The gangue minerals are largely pyrite and quartz containing small amounts of carbonate minerals and hematite.

Some oxidation of the vein occurred before the local deposition of conglomerate and volcanic rocks in the middle Tertiary. Ore above the 900 level has been enriched by supergene processes, but such enrichment generally is unimportant.

The bulk of the ore in the vein is in large shoots that plunge steeply westward; these are sporadically connected by irregular ore shoots that dip gently eastward. The chief controls favoring ore deposition were zones of permeable rocks adjacent to transverse faults. The "Main ore body" has been stoped continuously from near the surface to the 4900 level. To the east, the "Central ore bodies" are discontinuous ore shoots that plunge steeply westward parallel to the plunge of the "Main ore body." The "Central ore bodies" have been mined discontinuously from the 1600 level to the 4800 level. In contrast to the Old Dominion vein, diabase is a favorable host rock in the Magma vein (Hammer and Peterson, 1968).

Below the 2000 level in the Magma mine, replacement ore bodies occur in the Martin Limestone (Devonian). Chalcopyrite is the dominant ore mineral, with a little bornite, specular hematite, pyrite, quartz, barite, and calcite. The Martin Limestone has been recrystallized, and locally is vuggy and porous. The ore bodies in the Martin Limestone are large tabular masses that are elongated eastward and plunge about 30 degrees down the dip of the beds to below the 3600 level. Drilling has also revealed the occurrence of replacement deposits in the Escabrosa Limestone (Mississippian) (Hammer and Peterson, 1968).

Breccia Pipes

Breccia pipes are generally crudely circular to elliptical pipelike masses of broken rock fragments, which were derived in large part from the host rock, but, in some examples, partly from foreign rocks. Some pipes are tightly packed, whereas others have openings between fragments that are partly filled with quartz and sulfide minerals. Many breccia pipes in Arizona are spatially associated with Laramide stocks and it is assumed that the pipes are related to the igneous intrusion and the accompanying mineralization.

Mineralized breccia pipes are important economically at Cananea, in northern Sonora, and much interest has been shown in searching for similar pipes in Arizona. In the Copper Creek area (fig. 18, No. 11), the Childs-Aldwinkle pipe from 1933 to 1938, produced 70 million pounds of molybdenite, 3,000 tons of copper, 700 ounces of gold, and 27,000 ounces of silver. In this same area, the Copper Prince pipe produced 600 tons of copper between 1926 and 1939 (Kuhn, 1941).

A cluster of breccia pipes occur in Copper Basin west of Prescott (fig. 18, No. 6), in a complex of Precambrian metamorphic and granitic rocks, where Johnston and Lowell (1961) report that 25 mineralized pipes are associated with a Laramide stock. The Commercial, Copper Hill, and Loma Prieta mines have explored three pipes to depths ranging from 300 to 600 feet. Incomplete data to 1955 indicate that more than 150,000 tons of high-silica copper oxide ore was produced from the upper levels of the Commercial mine.

The mineralized breccia pipes are roughly cylindrical, and the central core is composed of heterogeneous, rotated, angular to rounded rock fragments surrounded by a zone of nonrotated "crackle breccia." The fragments are cemented by quartz, pyrite, chalcopyrite, and molybdenite (Johnston and Lowell, 1961). These mineralized breccia pipes are potential sources of copper and molybdenite.

Massive Sulfide Deposits

Lenses and pipelike masses of solid sulfide minerals are classified as massive sulfide deposits. In Arizona they are found largely in Mohave and Yavapai Counties in metamorphic rocks of Precambrian age. In general, the mineralogy is simple, consisting of pyrite, chalcopyrite, sphalerite, and galena in variable ratios. A small amount of quartz and carbonate minerals (calcite, dolomite, ankerite) occur between the sulfide grains.

The United Verde deposit at Jerome (fig. 18, No. 7) is pipelike in form and localized in a northwestward-plunging anticline of metamorphosed tuffaceous sedimentary rocks intruded by dikelike offshoots of quartz porphyry. Pyrite is the dominant mineral, and the hangingwall (northwest) part of the pipe is largely pyritic, locally containing appreciable sphalerite in thin layers or disseminated between pyrite. Chalcopyrite is the major copper mineral that forms the copper ore shoots, and in the pyritic pipe, chalcopyrite appears in veinlets of varying width cutting massive pyrite. The largest and highest-grade copper ore shoots are in the footwall (southeast) part of the pipe. These ore shoots plunge more steeply than the pyritic pipe and extend in depth into rocks enriched in chlorite, forming a rock that the miners called "black schist." The black schist ore consists of chalcopyrite and pyrite in branching and intersecting veinlets in the chloritic host. In a few places, some ore shoots extended in depth to weakly chloritized quartz porphyry, forming the smallest and lowest-grade ore shoots, which are made up of chalcopyrite veinlets cutting the quartz porphyry.

The United Verde Extension deposit is buried beneath Paleozoic and Tertiary rocks to the east of the Verde fault. This ore body is lenticular and trends eastward. The host rocks are rhyolitic flows and tuffs, a formation that is stratigraphically below the tuffaceous rocks exposed in the United Verde mine. Much of the ore in the United Verde Extension deposit was high-grade chalcocite formed by the supergene enrichment of the original pyrite-chalcopyrite massive sulfide; this enrichment occurred prior to the deposition of the Cambrian sandstone, proving the ore body is of Precambrian age. In lower levels, primary massive sulfide copper ore was mined, similar in mineralogy to the United Verde pyritic copper ore.

These two deposits at Jerome are largely mined out, but the Big Hole Mining Co., operating under a lease from Phelps Dodge Corp., is mining small ore shoots left in the south and western margins of the open pit at the United Verde mine.

Several small lenses of massive pyrite have been mined for copper in the Precambrian metamorphic rocks southeast of Prescott, but none are active at present. During World War II, enriched oxide ore was

mined from near-surface workings from three mines for direct shipment to smelters.

South of the Bagdad mine in western Yavapai County, three massive sulfide deposits have produced copper in the past. These deposits contain appreciable sphalerite, and smaller amounts of chalcopyrite, galena, and pyrite. Two mines, Old Dick and Copper Queen (fig. 18, No. 4), have been operated by Cyprus Mines. The Copper Queen deposit is mined out, but underground development at the Old Dick mine is in progress to exploit in depth a newly found lens of massive sulfide ore. Future production of copper from this mine is expected (Baker and Clayton, 1968).

The Antler mine in Mohave County (fig. 18, No. 2) is a massive sulfide deposit in Precambrian metamorphic rocks. Sphalerite, chalcopyrite, and galena are the chief ore minerals, associated with pyrrhotite and rare bornite. Early production was largely oxidized ore, averaging 5 to 12 percent copper. During and following World War II, the Arizona Antler Mining Co. produced more than 6,000 tons of primary massive sulfide ore, averaging 8.38 percent zinc, 2.43 percent copper, 0.69 percent lead and 0.95 ounces of silver and 0.009 ounces of gold per ton (Romslo, 1948); and between 1948 and 1953, the Yucca Mining and Milling Co. produced about 60,000 tons of ore, and from October 1950 to April 1953, milled about 35,000 tons with an average grade of 2.54 percent copper and 6.52 percent zinc. The Standard Metals Corp. now owns the mine. Following surface diamond drilling in 1966, the inclined shaft has been enlarged and deepened, and development work is in progress on the lowest level. If sufficient ore reserves are blocked out by this program, Standard Metals will construct a modern 250-ton-per-day flotation mill (A. R. Still, written commun., 1968).

Disseminated Deposits in Sandstone

Disseminated copper minerals are found in some sandstones in the northern part of Arizona in the Colorado Plateaus province. The boundary of this province in figure 18 is drawn differently from the map in the chapter on "Geology," (see fig. 4) to emphasize the area composed largely of sedimentary rocks. Two copper deposits in the Colorado Plateaus province are of sufficient importance to describe briefly.

At Jacobs Lake (fig. 18, No. 28) copper carbonate minerals (malachite and azurite) are the dominant minerals associated with some chalcopyrite and chalcocite. The copper minerals occur in cherty and limy sandstone that forms interbeds in the Kaibab Limestone (Permian). The deposits were discovered in the early part of this century and several unsuccessful attempts were made to process the ore. During World War II more than 14,000 tons of ore, ranging from 5 to 7 percent copper, were shipped from two properties to smelters. The U.S. Bureau of Mines drilled 152 holes in 1944 on two groups of claims; their assay returns reveal erratic distribution of the copper (Tainter, 1947).

In the White Mesa district (fig. 18, No. 29), malachite and copper silicate occur in the matrix of the Navajo Sandstone (Jurassic and Late Triassic(?)). Some black copper oxide is present along the walls of fissures, forming halos around disseminated chalcocite and bornite.

The mineralized sandstone is friable but as the copper content increases, the firmer the bond. The copper minerals, in general, are spaced along the stratification planes of the sandstone, but locally cut across these planes. Fracture intersections are favorable loci for copper concentration.

Two metallurgical processes, leaching and dry concentration, have been used at White Mesa in attempts to process the ores. The leaching tests recovered more than 90 percent of the copper, whereas the dry concentration tests recovered only 66 to 72 percent of the copper. The shortage of water poses a problem for the leaching process. Mayo (1955) has suggested that there are 2 million tons of copper-bearing material at White Mesa with a probable grade of 0.75 percent copper.

Reserves and Potential Resources

The term "reserves" designates the material that can be quantitatively estimated and is considered to be economically exploitable at the time of the estimate. The term "ore reserves" is applied to deposits being mined or known to be of such size and grade that they may be mined profitably. Several factors must be considered in the determination of ore reserves, including the price of the metal, amount of metal in the ore, and the cost of mining and beneficiation. As was pointed out in the history of the Miami mine, lowering of mining and milling costs by improved technology made it possible to convert large tonnages of low-grade copper-bearing rock to ore. Thus, the reserves at any given time depend on the ratio between the selling price and the cost of producing a particular metal or metals.

Many mining companies do not publish reserve figures for individual mines, and it is impossible to forecast accurately the ratio between metal prices and costs of production, so it is difficult to give a meaningful figure on copper reserves in Arizona in 1968.

Nevertheless, by conservative estimate, Arizona's copper resources probably total about 60 million tons. Of this amount, about 30 million tons are reserves and about 30 million tons are undiscovered, or potential, resources. The reserves are based on an analysis of the producing mines and on the expectation that the ratio of the price of copper to the cost of production will continue to permit a profit. The potential resources are predicted on the basis of a discovery rate that is expected to continue about as it has in the past and on expected technologic developments that will permit continued favorable cost-price ratios. At the 1968 production rate of about 700,000 tons of copper per year, the reserves should maintain an adequate supply for the next 40 years and the predicted resources should be adequate to sustain operations for an additional 35–40 years.

Several factors, however, indicate that there will be an increase in annual production of copper in Arizona. For example, Kennecott Copper Corp. explored a disseminated deposit near Safford (fig. 18, No. 26) that comprises about 2 billion tons of mineralized rock containing an average of 0.41 percent copper. This mineralized rock contains oxide copper, sulfide, and mixed oxide-sulfide minerals. Studies are under way by the Atomic Energy Commission, U.S. Bureau of Mines, and Lawrence Radiation Laboratory for a joint program, costing $13 million, to set off a deep underground nuclear blast

to be followed by an experiment in solution mining. If this program is successful in terms of a favorable cost ratio, a large mass of mineralized rock will become an "ore reserve" and eventually will add to the production of copper (Eng. Mining Jour., no. 11, 1967).

The General Services Administration is making agreements to purchase future deliveries of copper for the national stockpile at a fixed price and to advance funds to help develop newly discovered disseminated copper deposits in Arizona. Moreover, many companies have exploration geologists and geophysicists headquartered in Arizona who are making intensive efforts to discover new deposits, particularly of the copper porphyry type.

