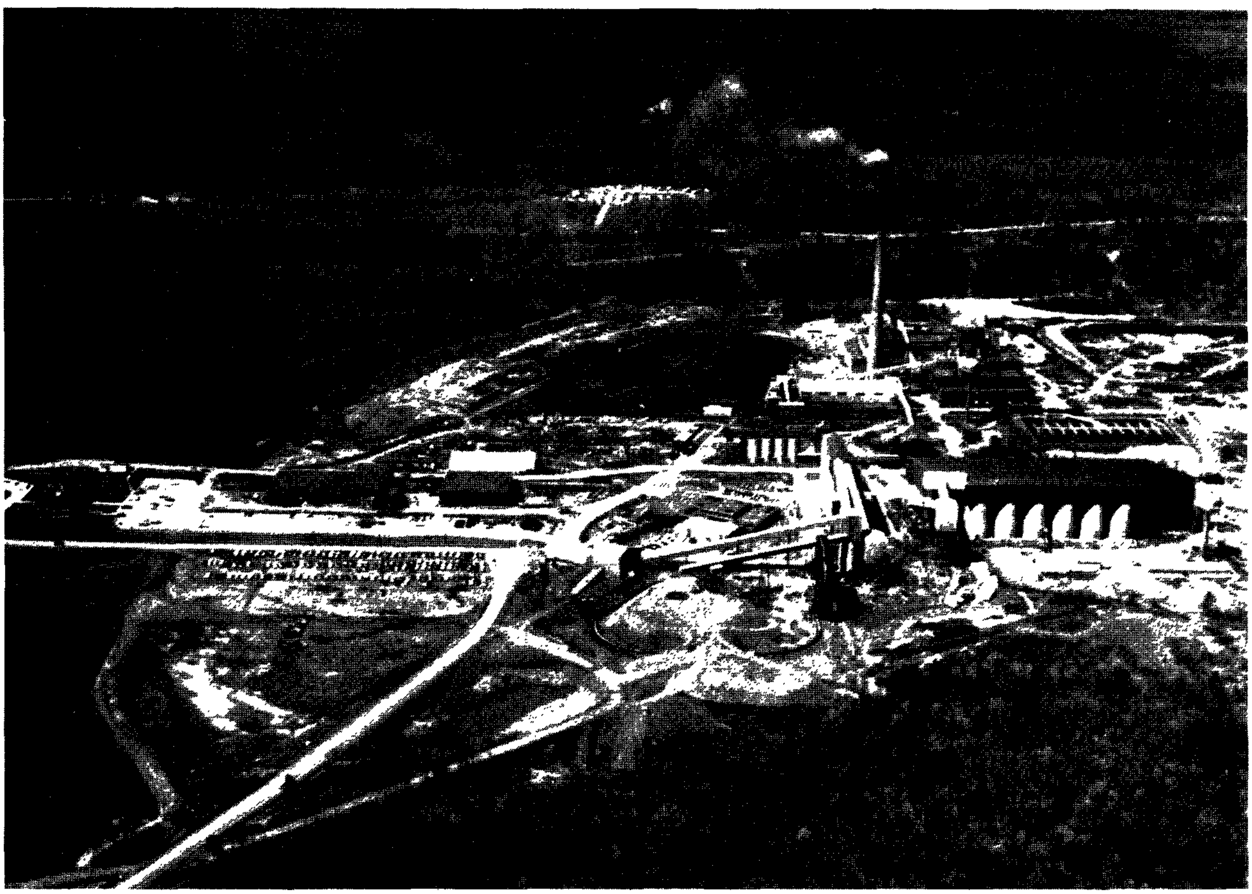

FIGURE 18. - Surface plant, White Pine copper mine, near White Pine, Mich.
(Courtesy, White Pine Copper Div., Copper Range Co.)

Bibliography

1. Ensign, C. O., Jr., W. S. White, J. C. Wright, J. L. Patrick, R. J. Leone, D. J. Hathaway, J. W. Trammell, J. J. Fritts, and T. L. Wright. Copper Deposits in the Nonesuch Shale, White Pine, Michigan. Ch. in Ore Deposits of the United States, 1933-1967, ed. by J. D. Ridge. American Institute of Mining, Metallurgical, and Petroleum Engineers, New York, v. 1, 1968, pp. 464-466.