All of Arizona is a potential area for the discovery of new copper deposits, but the greatest potential is in the Basin and Range province. The largest concentration of known copper deposits is in the southeastern part of the Basin and Range province where there is a concentration of intrusive igneous rocks of Late Cretaceous to early Tertiary age (fig. 18). The evidence is compelling that a relationship exists between many of the copper deposits and these intrusive rocks. Known copper deposits also exist in the southwestern and northwestern parts of the Basin and Range province, where there are many outcrops and expected hidden bodies of Upper Cretaceous and lower Tertiary intrusive rocks. Some of the future exploration in this area will be costly because of a widespread cover of younger rocks over the favorable potential copper-bearing rocks. A variety of skills will be needed to find the deposits—geologic mapping, geochemical prospecting, and various geophysical techniques.

Some additional disseminated deposits in sandstone may be found within the Colorado Plateaus province in the Kaibab and Navajo Formations. Such deposits will only constitute a small part of Arizona's copper resources, but may make a significant contribution to the local economy.

The fact that Arizona is the leading producer of copper in the United States is a tribute to the mining industry. It has invested large sums of money to search for, develop, mine, and treat large volumes of mineralized rock that contains an average of only 14 to 15 pounds of copper per ton. In some deposits costly removal of thick overburden is necessary to expose the copper-bearing rocks for mining. In other deposits, the copper-bearing rocks are so deep that costly underground development on a large scale is required for economic block caving. The willingness of the mining industry to invest large sums of money and the industry's high order of technical competence has converted large bodies of low-grade mineralized rock to ore. Because of such willingness and competence, the future of Arizona's copper industry appears bright.

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GOLD

(By Richard T. Moore, Arizona Bureau of Mines, Tucson, Ariz.)

Properties, Use, and Market Conditions

Gold, which is well known to most modern civilized peoples because of the monetary importance it enjoys, has been sought for and prized by man for many centuries. Artifacts unearthed in Egypt and other parts of the eastern Mediterranean region show that the yellow metal was in use at least as long ago as 4,000 B.C. (Rickard, 1932, p. 177–179).

Chemically, gold is rather inert. It does not readily combine with any of the more common solvents or reagents occurring in nature, so is frequently found as a native element. The specific gravity of pure gold is 19.3, but the presence of impurities, principally copper and silver, which are commonly alloyed with the naturally occurring

metal, usually lowers it to a range between 15 and 19. Because of its high specific gravity, the native metal concentrates readily in placers and such deposits probably were the source for the gold used by ancient man. The early development of uses for gold in the fashioning of jewelry and simple tools and fastening devices can be directly attributed to its softness, ductility, and malleability, which permitted it to be worked easily by beating and rolling it into desired shapes.

Gold has been used as a medium of exchange since earliest civilizations and the greatest use of gold in modern society is still for monetary purposes. After centuries of use in coinage for transactions between individuals, growth in worldwide commerce and population have placed very heavy demands on the available supply of gold. At present most gold is used to back other forms of money and to satisfy international balances of payments.

Unlike all other commodities, because of its monetary use the price of gold was fixed at $35 per troy ounce from 1934 to early 1968. This price is still maintained for settlement of balance of trade transactions, but the price of gold for industrial and other nonmonetary uses fluctuates in response to demand.

During the past 30 years several industrial uses for gold have been developed. It is used in electronic equipment for transmission and switching components where extreme reliability and resistance to corrosion are required, as coatings on aircraft engine shrouds and earth satellites to provide protection against heat and corrosion, and it is now being used to coat metals and ceramics for architectural applications. Appreciable quantities also are still used for goldleaf, jewelry, laboratory utensils, and for specialized items of glassware and ceramic ware (Ryan, 1965, p. 390). In 1966, our industrial consumption was nearly 6.1 million ounces (U.S. Bur. Mines, 1967).

The problems created by the growing shortage of monetary gold in the United States have been further complicated by these increasing industrial demands, a demand which apparently cannot be met by domestic production. In most mines in this country where gold was the principal metal produced, the costs of mining and treatment have risen above the level where the present (1968) price of gold will permit the profitable extraction of the metal.

The seriousness of these problems has prompted the Federal Government to initiate several programs designed to help alleviate them. In April 1966, the Heavy Metals program was started as a joint project of the U.S. Geological Survey and U.S. Bureau of Mines to stimulate domestic production of a group of metals in short supply; during the first 18 months of the program about 90 percent of the project effort was expended on gold. In addition to the Heavy Metals program, assistance is available to industry in the form of loans for gold exploration projects, through the Office of Minerals Exploration. In March 1968, the Treasury Department, in an additional step to alleviate the situation, announced that, under agreements made with other interested nations, it would no longer buy or sell gold in the private market.

Under these agreements the $35 per ounce price for governmental gold stocks would be retained, but the Treasury would no longer supply gold to the speculative markets. The effect these actions will have on the domestic gold mining industry is not predictable.

Production and History

In 1966, domestic mine production was slightly more than 1.8 million ounces, or only about 10 percent of our industrial consumption plus net exports. Of that production, 58 percent came from dry and siliceous ores, 37 percent from base-metal ores, and 5 percent from placer deposits. Listed in the order of importance, just four states, South Dakota, Utah, Nevada, and Arizona, produced a total of more than 1.5 million ounces of gold in 1966, or about 86 percent of the total domestic production for that year (U.S. Bur. Mines, 1967, p. 236).

Since 1945, Arizona has ranked seventh or higher among the states in yearly production of gold, and since 1960 it has annually ranked either third or fourth. In 1966, of the 25 leading gold-producing mines in the United States, 7 were in Arizona and for the period 1858–1967, the State's total recorded production of gold is more than 13.7 million ounces valued at almost $365.5 million (Elsing and Heineman, 1936; U.S. Bur. Mines, 1935–67; Larson and Henkes, 1968). Over 95 percent of the gold produced in Arizona since 1950 has been derived as a by-product of base-metal mining, with copper mining accounting for about 80 percent and lead-zinc mining about 15 percent. Siliceous and dry ores and placer production have not contributed more than 5 percent to Arizona's gold production since 1950. This is in marked contrast with the period before 1933 when the siliceous and dry ores and placer deposits accounted for at least 50 percent of the production.

The search for gold has played an important part in the development of Arizona. The history of the early period of Arizona's gold mining industry has been well summarized by Wilson (1961), Wilson and others (1934), and Heineman (1938), from which the following sketch has been largely abstracted.

The Spanish explorers, although more frequently identified with the mining of silver, were, nonetheless, continually on the watch for gold, and it is reported that a Castilian priest, Padre Lopez, had by 1774, extensively worked the placer deposits in the Quijotoa district (fig. 21, No. 17). It was not until after the Gadsden Purchase, in 1853, that Americans began entering the area to prospect, but within 10 years a large number of prospectors had arrived and several placer deposits had been discovered. The Chemehuevis district (fig. 21, No. 13), near the confluence of Sacramento Wash with the Colorado River, was found in 1857; the Gila City or Dome placers (fig. 21, No. 50), near Yuma, were discovered in 1858; Capt. Pauline Weaver opened the La Paz diggings (fig. 21, No. 43) in 1862; and several small but rich gold placer deposits, such as those in the Lynx Creek (fig. 21, No. 27) and Big Bug (No. 28) districts in the Bradshaw Mountains, near Prescott, were being exploited in 1863. The districts containing these and other placer deposits in Arizona are listed below in table 13.

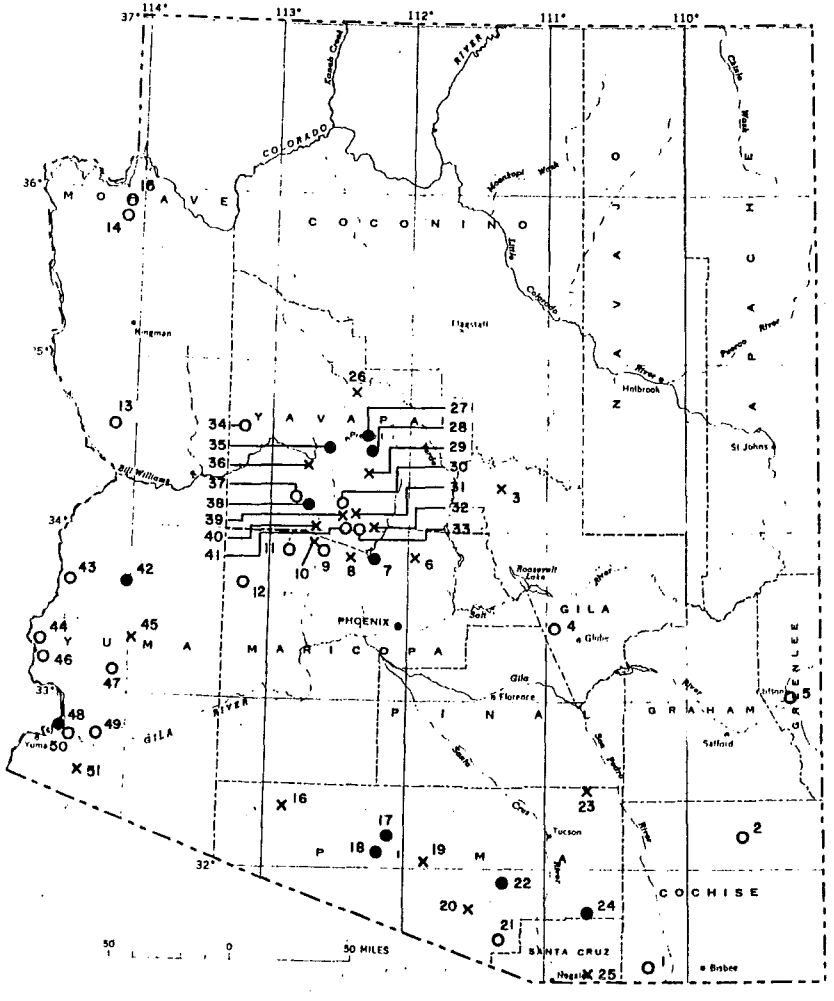
While the placer deposits were being developed, many lode deposits also were found in adjacent areas, and between 1853 and 1863 several mines were opened in what are now Maricopa, Mohave, Yavapai, and Yuma Counties. Lode deposits in the Castle Dome district (fig. 22, No. 95), near Yuma, and the Moss deposit in the Oatman district (fig. 22, No. 34), Mohave County, were discovered in about 1860, and the famous Vulture deposit in the Vulture district (fig. 22, No. 24), near Wickenburg, Maricopa County, was found in 1863. Numerous lode deposits were also found in the Prescott region, and in 1863 Prescott was named the Capitol of the newly established Arizona Territory, largely on the strength of the mining developments in the vicinity. The districts containing the lode gold deposits in Arizona are listed below in table 14.

By 1875, most of the placer deposits known in Arizona today had been discovered, and by 1885 the bulk of the placer gold production recorded for the State had been made. In the lode deposits most of the free-milling gold was found to be superficial and, with few exceptions, the deposits were shortly abandoned and mining interests turned to silver and the base metals.

A few large, rich gold deposits were still being found, however, and in 1887, the Congress deposit in the Martinez district (fig. 22, No. 84), Yavapai County, was discovered, and in 1888, development work on the Harquahala gold deposit in the Ellsworth district (fig. 22, No. 91), Yuma County, was started. The demonetization of silver in 1893 was followed by a sharp business recession, and many prospectors regained their interest in gold. The development of the cyanide process for the recovery of gold, in 1887, contributed greatly to the reestablishment of the gold mining industry because this made it possible to reopen many of the lode deposits in which the free-milling gold had been exhausted, but in which gold remained in base-metal sulfides or in very finely divided form.

During the next few years the gold industry in Arizona thrived, and several large deposits were opened. In Yuma County, the Fortuna deposit (fig. 22, No. 97) was discovered in 1895 and the King of Arizona mine in the Kofa district (No. 94) was opened in 1896. Between 1900 and 1917 several large gold lodes were discovered in the Oatman-Katherine district (fig. 22, No. 34), Mohave County, including the Gold Road in 1903, the Tom Reed in 1908, the United Eastern in 1915, and the Big Jim in 1916. During its years of peak production, 1917–23, this district produced gold valued at between $2.3 million and $2.8 million per year, (Wilson and others, 1934, facing p. 80), and its total production has exceeded 2.04 million ounces valued at about $46.9 million (Elsing and Heineman, 1936; U.S. Bur. Mines, 1935–67).

After several years of moderately high gold production (see fig. 23), the metals market began to collapse, and gold production dropped from a high of nearly 300,000 ounces in 1923 to a low of about 65,000 ounces in 1932. With the revaluation of the dollar in 1934, when the price of gold was raised from $20.67 to $35 per troy ounce, production again soared, and until 1941, averaged about 300,000 ounces per year. Because of a wartime labor shortage in 1942, Government Order L-



EXPLANATION

●7 Production more than 1,000 troy ounces

○4 Production 100 - 1,000 troy ounces

×6 Production less than 100 troy ounces

(Numbers refer to districts listed in table 13 and mentioned in text)

FIGURE 21.—Placer gold in Arizona.

TABLE 13.—*County listing of placer gold districts*

[Locations are shown in fig. 21]

Locality No. in fig. 21	*County and District*
	Cochise:
1.	Hartford
2.	Dos Cabezas-Teviston
	Gila:
3.	Green Valley
4.	Globe-Miami
	Greenlee:
5.	Chase Creek-San Francisco River
	Maricopa:
6.	Cave Creek
7.	Agua Fria
8.	Pikes Peak
9.	San Domingo
10.	Hassayampa River
11.	Vulture
12.	Big Horn
	Mohave:
13.	Chemehuevis
14.	Gold Basin
15.	Lost Basin
	Pima:
16.	Ajo
17.	Quijotoa
18.	Horseshoe Basin
19.	Cobabi
20.	Baboquivari
21.	Arivaca
22.	Papago
23.	Old Hat
24.	Greaterville
	Santa Cruz:
25.	Patagonia
	Yavapai:
26.	Granite Creek
27.	Lynx Creek
28.	Big Bug
29.	Peck
30.	Walnut Grove
31.	Silver Mountain
32.	Tip Top
33.	Humbug
34.	Eureka
35.	Copper Basin
36.	Kirkland
37.	Martinez
38.	Weaver
39.	Black Rock
40.	Blue Tank
41.	Castle Creek
	Yuma:
42.	Plomosa
43.	La Paz
44.	Trigo Mountain
45.	Kofa
46.	Colorado River
47.	Castle Dome
48.	Laguna
49.	Muggins Mountain
50.	Dome
51.	Fortuna

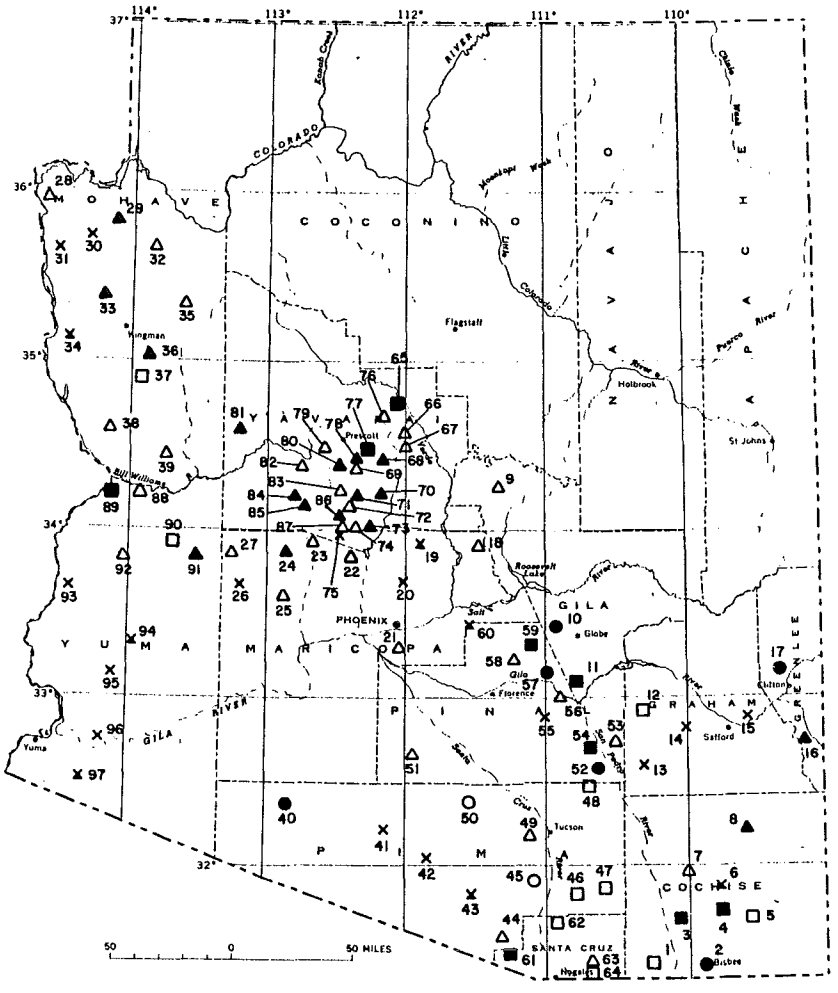
208 closed essentially all of the gold mines in Arizona; since then gold production has been primarily a byproduct of base-metal mining.

TYPES OF DEPOSITS

The lode deposits in Arizona can be grouped into four main categories: (1) hydrothermal gold-quartz veins, (2) siliceous fissure veins containing gold-bearing base-metal sulfides, (3) massive sulfide replacement deposits carrying gold as an accessory, and (4) gold-bearing disseminated copper deposits. Nearly all of the known deposits in categories 1 and 2 in Arizona have been described in detail by Wilson (Wilson and others, 1934) from which the following summaries largely have been compiled.

GOLD-QUARTZ VEINS

In several districts notable quantities of gold have been produced from quartz veins in which gold, along with some silver, is the most valuable constituent. These veins are of the epithermal type, as defined by Lindgren (1933, p. 444), and in Arizona are best developed in Ter-



EXPLANATION

Types of deposits and total production in troy ounces

More than 10,000	Less than 10,000
●40	○50
Disseminated copper	
■4	□5
Base-metal sulfide replacement	
▲71	△9
Siliceous base-metal vein	
✕19	×14
Gold-quartz vein	

(Numbers refer to districts listed in table 14 and mentioned in text)

FIGURE 22.—Lode gold in Arizona.

TABLE 14.—*County listing of lode gold districts*

[Locations are shown in fig. 22]

Locality No. in fig. 22	*County and District*
	Cochise:
1.	Huachuca
2.	Warren
3.	Tombstone
4.	Turquoise
5.	Swisshelm
6.	Pearce
7.	Dragoon
8.	Dos Cabezas
	Gila:
9.	Green Valley (Payson)
10.	Globe-Miami
11.	Banner-Dripping Spring
	Graham:
12.	Aravaipa
13.	Rattlesnake
14.	Clark
15.	Lone Star
	Greenlee:
16.	Ash Peak
17.	Morenci-Metcalf
	Maricopa:
18.	Sunflower
19.	Cave Creek-Magazine
20.	Winifred
21.	Salt River Mountain
22.	Pikes Peak
23.	Wickenburg
24.	Vulture
25.	Osborn
26.	Big Horn
27.	Ellsworth
	Mohave:
28.	Minnesota
29.	Gold Basin
30.	White Hills
31.	Weaver
32.	Music Mountain
33.	Wallapai
34.	Oatman-Katherine
35.	Cottonwood
36.	Maynard-McConnico
37.	Cedar Valley
38.	Chemehuevis
39.	Owens
	Pima:
40.	Ajo
41.	Quijotoa
42.	Cobabi
43.	Baboquivari
44.	Arivaca
45.	Pima
46.	Helvetia
47.	Empire
48.	Control
49.	Amole
50.	Silver Bell
	Pinal:
51.	Casa Grande
52.	San Manuel
53.	Bunker Hill
54.	Mammoth
55.	Cottonwood
56.	Ripsey
57.	Mineral Creek (Ray)
58.	Mineral Hill
59.	Pioneer (Superior)
60.	Goldfield
	Santa Cruz:
61.	Oro Blanco
62.	Tyndall
63.	Harshaw
64.	Patagonia
	Yavapai:
65.	Verde
66.	Cherry Creek
67.	Ash Creek
68.	Agua Fria
69.	Turkey Creek
70.	Black Canyon
71.	Pine Grove-Tiger
72.	Silver Mountain
73.	Tip Top
74.	Humbug
75.	White Picacho
76.	Black Hills
77.	Big Bug
78.	Walker
79.	Copper Basin
80.	Hassayampa
81.	Eureka
82.	Kirkland
83.	Walnut Grove
84.	Martinez
85.	Weaver
86.	Black Rock
87.	Castle Creek
	Yuma:
88.	Planet
89.	Cienega
90.	Harcuvar
91.	Ellsworth
92.	Plomosa
93.	La Paz
94.	Kofa
95.	Castle Dome
96.	Muggins Mountain
97.	Fortuna

tiary volcanic rocks. They generally occur as irregularly shaped, tabular or lenticular masses, and consist of finely crystalline, greenish-yellow quartz, displaying marked banding or crustiform layering.

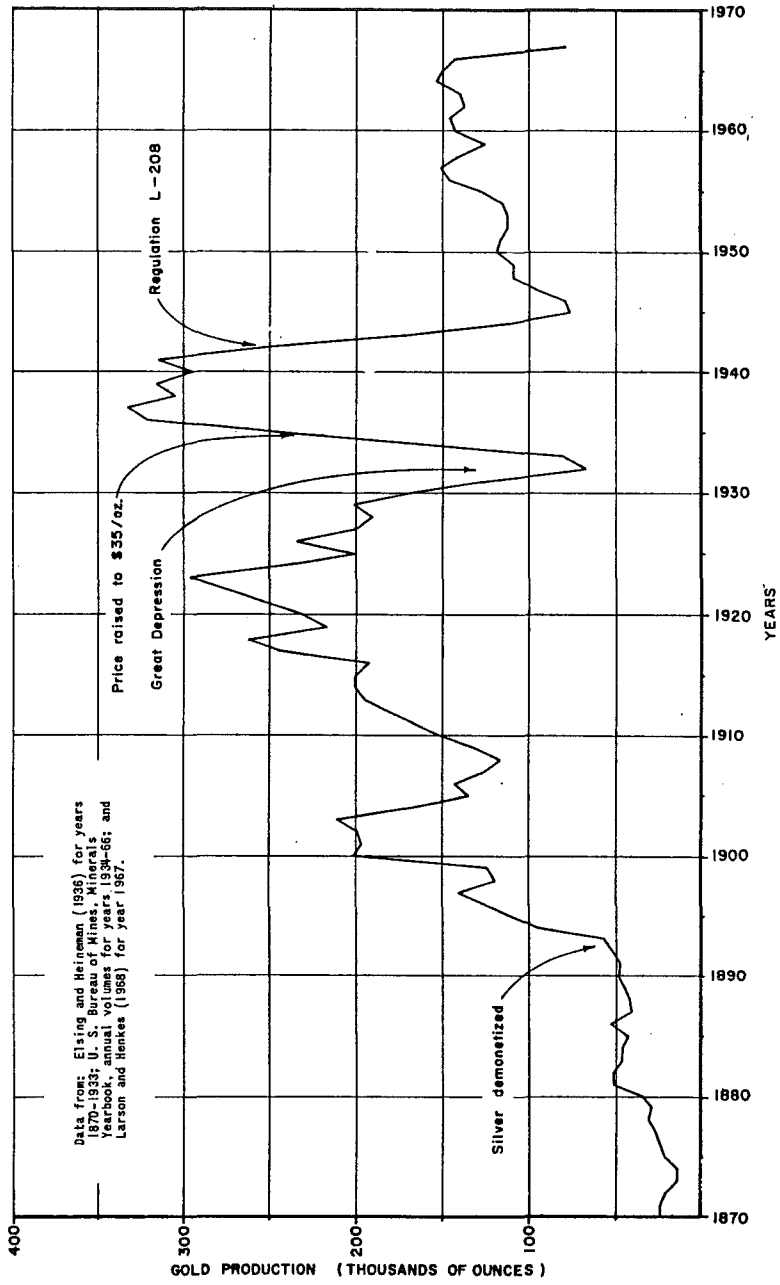


FIGURE 23.—Arizona gold production, 1870–1967.

Calcite and microscopic adularia commonly accompany the quartz, and the gold occurs as finely divided, pale yellow particles, alloyed with silver. Wall rock alteration is common, and chlorite, various carbonate minerals, quartz, and fine-grained sericite are developed in zones ranging from a fraction of an inch to several inches thick in the walls of veins.