2. Joralemon, I. B. Copper. Howell-North Books, Berkeley, Calif., 1973, pp. 344-347.

3. Rickard, T. A. The Copper of Lake Superior. Ch. 10 in A History of American Mining. McGraw-Hill Book Co., Inc., New York, 1932, pp. 222-248.

SUMMARY

Exceptional tenacity, persistence, and a willingness to undertake substantial financial risk characterize the temperament of those who search for economic mineral deposits. A study of case histories of successful mineral exploration ventures in the United States reveals that many of the most important discoveries were made in districts long known for their mineral potential. Continuing reassessment of favorable ground is necessitated by the acquisition of additional geologic data, changing economics, improved technology, and different exploration philosophies. Several discoveries in previously unproved ground are the result of astute geologic reasoning and the application of well-developed exploration techniques.

An economic mineral discovery is a tribute to the ingenuity, resourcefulness, perseverance, and, often in no small measure, the luck of the explorer. Whether the deposits are found in established districts or are pioneer discoveries in new areas, their recognition usually comes after many years of geologic investigation and application of improved exploration techniques. The mine exploration case histories recounted here are no exception. For San Manuel and Kalamazoo, the exploration efforts credited with discovery are only the culmination of prospecting efforts that nearly span the life of the district.

However, Newmont's Carlin gold mine in northern Nevada entered production in 1967, after only 6 years of exploration and development. The success of the exploration project and consequent mine development is due to a shift in exploration emphasis from vein deposits to low-grade, large-tonnage deposits similar to the southwest's copper porphyries, and a recognition in 1961 of new target areas for prospecting.

In the early 1960's, declining reserves in the New Jersey Zinc Co.'s east Tennessee mines prompted regional exploration to find another ore body. A favorable host rock in the Nashville dome, central Tennessee, was probed by randomly located drill holes beginning in 1964. Discovery of a zinc ore body was announced in 1969 and the Elmwood mine first produced in 1975, 11 years after field exploration began.

The discovery of the Flambeau copper ore body in northern Wisconsin by the Kennecott Copper Corp. in 1970 capped a 20-year search for rocks similar to those known to enclose massive sulfide deposits in Canada. News of Kennecott's find drew other mining companies to the area, and soon more discoveries, some larger than Flambeau, were made. Mine construction awaits resolution of a number of items, including improvement in the depressed copper market.

The Henderson molybdenum discovery in Colorado was the result of a determined effort, beginning in 1961, to prove additional reserves at Climax's fading Urad mine on Red Mountain. Success was achieved in 1963, when an extension of the last scheduled drill hole intercepted ore-grade material. The mine is still developing, and full production is anticipated in 1980.

The San Manuel, Kalamazoo, and Sacaton copper ore bodies were all discovered in a part of Arizona long noted for its copper mines. San Manuel, the oldest, required 13 years of exploration and development before production began in 1956. Kalamazoo, the faulted off upper portion of the San Manuel ore body, was discovered in 1967 after 2 years of renewed exploration and 19 years after San Manuel's discovery. Production is scheduled for 1978-80. The Sacaton mine entered production in 1974 after 13 years of exploration and development.

United States Borax & Chemical Corp. announced an important molybdenum discovery, Quartz Hill, in southeast Alaska in 1976. Deposit development continues.

St. Joe's Indian Creek deposit was the initial discovery (1948) in a new lead-zinc belt in Missouri, the Viburnum Trend. Similarly to the Elmwood mine, exploration was motivated by the company's declining reserves in Missouri's old southeast lead belt. The mine came on-stream in 1954, 11 years after exploration began.

The Pea Ridge iron deposit, also in Missouri, was detected during an airborne magnetic survey in 1950 after an earlier ground survey in 1930-32 failed to register an anomaly. The mine began production in 1965.

The occurrence of copper near White Pine, Mich., was known in prehistoric times. However, the disseminated nature of the ore in strata bound deposits thwarted serious development and production until 20th century technology and know-how made mining feasible. Although the deposit's modern day potential was recognized in 1929, experimental mining did not begin until 1945, and full-scale production did not begin until 1954.

U. S. GOVERNMENT PRINTING OFFICE : 1979 O - 287-091