The best known and most productive deposits of this type in Arizona are found in the Oatman-Katherine district (fig. 22, No. 34). Other districts containing epithermal gold-quartz veins include the Kofa district (No. 94), Yuma County, the Winifred (No. 20), and Big Horn (No. 26) districts in Maricopa County, and the Cobabi (No. 42) and Baboquivari (No. 43) districts in Pima County.

SILICEOUS BASE-METAL VEINS

Siliceous base-metal vein deposits are classified as mesothermal veins, as defined by Lindgren (1933, p. 529) and the characteristics of the Arizona deposits have been summarized by Wilson (Wilson and others, 1934, p. 22) as follows:

> In general, these veins, though locally lenticular, are persistent, straight, and narrow, with definite walls. Their gangue is massive to drusy milky-white quartz, with or without ankeritic carbonates. Their ore shoots, below the zone of oxidation, contain abundant sulphides, principally pyrite, galena, sphalerite, chalcopyrite, arsenopyrite, and tetrahedrite. Most of them are silver bearing, and may contain more silver than gold by weight. In the primary zone, some of their gold is free, but most of it occurs as sub-microscopic intergrowths with the sulphides, particularly the finer-grained galena, chalcopyrite, and pyrite. Their oxidized zone was rich in free gold but generally shallow. They have yielded placers only where their primary zone carried considerable free gold. The vein wall rocks generally show sericitization and carbonatization. High-temperature minerals are absent.

Important veins of this type are found in the Humbug (fig. 22, No. 74), Pine Grove-Tiger (No. 71), Walker (No. 78), Weaver (No. 85), and Martinez (No. 84) districts, Yavapai County.

BASE-METAL SULFIDE REPLACEMENT DEPOSITS

Since 1955 between 10 and 20 percent of the gold produced in Arizona has been derived from base-metal sulfide replacement deposits, principally lead and zinc producers, such as in the Big Bug (fig. 22, No. 77) and Verde (No. 65) districts in Yavapai County, and the Tombstone (No. 3) and Turquoise (No. 4) districts in Cochise County. The gold content of ore bodies of this group ranges widely but averages between 0.01 and 0.3 ounce per ton of ore. In 1966 nearly 14,000 ounces was recovered from the treatment of a little more than 322,000 tons of ore from about 13 lead and zinc producing mines (Larson and Henkes, 1967, p. 95, table 8).

The gold-bearing base-metal sulfide replacement deposits generally contain galena, sphalerite, chalcopyrite, and pyrite in varying proportions, and the gold is usually contained in one or more of these sulfide minerals. The sulfide replacement masses occur as irregular lenticular or tabular bodies in favorable limestone masses, as pipelike bodies along the intersections of favorable structures, and as ore shoots in vein-filling material. The following brief geologic descriptions are representative of the replacement type deposit.

In the Tombstone district (fig. 22, No. 3), gold is associated with argentiferous galena, sphalerite, and chalcopyrite. Sulfide replacement bodies occur along northeast-trending fissures in Paleozoic and Mesozoic limestone and in dikes of Laramide age. Anticlinal rolls in favorable host rocks act as local traps for the mineralizing solutions. The gold values vary greatly from one part of the district to another. In some areas values as high as 5 ounces per ton have been found and in others the gold content is as low as 0.3 ounce per ton (Butler and others, 1938).

In the Turquoise district (No. 4), oxidized lead-silver and zinc ore bodies, and some sulfide bodies occur as replacements in impure Carboniferous limestone along steeply dipping faults and beneath low-angle faults, particularly where intersected by northeasterly trending fissures. Gold commonly accompanies the lead-silver minerals and ranges from 0.03 to 0.2 ounce per ton (Wilson, 1951).

The lead-zinc deposits in the Mammoth (No. 54) and Oro Blanco (No. 61) districts are examples of gold-bearing base-metal sulfide deposits occurring as fissure-filling and wall-rock replacements in shear zones. In the Montana mine in the Oro Blanco district (Fowler, 1951), galena and sphalerite form massive sulfide ore shoots in the Montana shear zone, and form replacement masses in conglomerate in the hanging wall of the shear. The Mammoth-St. Anthony deposit, Mammoth district, is more complicated in that it involved at least two stages of gold mineralization (Creasey, 1950). The first stage involved the deposition of gold-quartz fissure veins, similar to the epithermal vein type described above, and in the second stage the gold was deposited in association with galena in massive vein and wall rock replacement bodies.

DISSEMINATED COPPER DEPOSITS

The major gold-producing mines in Arizona are the large disseminated copper deposits, such as those at Ajo, Bisbee, San Manuel, and Morenci. Since 1953, over 80 percent of the State's production has come from the treatment of copper ores and, in 1966, 89 percent was recovered as a byproduct of copper refining (Larson and Henkes, 1967, p. 9). The average gold content of the disseminated copper ores is between 0.001 and 0.002 ounce per ton, but because of the large tonnage of ore handled annually—over 101.5 million tons in 1966—large quantities of gold are recovered from them.

Descriptions of the disseminated copper deposits are given in "Copper" (p. 139).

PLACER DEPOSITS

As mentioned above, the first gold produced in Arizona came from placer deposits. These deposits are located generally in the southwestern half of the State (fig. 21), and a detailed account of them has been given by Wilson (1961).

Although some placer gold can be derived from almost any lode gold deposit, the more productive placers in Arizona, and those in which the larger nuggets have been found, were derived mainly from the oxidized parts of the deeper-seated, mesothermal vein deposits

(Wilson 1961, p. 14). This association is apparent when the distribution of placer and lode deposits, as shown in figures 21 and 22, is compared. The main concentration of placer deposits, including five of the eleven that have a recorded production exceeding 1,000 ounces, are located in the Bradshaw Mountain area, Yavapai County, in close proximity to the major concentration of mesothermal vein deposits.

Summary and Conclusions

During the past several years Arizona has produced between 130,000 and 150,000 ounces of gold per year, the greater percentage of which was a byproduct of copper mining. As long as the State's copper production remains at its current level, as seems most likely, gold production should continue at least at present levels.

Some chance for an expansion in the gold-mining industry in Arizona, though, is possible in light of two recent developments. First, under the Heavy Metals program, the U.S. Geological Survey has examined placer deposits in the Gold Basin (fig. 21, No. 14) and Lost Basin (No. 15) districts, Mohave County, and preliminary tests indicate resources that may exceed 500 million cubic yards of gravel containing 0.01–0.02 ounce of gold per cubic yard (U.S. Geol. Survey, 1968, p. 6). Second, with the freeing of the gold price effected by the Treasury Department's action of March 17, 1968, some increases in the price of gold have occurred which may make it feasible for some gold mines to reopen.

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IRON

(By Harry Klemic, U.S. Geological Survey, Washington, D.C.)

Introduction

Iron ore is one of the basic raw materials utilized in our industrial civilization. The per capita consumption of iron in all great industrial nations is greater than that of all other metals combined. Although more than 99 percent of all iron ore mined is used for making iron and steel products, other uses for iron ore such as in cement, concrete aggregates, paint pigment, heavy media, metallurgical fluxes, and sponge iron as a precipitant of copper are of local importance. In addition, titanium, copper, sulfur, phosphorus, gold, and silver are obtained as byproducts or coproducts of iron from some ores.

The United States is the world's largest steel producing nation; it produced an estimated 126.5 million short tons of steel in 1967, with the industry operating considerably below capacity. About 127 million long tons of iron ore and 91.6 million short tons of scrap metal were consumed in achieving this production. Iron ore production in 1967 was 83 million long tons and 45.8 million tons were imported. Stocks at mines, plants, and docks at the end of 1966 were 71 million long tons (U.S. Bur. Mines, 1968, p. 72–77). About 6.5 million long tons of ore were exported in 1967. In contrast, production in the Soviet Union, the second largest steel producer, was 102.2 million short tons of steel (Izvestia, 1968) made from domestic iron ore and scrap metal, and that of Japan, the third largest steel producer, was 66 million tons of steel, mostly from imported ores, and from scrap metal (U.S. Bur. Mines, 1968, p. 72–77).

In 1966, more than 4,500 long tons of magnetite and hematite ore having an iron content totaling more than 2,400 long tons, were produced in Arizona. Sponge iron produced from converter slag and pyrite was more than 17,000 long tons having an iron content of more than 9,000 long tons (S. B. Keith, written commun., 1968).

Iron ore resources are widely distributed in the United States (Carr and Dutton, 1968, p. 61–134; Carr and others, 1967), but about 75 percent of the known and potential resources are in the Lake Superior region, which in recent years, has supplied about the same percentage of total domestic production of iron ore. Most of the remainder was produced in New York, Pennsylvania, Alabama, Missouri, Texas, Wyoming, Utah, and California (U.S. Bur. Mines, 1967, p. 245–273). Arizona is estimated to contain less than one percent of the Nation's iron ore resources, and total iron ore production from the State has been small (Harrer, 1964).

Iron is one of the most abundant metallic elements in the earth's crust. It is rarely found in its metallic form in nature, because of its affinity for combining with sulfur, oxygen, and other elements under the conditions that prevail at and near the surface of the earth. A great variety of iron-bearing minerals are common constituents of rock, but only a few are important sources of iron.

The iron oxides, magnetite and hematite, which contain about 72 and 70 percent iron, respectively, and the hydrous iron oxide, goethite, which contains about 62 percent iron, are the principal iron-ore minerals. They occur in large deposits, in some of which one or more of

these minerals are the major constituents of the ore. The iron carbonate mineral siderite contains 48 percent iron and the iron sulfides, pyrite and marcasite, each contain 46 percent iron. Iron silicates generally contain lesser percentages of iron. Jarosite, a hydrous sulfate of iron and potassium, contains about 35 percent iron.

Magnetite is a hard black mineral that is readily attracted to a magnet, hence its name. Titaniferous magnetite generally contains inclusions of the black titanium-iron mineral ilmenite. Hematite has a variety of physical forms. It occurs as an alteration product of magnetite, called martite, that outwardly resembles magnetite, but is much less magnetic and is softer than magnetite. Specular hematite is a silvery gray splendant mineral. Hematite most commonly occurs in red or reddish brown hard masses and in earthy or pulverulent forms. When crushed or scratched it yields a red powder. Some hematite is a natural pigment. Limonite is a brown iron-bearing material of which goethite is a common mineral species. Limonite or goethite occur in soft earthy and hard massive or nodular forms. Jarosite is another brown or yellowish brown ocherous iron mineral that occurs in fine earthy or hard nodular forms. Siderite occurs in gray to brown crystalline and massive forms and is commonly found as concretionary nodules. Pyrite and marcasite are common iron minerals that occur in brass-yellow crystalline forms. Most of the iron-rich silicates occur as fine-grained micaceous rock-forming minerals.

Many geologic processes relating to sedimentation, magmatic activity, metamorphism, and weathering result in the formation and concentration of iron ore minerals in a great variety of types of ore deposits. These may be grouped into three major types—bedded, massive, and residual deposits (Percival, 1955, p. 45–76), and various subtypes. The largest deposits, and those which furnish the bulk of the iron ore produced in the United States are bedded deposits of Lake Superior types. These include primary and enriched deposits of magnetite, hematite, goethite, iron silicates, and iron carbonates in sedimentary strata called iron formations. Many of these deposits include siliceous iron formations called jaspilite and taconite ores which are very fine grained and have relatively low percentages of iron—15 to 35 percent—except in local zones which have been enriched to high-grade ores. However, the low-grade ores may be of value if the ore minerals are amenable to concentration, and providing the ores occur in great quantities and are situated so they can be mined by open-pit methods.

Bedded deposits of oolitic hematite ores, the Clinton-type ore, also occur in extensive deposits. These are generally in sedimentary rocks of Paleozoic or younger age. They commonly contain greater percentages of iron than the taconite ores but generally are in thinner beds. Clinton-type deposits are not known to occur in significant amounts in Arizona.

Massive deposits of magnetite, hematite, and iron sulfides formed as a result of magmatic or hydrothermal activity are known in several places in Arizona. These deposits are generally of higher grade in iron, but generally are considerably smaller than most of the bedded deposits.

Residual deposits of goethite and jarosite, formed by the weathering and leaching of other types of deposits of iron-bearing minerals, are known in many localities in Arizona, but are generally small.

Pyrite is available in Arizona as a byproduct or waste product of mining and processing nonferrous ores. Although large quantities of pyrite are known, their use is dependent to a great degree on the competitive costs and availability of scrap iron for use in place of sponge iron for precipitating copper at refineries in the State, and is dependent upon the demand for sulfuric acid which is also produced from pyrite.

Iron Resources of Arizona

The iron resources of Arizona are largely in deposits that at present can only be classed as potential ores. If large deposits of inferred or only partly explored low-grade material are included, the resources may total more than a billion tons (Harrer, 1964, p. 16). These include low-grade deposits of Lake Superior types, alluvial deposits of magnetite, and smaller deposits of magnetite, hematite, and limonite. The deposits of iron sulfides will be discussed in the section on sponge iron. Metallurgical slags accumulated in the processing of nonferrous ores are another source of iron.

The distribution of iron deposits in Arizona is shown in figure 24, and a summary of the available resource data for them is listed in table 15. Some of the deposits are probably large, but have not been thoroughly studied; others are small occurrences in what may be favorable zones for exploration. Also shown are a few copper deposits that contain abundant iron sulfides. Because crude iron ores generally have relatively low unit value, and require large expenditures in their exploitation, only the larger or higher-grade deposits are discussed. In the sections that follow the deposits are described under bedded, alluvial, and massive types.

BEDDED DEPOSITS

In the Black Hills area of Yavapai County (fig. 24, No. 1) extending from about 8 to 15 miles east-northeast of Dewey, iron formations of Lake Superior type occur in the Yavapai Series of metamorphosed volcanic and sedimentary rocks of Precambrian age (Harrer, 1964, p. 94–99).

Altitudes in the area range from 5,200 to 7,000 feet above sea level. U.S. Route 89 is about 1 mile to the northwest of the area and the Atchison, Topeka and Santa Fe railroad extends through Dewey. Magnetitic and jaspilitelike beds as much as 30 feet thick in the Grapevine Gulch Formation crop out over lengths of a half mile to a mile in a few places in an area about 2½ miles wide and 9 miles long; these beds trend north-northwest. The iron formations are folded siliceous taconites, jaspilites, and schists that contain magnetite, hematite, and manganese oxides. Analyses of samples of the iron formation show the following percentage ranges (Harrer, 1964, p. 65):

Constituent	*Percentage range*
Iron	26.9–37.4
Manganese	0.9–4.5
Silica	25.2–53.0
Phosphorus	0.02–0.42
Sulfur	0.04–0.12

The percentage of iron recoverable in concentrates from this material is not known. The iron oxides and other rock minerals show con-

siderable interlocking even at minus 325-mesh size. Precise estimates of the resources have not been made, but millions of tons of low-grade material can be inferred to shallow depths (Harrer, 1964, p. 17).

Also in Yavapai County, taconitelike iron formations 50 to 500 feet thick, noted in several zones each more than a mile in length, occur in three major northerly trending belts and a few smaller belts within an area of about 250 square miles that includes the Mayer area (No. 2), Rock Springs-Cordes area (No. 3), Goodwin-Crown King area (No. 4), and Cleator area (No. 5) (Harrer, 1964, p. 62–112; Jerome, 1956, 183 p.).

Arizona Route 69 is about 3 miles east of the area, and Mayer is served by the Atchison, Topeka, and Santa Fe railroad.

The iron formations consist of taconite and jaspilite beds in the Yavapai Series of Precambrian age, similar to those in the Black Hills area at several places.

Analyses of samples taken show the following percentage ranges (Harrer, 1964, p. 65):

Constituent	*Percentage range*
Iron	20.8 –38.88
Manganese	0.1 –10.91
Silica	35.0 –52.4
Titania	0.2 – 0.6
Phosphorus	0.1 – 0.3
Sulfur	0.08– 0.25

The percentage of iron recoverable in concentrates made by standard beneficiation processes and containing tolerable amounts of silica is not known. On the basis of observed widths of hundreds of feet and observed and inferred lengths of miles of iron formation, the potential resources of low-grade iron-bearing taconite in this group of deposits are more than 100 million tons (Harrer, 1964, p. 62–112). Beneficiation tests using reductive roasting and wet magnetic separation on samples from these deposits resulted in recoveries of 85.5 percent to 94.5 percent of the iron in the magnetic fraction (Harrer, 1964, p. 153–158). However the silica content of the magnetic separates was high even in samples ground to minus 325-mesh size before separation.

Another occurrence in Yavapai County is the Stanton deposit (No. 6), which is about 3 miles south of Yarnell and 6 miles east of Congress, and is on U.S. Route 89 and along the A. T. & S. F. railroad. The iron formation is of Lake Superior type consisting of magnetitic siliceous taconite in the Yavapai Series, of Precambrian age (Harrer, 1964, p. 112). It is similar to the Precambrian iron formation in other areas of Yavapai and Maricopa Counties. A magnetitic taconite unit, 200 feet wide, in a taconite, schist, quartzite, and greenstone sequence, can be traced northward for 3 miles. The beds dip 50° W. to vertical. Analyses of two samples showed the following respective compositions:

Constituent	*Percentages*
Iron	20.6 and 30.6
Manganese	0.2 and 0.4
Manganese	1.8 and 2.9
Phosphorus	0.11 and 0.27
Sulfur	0.10 and 0.08
Silica	59.2 and 43.8

A recovery of 91.4 percent of the iron was obtained in beneficiation tests that were made using reductive roasting and wet magnetic separation on a sample ground to minus 325 mesh (Harrer, 1964, p. 158). The

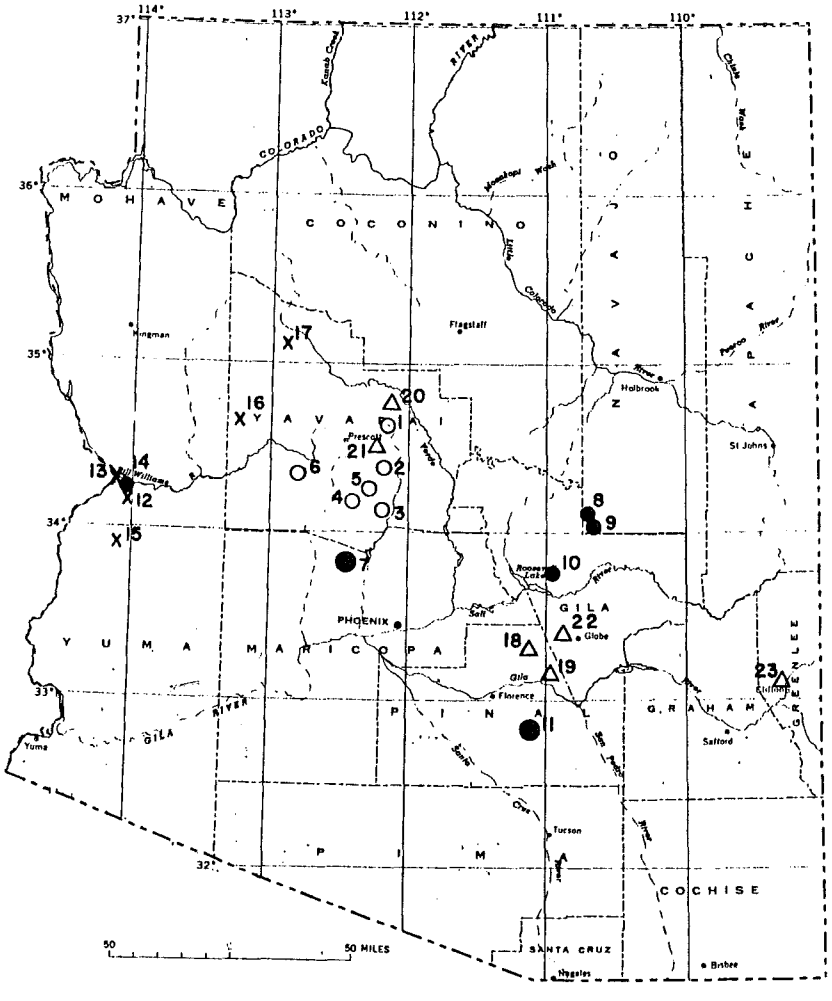

FIGURE 24.—Iron in Arizona.

TABLE 15.—*Iron resources of district, areas, or deposits in Arizona*

Locality No. in fig. 24	County	Area, district, or deposit and type of deposit	Principal iron minerals	Percent iron	Estimated resources in millions of long tons		References
					Reserves	Potential ores	
1	Yavapai	Black Hills area; taconite deposit	Magnetite; hematite	27-37	No est.	Several	Harrer, 1964, p. 94-99.
2	Do.	Mayer area; taconitelike iron formation	do.	21-39	No est.	+ 10	Harrer, 1964, p. 62-112.
3	Do.	Rock Springs-Cordes area; taconitelike iron formation	do.	21-39	No est.	+ 10	Harrer, 1964, p. 62-112; Jerome, 1956, 138 p.
4	Do.	Goodwin-Crown King area; taconite-like iron formation	do.	21-39	No est.	+ 10	Do.
5	Do.	Cleator area; taconitelike iron formation	do.	21-39	No est.	+ 10	Do.
6	Do.	Stanton deposit; taconite	Magnetite	21-31	No est.	+ 10	Harrer, 1964, p. 112.
7	Maricopa	Pikes Peak district; taconite deposit	Hematite	30	100	No est.	Farnham and Havens, 1957, 31 p.; Harrer, 1964, p. 67.
8	Navajo	Apache deposit; bedded	do.	43-66	15	No est.	Butler, 1934, 3 p.; Burchard, 1931, p. 51-75; Stewart, 1947, p. 6, Moore, 1967, p. 28.
9	Do.	Chediski deposit; bedded	do.	23-62	No est.	10-15	Do.
10	Gila	Zimmerman-Asbestos Points deposits; massive	Magnetite	30-68	No est.	Several	Harrer, 1964, p. 57.
11	Pinal	Florence-Oracle Junction-Red Rock area; alluvial deposits	do.	3	No est.	100-500	Harrer, 1964, p. 87-90; Mining World, 1962, p. 58; S. B. Keith, written commun., 1968.
12	Yuma	Buckskin Mountain area; massive deposits	Hematite	No data	No est.	No est.	Harrer, 1964, p. 125-135.
13	Do.	Mineral Hill deposit; massive	do.	38-48	4.3	No est.	Harrer, 1964, p. 128-130.
14	Do.	New Planet deposit; massive	do.	35-60	1.25	21	Harrer, 1964, p. 130-133; Mining World, 1961, p. 23.
15	Do.	Plomosa Mountains deposits; massive	do.	Low	No est	No est	Keyes, 1923, p. 383-384; Farnham and Stewart, 1958, p. 71-77; Harrer, 1964, p. 120-125.
16	Yavapai	Boulder Creek-Milholland Creek deposits; massive	Magnetite	60-62	No est.	No est.	Anderson and others, 1956, p. 14.

TABLE 15.—*Iron resources of district, areas, or deposits in Arizona*—Continued

Locality No. in fig. 24	County	Area, district, or deposit and type of deposit	Principal iron minerals	Percent iron	Estimated resources in millions of long tons		References
					Reserves	potential ores	
17	Yavapai—Continued	Seligman-Cowden deposits; massive	Hematite	55-60	No est.	No est.	Harrer, 1964, p. 116-119.
18	Pinal	Magma deposit; massive	Pyrite	1/	No est.	1/	Harrer, 1964, p. 3; S. B. Keith, written, commun., 1968.
19	Do.	Ray deposit; massive	do.	1/	No est.	1/	Do.
20	Yavapai	United Verde deposit; massive	do.	1/	No est.	1/	Harrer, 1964, p. 3.; Kelly, 1962, p. 16.
21	Do.	Iron King deposit; massive	do.	1/	4.2	1/	C. A. Anderson, written commun., 1968.
22	Gila	Miami-Inspiration deposits; massive	do.	1/	No est.	1/	Wideman, 1957, p. 42-61.
23	Greenlee	Morenci deposit; massive	do.	1/	No est.	1/	Do.

1/The iron content of copper ores and the quantities of potential ores in pyrite-rich copper deposits have not been determined. Pyrite used for the production of sponge iron and sulfuric acid is produced on a relatively small scale as a byproduct in the treatment of copper ores.

magnetic concentrates contained 50.4 percent iron and 23.1 percent silica. The percentage of iron recoverable in a low silica magnetic concentrate by standard methods used in beneficiation to high-grade concentrates is not known. The deposit has not been sufficiently explored to permit exact assessment of resources. Inferred quantities of low-grade iron formation are in the tens of millions of tons.

In Maricopa County, in the Pikes Peak district (No. 7), about 35 miles northwest of Phoenix, iron deposits occur on the south slope of the Hieroglyphics Mountains in an area where the altitudes range from 2,100 to 2,800 feet above sea level (Farnham and Havens, 1957). The A.T. & S.F. railroad at Wittman is about 7.5 miles to the southeast of the area. The Kaiser Steel Corp. and the U.S. Bureau of Mines studied the deposits in 1942; there was no further activity at the deposits as of 1961 (Harrer, 1964, p. 67).

Taconite and semitaconite consisting chiefly of hematite in a siliceous gangue occur as steeply dipping beds in Yavapai schists, of Precambrian age, in an outcrop area as much as 2,000 feet wide and 18,000 feet long. Ten large beds or lenticular bodies 50 to 300 feet wide by 400 to 2,000 feet long and several smaller bodies occur in the area. Some of the larger deposits are exposed through a vertical range of 360 feet. Dikes of andesite porphyry intrude the schist and the iron deposits. Hematite and magnetite and minor amounts of manganese

oxides are the iron-bearing minerals, and quartz is the chief gangue mineral. The deposits were explored by trenching, drifting, and by diamond drilling. Surface samples average 29.74 percent iron, 2.81 percent manganese, and 0.126 percent phosphorus. The quantities of potential ores calculated on the basis of mapping and trenching and using a factor of 10.5 cubic feet per ton are about 250,000 tons per foot of depth. As two of the large bodies are exposed over a vertical range of more than 300 feet, indicated potential ore to a depth of 300 feet is estimated to be about 75 million tons, and the inferred potential ore to a further depth of 100 feet would bring the total of estimated resources to about 100 million tons (Harrer, 1964, p. 67–70).

The deposit is accessible for open-pit mining. Beneficiation tests indicate that wet magnetic separation following reductive roasting with natural gas or oil of taconite ground to minus 100 mesh yields concentrates assaying 59–62 percent iron plus manganese and 9–12 percent silica. Iron recoveries ranged from 93 to 94 percent using gas reduction as compared to a range from 84 to 86 percent using oil reduction (Farnham and Havens, 1957, p. 30–31).

The Apache (Canyon Creek) iron deposits (No. 8), in Navajo County, are in the western part of the Fort Apache Indian Reservation (Burchard, 1931, p. 51–75; Stewart, 1947, p. 6) about 50 miles north of Globe, which is served by the Southern Pacific Railroad. The nearest railroad siding is at Sedan, on the Apache Railroad, which connects with the A. T. & S. F. railroad at Holbrook. The local terrain is rough, having a maximum relief of about 1,200 feet. Altitudes of the exposed parts of the iron deposits range from 5,285 feet at Canyon Creek to 6,750 feet on Swamp Creek Mountain.

The area is underlain by the Apache Group of sedimentary rocks of Precambrian age which is overlain by a diabase sill and by sandstone beds of Cambrian age. Stratiform hematite deposits are associated conformably with ferruginous chert or jasper in the Mescal Limestone of the Apache Group. The chert grades downward into iron ore (Stewart, 1947, p. 7). The iron deposits antedate the intrusion of the sill and were locally reconstituted near the intrusives (Shride, 1967, p. 38–39).

The strata are folded into an anticlinal structure that plunges south, has minor flexures, and is faulted. The ore ranges from soft earthy hematite to hard massive hematite and some specularite beds interlayered with chert. Much of the hematite is fine grained and massive. As much as 1 percent apatite and 3–5 percent sericite occur as gangue minerals in addition to the chert. High-grade ore in the deposit contains 50–65 percent iron, 4.5–26.5 percent silica, and 0.12–0.40 percent phosphorus (Butler, 1934). As a result of drilling by the U.S. Bureau of Mines (Stewart, 1947, p. 6), the iron-bearing zone (calculated at a cutoff of 35 percent iron) was found to range from 2 to 47 feet in thickness. Potential ore containing 43–66 percent iron, and averaging about 55 percent iron totaled 15 million tons (Burchard, 1931, p. 66–68), in a zone extending along an outcrop length of 9,000 feet to a distance of 1,500 feet back from the outcrop, based on an average thickness of 10 feet. Underground mining would be necessary at the part of the deposit west of Canyon Creek and not all of that ore would be recoverable. Part of the deposit east of Canyon Creek could be mined by open-pit methods.

The Chediski hematite deposit (No. 9), in Navajo County, is exposed along Canyon Creek about 3 miles south-southeast of the Apache deposit (No. 8) and is similar in character to that deposit. A hematite-rich zone in the cherty Mescal Limestone unit of the Apache Group contains 23–61.5 percent iron in a bed ranging from 2 to 21 feet in thickness that is exposed along an arcuate outcrop for a distance of about 10,000 feet (Stewart, 1947, p. 79–80). A bed averaging 18.7 feet thick over a length of 2,000 feet contains 42 percent iron near the south end of the outcrop. A fault has displaced the hematite-rich bed at the north end of the outcrop; the extension of the bed to the south and east is lower-grade ferruginous material or barren rock interlayered with discontinuous lenses of high-grade hematite. Although the Chediski deposits have not been explored in as much detail as have the Apache deposits, the similarity in geologic setting, the comparable lengths of outcrop and thicknesses of the hematite-rich zone make it reasonable to infer that resources at the Chediski deposit to a distance of 1,500 feet back from the outcrop total 10–15 million tons. Both of these deposits as well as the occurrence of hematite at Cow Creek, about 2 miles north of the Apache deposit are part of a much larger potential source of iron ore in Navajo County. Several other deposits and occurrences of hematite and magnetite in the Mescal Limestone are known in Gila County (Harrer, 1964, p. 26–56). Although many of these are small, or of unknown size, they may be indications of a large potential source of iron in Gila County.

The Apache and Chediski deposits were leased as possible sources of iron ore for the blast furnaces of the Colorado Fuel and Iron Corp. at Pueblo, Colo., in 1960 and mining was started on a trial basis in 1966. The ore is shipped to Pueblo, Colo., for testing (Moore, 1967, p. 28).

In Gila County, the Zimmerman-Asbestos Points magnetite deposits (No. 10) are about 30 miles north of Globe and east of Arizona Route 288. Magnetite occurs in the Mescal Limestone of the Apache Group, of Precambrian age, in stratiform bodies that have some characteristics of contact metamorphic and metasomatic replacements. The limestone, 100–300 feet thick, is between two large diabase sills, the upper one 500 feet thick, and the lower one about 1,000 feet thick. Massive high-grade magnetite bodies are separated by low-grade material. The magnetite zone is as much as 100 feet thick, and can be traced intermittently more than 2 miles to the northeast and to the southwest near Zimmerman Point on the western flank of the Sierra Ancha.

Analyses of two samples of the potential ore showed the following respective compositions (Harrer, 1964, p. 57):

Constituent	*Percentages*
Iron	50.8 and 68.4
Manganese	0.02 and 0.2
Titania	0.05 and <0.1
Phosphorus	0.03 and 0.06
Sulfur	0.09 and 0.11
Silica	12.2 and 1.4
Alumina	2.72
Lime	0.04
Magnesia	9.87

Potential ore was inferred to amount to several million tons, ranged from 30 to 68 percent iron and had a possible yield of 2 million gross tons of concentrates averaging 65 percent iron (Harrer, 1964, p. 57).

ALLUVIAL DEPOSITS

Magnetite-bearing alluvium occurs in Pinal County in the Florence-Oracle Junction-Red Rock area (No. 11) an area of about 800 square miles that extends from about 25 miles north of Tucson toward Florence. Florence, Oracle Junction, Red Rock, and Casa Blanca are near the borders of the area, which is accessible from U.S. Route 789. Much of the terrain is gently sloping desert plains at altitudes of 2,000 to 3,500 feet above sea level (Harrer, 1964, p. 87–90).

Titaniferous magnetite in amounts ranging from about 1 to 15 percent, occur in alluvial deposits at the surface and to depths of more than 250 feet. The magnetite is stratified in thin layers and disseminated in silty sand and gravel. Screening and magnetic concentration were used to extract the magnetite. At the Omega mine, 15 cubic yards of alluvium were expected to yield 1 ton of magnetite concentrate containing 55 percent iron (Harrer, 1964, p. 90). Two analyses of the magnetic concentrates were as follows: 63.2 and 62.8 percent Fe; 2.3 and 2.8 percent TiO_2; 0.14 and 0.30 percent Mn; and 0.39 percent P; 0.06 and 0.36 percent S, and less than 2 percent of Al_2O_3 and of $CaCO_3$ (Harrer, 1964, p. 90). At the Arkota Steel Corp. plant, using concentrates from the Omega deposit, the magnetic concentrate ground to minus 200-mesh size and separated magnetically reduced the phosphorus content from 0.3 to 0.03 percent, and reduced the titanium to less than 0.3 percent (Mining World, 1962, p. 58). The final product contained 68–69 percent iron and was used in a direct reduction plant to produce sponge iron at Coolidge, Ariz.

Reserve estimates are not available for most of the area, although Harrer (1964, p. 89) reported that 38,000 acres of alluvium in the Omega placer area contained 3–15 percent magnetite to an unstated depth. Preliminary tests indicated that 1 ton of magnetite concentrates containing 55 percent iron could be recovered from 15 cubic yards of alluvium. At this ratio 1 square mile to a depth of 10 yards would yield a little more than 2 million tons of magnetite. Resources on the Omega claims probably total more than 100 million tons and were estimated to contain as much as 500 million tons (American Metal Market, 1960, p. 3).

A 25,000-ton-per-year capacity direct reduction plant for producing sponge iron from these concentrates was dedicated at Coolidge in 1961 and was in use in 1962 (Harrer, 1964, p. 90). The fact that many square miles of claims have been staked in this area and that the direct reduction plant was installed, suggests that large resources of magnetite-bearing alluvium are known.

The deposits were worked by open-pit methods in 1962, and the alluvium was screened, crushed, and separated magnetically. The minus 35-mesh concentrates were trucked to the plant near Coolidge and pelletized, then smelted (Harrer, 1964, p. 90). More recently Sovereign Industries has acquired the Omega mine properties and

the sponge iron plant at Coolidge and is reportedly planning larger-scale operation of these facilities (S. B. Keith, written commun., 1968).

MASSIVE DEPOSITS

In Yuma County, the Buckskin Mountain area (No. 12) east of Parker is underlain by Precambrian gneiss and schist, which is overlain by metamorphosed Paleozoic limestone; the western part of the mountains is capped by a sheet of basaltic volcanics (Harrer, 1964, p. 125). Within this area several replacement deposits of hematite with associated copper minerals occur in the Paleozoic limestone. Among these are the Swansea, Brown Mountain, Ruthie and Linda, and Planet Peak deposits and prospects, some of which have been worked for copper and other metals, and a few have been examined for iron ore. The size and iron content of these deposits have not been determined. Iron-rich beds 2 to 15 feet thick at the Brown Mountain deposit and 20 to 30 feet thick at the Swansea deposit have been reported. Samples of specularite-rich mill tailings from the copper ore mill at the Swansea deposit contained 57.8 to 61 percent iron (Harrer, 1964, p. 127–135). These deposits are likely to be of local interest if the larger deposits in adjoining parts of the Buckskin Mountain area—the Mineral Hill and New Planet deposits—are exploited for iron.

The Mineral Hill cupriferous hematite deposit (No. 13), is about 17 miles east-northeast of Parker, Yuma County. The area is in desert terrain and is accessible by unpaved roads that range from 500 to 1,200 feet above sea level. Specular hematite deposits occur as hydrothermal replacements of metamorphosed limestone of Paleozoic age; the limestone overlies Precambrian gneiss (Harrer, 1964, p. 127–130). Younger basalt flows cap the plateau to the west. Rocks in the area have been folded, and dips range from horizontal to 50 degrees. Massive hematite occurs at several horizons in bodies more than 25 feet thick. Two replacement beds of hematite in a zone about 75 feet thick have been traced more than 2,200 feet southeastward from Specularite Point where they merge to a composite thickness of 40 feet; the outcrop of the basal bed extends for about 900 feet west-southwest from Specularite Point; the area south of this has been tested by drilling.

The ore consists of massive and specular hematite and secondary copper minerals which occur in fractures in the hematite. Samples of the upper bed contained 35.8–55.7 percent iron and averaged 45.1 percent iron. Samples of the lower bed contained 33.0–63.2 percent iron, and averaged 49.3 percent iron. Two samples contained 4.6 and 6.4 percent manganese, respectively. A character sample of outcrop material contained the following percentages:

Constituent	*Percent*
Iron	38.1
Manganese	0.1
Titania	0.1
Copper	5.55
Phosphorus	0.07
Sulfur	0.36
Silica	27.6

Reserves in June 1964 were estimated to be 3,356,000 tons, averaging 48.3 percent iron and about 1 million tons of siliceous cupriferous ore, averaging 38 percent iron (Harrer, 1964, p. 130). Considerably more lower-grade hematitic material is known in the area.

The New Planet iron deposit (No. 14), Yuma County, is about 28 miles north-northeast of Bouse and about 3 miles east of the Mineral Hill deposit and is accessible by dirt road from Bouse, which is on the A.T. & S.F. railroad.

The area is underlain by a gneissic basement complex that is probably of Precambrian age, and a younger series of schist and limestone of Paleozoic age. The ore occurs as a replacement of the limestone (Cummings, 1946, p. 4). The deposits are similar in character to those at Mineral Hill. "Individual bodies of hematite are as much as 700 feet long, 250 feet wide and 50 feet thick . . . consisting mainly of specularite and massive hematite with some limonite, malachite, azurite, chrysocolla, and a little pyrite, chalcopyrite, bornite, gold, and silver. Gangue minerals include quartz, calcite, and limestone." (Harrer, 1964, p. 131). Hard hematite occurs in the upper 10 feet and pulverulent hematite below.

A character sample of cupriferous hematite had the following composition:

Constituent	*Percent*
Iron	57.9
Copper	7.9
Lead	0.05
Sulfur	0.09
Lime	0.1
Alumina	1.65
Silica	1.6
Insolubles	2.4

The iron content varies widely from place to place depending upon the completeness of replacement of limestone and schist (Harrer, 1964, p. 131).

Reserves estimated in 1945 were 1.25 million tons of material that averaged 60 percent iron. There was no production subsequent to 1961 (Harrer, 1964, p. 132). Inferred resources of 21 million tons of low-grade material that contained about 35 percent iron and 40 percent silica have been reported (Mining World, 1961, p. 23).

Low-grade manganiferous hematite-limonite deposits at several localities in the Plomosa Mountains (No. 15), Yuma County, in the general vicinity of Bouse have been prospected for gold, silver, manganese, and iron. The iron occurs in contact metamorphic deposits as a replacement of Paleozoic limestone in the vicinity of intrusive rocks and in volcanic rocks (Keyes, 1923, p. 383–384; Farnham and Stewart, 1958, p. 71–77; Harrer, 1964, p. 120–125). Hematite, limonite, magnetite, siderite, pyrite, and probably jarosite are the iron-rich minerals. Manganese oxides and primary and secondary copper minerals occur in some of the deposits. Most of the deposits are small, or of undetermined size, and are relatively low grade in iron.

The Boulder Creek-Milholland Creek magnetite-ilmenite deposits, of Yavapai County, which contain some specularite, occur in a northeast-trending zone of gabbro about 2½ miles northwest of Bagdad (No. 16). Dikelike bodies of titaniferous magnetite 1 to 20 feet thick

and up to several hundred feet long both crosscut and parallel the gneissic structure of the gabbro (Anderson and others, 1956, p. 14). Analyses of three samples showed 60–62 percent iron, 8.2–9.8 percent titanium, and traces of manganese. The deposits were trenched and sampled in 1952 and were found to be larger and to contain greater percentages of titanium than that cited above. Further exploration and beneficiation tests are required to evaluate these deposits.

The Seligman-Cowden hematite deposits (No. 17), of Yavapai County, are about 19 miles by road south of Seligman, at an altitude of about 5,600 feet, in the Juniper Mountains (Harrer, 1964, p. 116–119). Seligman is on the A.T. & S.F. railroad. The hematite occurs in replacement deposits in the Redwall Limestone, of Mississippian age. They occur along the contact of limestone and intrusive sill-like masses of andesite porphyry. The hematite-bearing zone is exposed along Walnut Creek for about a half mile where the limestone dips gently eastward. Lenticular bodies as much as 1,000 feet long and 2–20 feet thick were mined by opencuts in 1961 and the high-grade hematite was produced for use in mineral pigment. Analyses of samples of the ore showed the following percentage ranges (Harrer, 1964, p. 119):

Constituent	*Percentage range*
Iron	55.2–68.4
Manganese	0.03–0.14
Phosphorus	0.005–0.1
Sulfur	Trace–0.1
Silica	1.5–8.7
Lime	0.07–4.6
Alumina	0.1–3.19

These deposits have been worked on a small scale in recent years, but production data have not been disclosed.

SPONGE IRON

Sponge iron has been produced from iron oxides from the smelter products of ores from the United Verde mines of the United Verde Copper Co., in a plant at Clarkdale (Harrer, 1964, p. 163), and at the Phelps Dodge Corp.'s plant at Douglas and from pyrites at the Kennecott Copper Corp.'s plant at Hayden (U. S. Bur. Mines, 1965, p. 95–99).

Metallurgical slags in Arizona which contain 30–50 percent iron, along with copper, zinc, and other impurities, are estimated to total almost 100 million tons (Harrer, 1964, p. 163). Not all of this slag is considered to be suitable for the production of sponge iron.

Pyrites from the Magma and Ray mines, Pinal County (localities 18 and 19) and from other sources supply the sponge iron plant at Hayden. In 1964 the plant had a capacity of about 40 tons per day (Harrer, 1964, p. 3). Sulfuric acid and sponge iron produced as coproducts from the pyrites are used in the leaching of copper from ores. About 30,000–40,000 long tons of pyrite are produced annually at Ray and Magma and the combined production of sponge iron from pyrite and slag is 15,000–20,000 long tons per year; actual production figures are not released (S. B. Keith, written commun., 1967). As scrap iron also is used in the precipitation of copper, the demand for sponge iron is related to the availability and cost of scrap iron as well as to the needs of the copper industry.

The pyrite deposit at the United Verde mine near Jerome, Yavapai County (No. 20) is a large potential source of pyrite (Kelly, 1962, p. 16; Anderson and Creasey, 1958, p. 112–116, 119). Pyrite is produced from impounded tailings at the Iron King mine (No. 21) at Humboldt, Yavapai County by the Shattuck Denn Corp., and treated for use as a soil conditioner. An estimated 4.2 million tons of tailings contain about 30 percent pyrite. The pyrite is acidulated with concentrated sulfuric acid to produce ferrous sulfide and polysulfide, then dried to produce clinker, which is reacted with anhydrous ammonia to produce a granular soil conditioner. Output is about 5–6 tons per 8-hour shift (C. A. Anderson, written commun., 1968).

Pyrite may also be obtained from the ores and tailings of the Miami-Inspiration mines in Gila County (No. 22), the Morenci mine in Greenlee County (No. 23), and from several other operating copper mines in the State (Wideman, 1957, p. 42–61). In addition to the iron and copper deposits mentioned above, numerous small iron deposits of various types including stratiform deposits and replacement deposits in limestones of Precambrian and Paleozoic ages, iron-rich diabase intrusives, alluvial deposits of titaniferous magnetite, iron-rich copper deposits, and gossans occur in various parts of the State (Harrer, 1964), but are not considered to be of economic value for iron. They do indicate, however, that geologic conditions favorable for the formation of iron deposits have existed in widespread areas in the State.

Summary of Iron Resources and Outlook

The iron industry in Arizona will remain small until increased market demands for ore, and more favorable prices furnish the incentive for the capital investments that will be required to develop and exploit the potentially large resources, particularly the hematite deposits in the Mescal Limestone in Navajo and Gila Counties, and the taconites and jaspillites in the Precambrian rocks of Maricopa and Yavapai Counties. The titaniferous alluvial magnetite deposits of Pinal County have already been tested by small-scale operations, although their mining has been discontinued. These, too, may be exploited under more favorable market conditions, although the presence of excess titanium in the magnetite concentrates detracts from their value. In some areas in the State where geologic conditions were favorable for the formation of replacement deposits in limestone strata, some large concealed deposits may occur. Further geological and geophysical exploration and feasibility studies will be required if a large-scale iron mining industry is to be established in Arizona.

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LEAD AND ZINC

(By Richard T. Moore, Arizona Bureau of Mines, Tucson, Ariz.)

Introduction

Lead and zinc have been important to mankind for many centuries. The use of lead can be traced back nearly 5,000 years to the civilization of ancient Troy, in the eastern Mediterranean region, where lumps of the metal have been found in ruins dating between 3000 and 2500 B.C., and zinc, as a component of brass, was used in China and Rome 2,000 years ago, long before it became known as an element (Rickard, 1932, p. 153; Schroeder, 1965, p. 1084). The earliest use for lead was probably in items of ornamentation, but in later years (500 to 200 B.C.) Athenians produced sizable quantities as a byproduct of silver mining at Laurium, and used it extensively for pipe in their municipal water system and in the fabrication of utensils for the production of wine. Zinc was used by the ancient Chinese for coins and was known

to the early Greeks, who called it "false silver," but it was not produced commercially in Europe until the 17th century, when knowledge of zinc smelting was brought to England from China (Eng. Mining Jour., 1966).

Properties, Use, and Occurrence

Lead is a malleable, dark gray metallic element having a relatively low melting point of 327.4° C. (621.3° F.) and a high specific gravity (11.3). It is so soft and ductile that it can be extruded through dies at ordinary temperatures to form pipe. Lead has wide application in many industries and large quantities are used in the manufacture of storage batteries, both in the form of metal and as oxide. It also is used extensively in the compounding of "no-knock" gasoline additives, in armored telephone cables, as red lead and litharge for protective coatings, and in various alloys such as pewter, type metal, and solder (Moulds, 1965, p. 494). In 1966, the consumption of lead in the United States was distributed as follows: 36 percent in batteries, 19 percent in the manufacture of gasoline additives, 7 percent for red lead and litharge, 6 percent each in solders and ammunition, and 5 percent each for cable coverings and calking lead (U.S. Bur. Mines, 1968, p. 80).

Zinc is a relatively soft, bluish-white, metallic element having a specific gravity of 7.13 and a melting point of 419.5° C. (787.1° F.). In the United States, the principal uses of zinc are in diecasting alloys and in galvanizing. The total domestic consumption of zinc in 1966 was slightly more than 1.8 million tons distributed approximately as follows: diecasting alloys 43 percent, galvanizing 35 percent, brass and bronze 13 percent, rolled zinc 4 percent, and zinc oxide and other uses 5 percent (U.S. Bur. Mines, 1967, p. 398, table 17).

Lead rarely occurs as a native element and zinc probably never does. The common ore minerals of lead are galena (lead sulfide), cerussite (lead carbonate), and anglesite (lead sulfate). Other lead minerals which are less common but are of local importance include pyromorphite (lead chlorophosphate), crocoite (lead chromate), wulfenite (lead molybdate), and vanadinite (lead vanadate). The more common ore minerals of zinc include sphalerite (zinc sulfide), smithonite (zinc carbonate), willemite (zinc silicate), and calamine (hydrous zinc silicate). Many of these lead and zinc minerals are commonly associated in the same deposits in Arizona.

Industry Practices and Trade

In order to produce metallic lead and zinc, their ores, or beneficiated ore minerals, must be smelted. For lead this a fairly straightforward process involving roasting the ore, if necessary (as in the case of sulfide ores), treatment in a blast furnace to produce base bullion, and then refining the base bullion. Zinc sulfide ores also require roasting to produce oxides, but the roasted zinc ore, rather than being treated in a blast furnace, either is mixed with a carbonaceous material, such as anthracite fines, and treated in retorts, or is refined electrolytically. In retorting, the zinc is fumed off as a vapor, collected in condensers, remelted, and cast into slabs, the commercial form in which the metal is marketed. Currently there are no plants in Arizona for the smelting of either lead or zinc. Custom zinc smelters are located at Bartlesville, Okla., and Amarillo, Tex., and a custom lead smelter is in operation at El Paso, Tex.

The United States has been one of the leading producers of lead since 1893. Since 1939, however, imports have been necessary to fulfill the Nation's requirements (Moulds 1965, p. 490). In 1966 domestic consumption was over 1.32 million tons, of which 43 percent was secondary lead, recovered primarily from scrap, 32 percent was imported, and 25 percent was derived from domestic mine production. During 1963–66, Mexico furnished about 22 percent of our imports, Australia 19 percent, Canada 19 percent, Peru 18 percent, and the remaining 22 percent came from about 18 other countries (U.S. Bur. Mines, 1967, p. 306–307; 1968, p. 80). Nearly 90 percent of domestic lead production in recent years has come from just four states, in order of importance: Missouri, Idaho, Utah, and Colorado.

The zinc industry in the United States was established in 1860 when two ore treatment plants, one in Illinois and the other in Pennsylvania, were completed and successfully put into operation. The first real growth of the industry, however, started about 1905, after the selective froth flotation process for separating complex sulfide ores had been developed. With that breakthrough, it was possible to separately concentrate the zinc sulfide that is present in the copper-lead-zinc sulfide ores commonly found in the western states. Thus, by 1909, the United States became the major producer and consumer of zinc in the world. In 1967 the total domestic consumption of slab zinc amounted to nearly 1.22 million tons, and imports, in the form of ore and refined metal, were about a third larger than domestic mine production. During 1963–66 Canada furnished about 47 percent of our imports, Mexico 23 percent, Peru 15 percent, and approximately 20 other countries furnished the remaining 15 percent (U.S. Bur. Mines, 1967, p. 407; 1968, p. 164). Domestic mine production in 1966 came principally from five states, in order of importance: Tennessee, New York, Idaho, Colorado, and Utah.

History and Production

Although early records are incomplete, it is known that lead was produced in Arizona prior to the Civil War. Most of the early production, however, was either as a byproduct of silver mining, or lead produced as a base-metal carrier for the recovery of silver from refractory ores. Continuous records of lead production have been maintained for the State since 1894 (U.S. Geol. Survey, 1895–1927; U.S. Bur. Mines, 1927–34, 1933–67; Larson and Henkes, 1968). Between 1894 and 1910 annual production averaged 2,075 tons, but ranged between 4,040 tons produced in 1901 and 600 tons produced in 1902. (See fig. 25.) Since 1910, annual production has at times exceeded 10,000 tons, mainly during wartime and during postwar expansion years; since 1940, Arizona has ranked eighth or higher among the states in the production of lead, and in the peak year of 1949 it ranked third, when 33,568 tons of lead was mined.

Zinc was not produced commercially from Arizona ores until 1905, when selective flotation was adopted. Between 1905 and 1940, the production of zinc was quite sporadic (see fig. 26); in the peak years of 1917 and 1926, only 10,447 tons and 6,473 tons, respectively, were

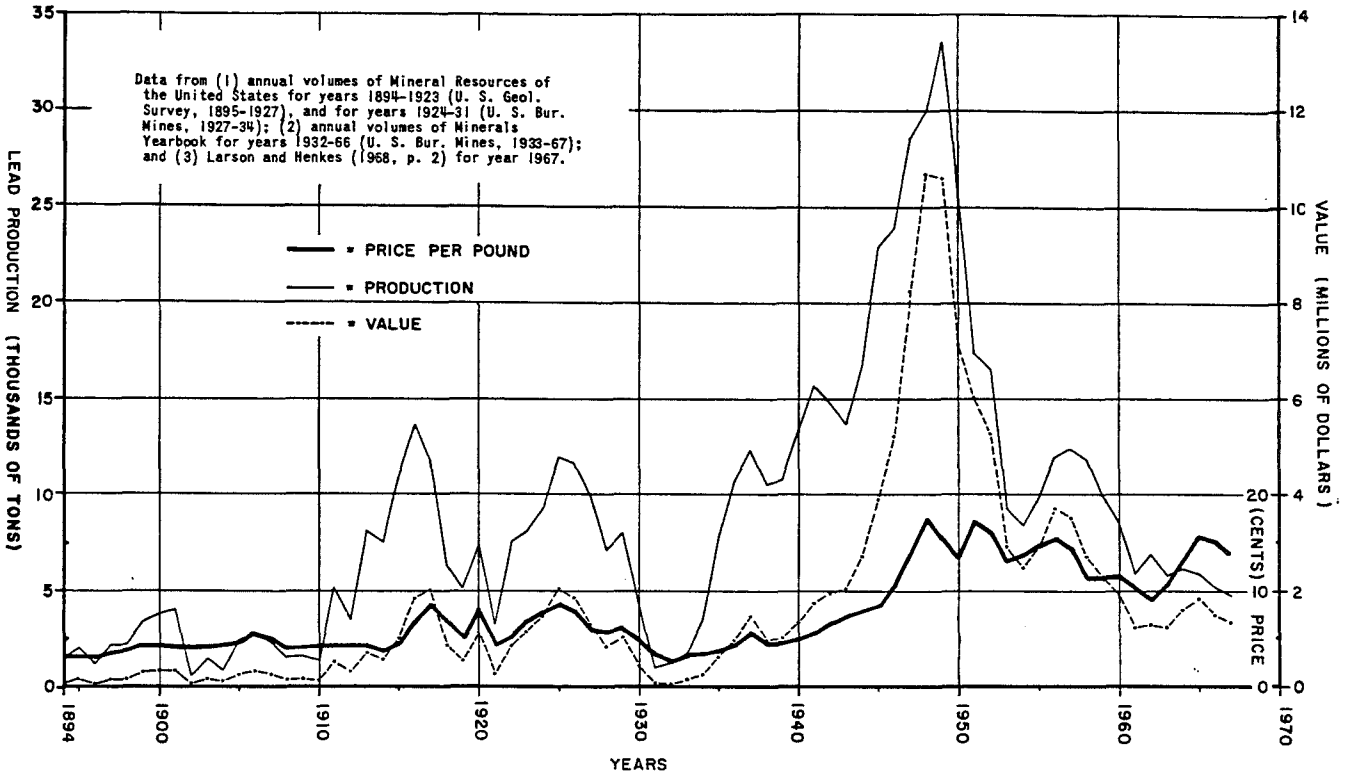


FIGURE 25.—Arizona lead production, 1894–1967.

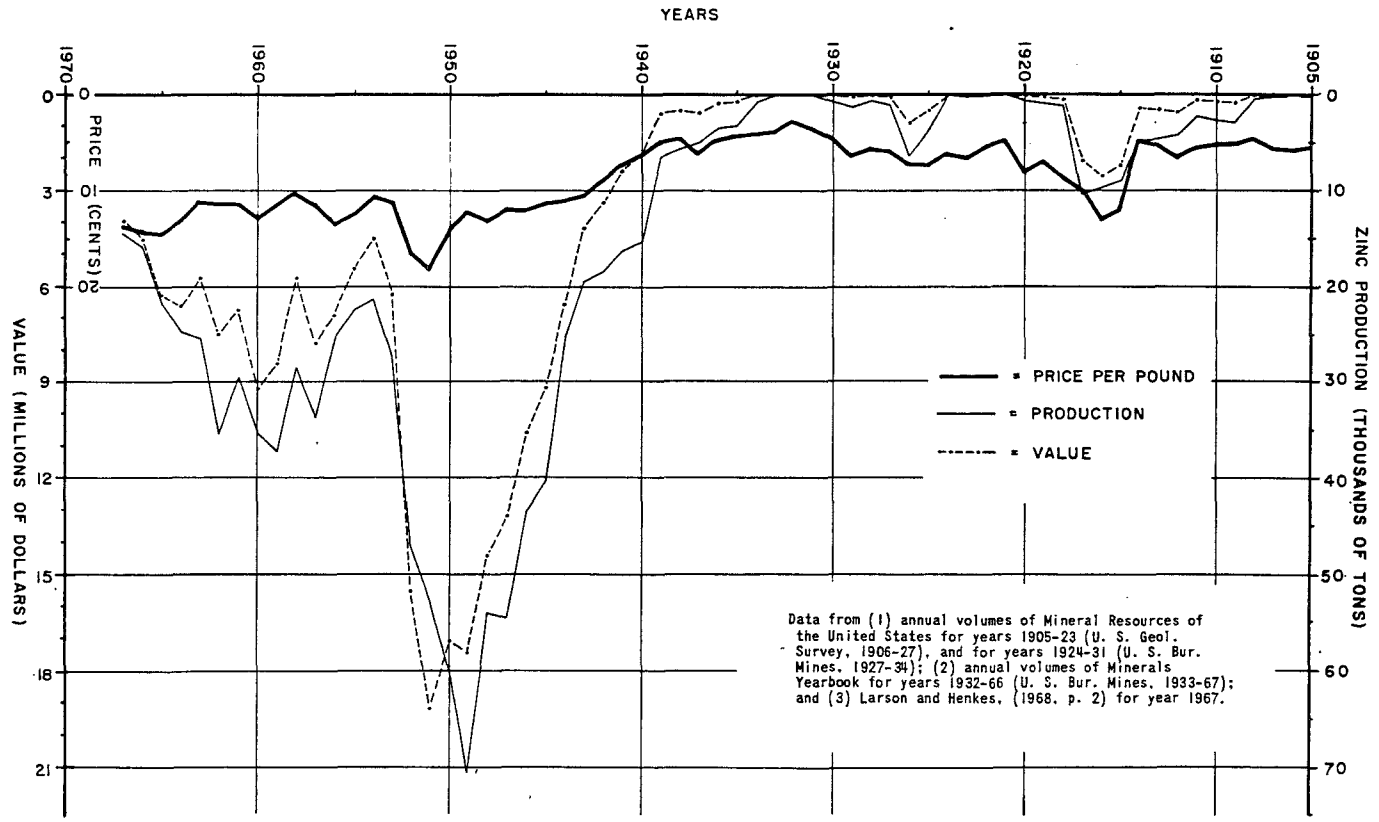


FIGURE 26.—Arizona zinc production, 1905–67.

produced. With the war-created demands for metals that developed in 1939 and the years following, production soared, and exceeded 20,000 tons annually from 1944 to 1965. Since 1940, Arizona has ranked high among the states in the production of zinc, and in 1949 it ranked second when 70,658 tons was produced (U.S. Geol. Survey, 1906–27; U.S. Bur. Mines, 1927–34, 1933–67; Larson and Henkes, 1968).

The production of lead and zinc in Arizona during the next few years, however, is expected to be drastically curtailed. The Iron King mine, in the Big Bug district, Yavapai County, which since 1963 has produced about 80 percent of the State's lead and over half of its zinc, closed down in January 1968, because of a reduction in zinc values in the lower levels, and shifting ground (Eng. Mining Jour., 1968, p. 161). With this development, nearly all of Arizona's zinc production will be derived from copper-zinc tactite deposits, and lead production, at least for the present, will almost cease.

The total recorded production of lead in Arizona, through 1967, is more than 650,000 tons, valued at $126.8 million and was obtained from more than 250 mines and prospects in 118 mining districts (fig. 27). More than 500 tons of lead has been mined in each of 35 districts but about 85 percent came from only 10 districts. Total zinc production through 1967 is more than 1,015,000 tons, valued at more than $247.7 million, and was produced from about 135 mines in 50 of the 118 lead-producing districts shown in figure 27 and described in table 16. The 50 zinc-producing districts are shown separately in figure 28. Of the 50 zinc-producing districts, 23 have produced more than 500 tons of zinc each, and the 10 leading districts have accounted for over 90 percent of the State's zinc production.

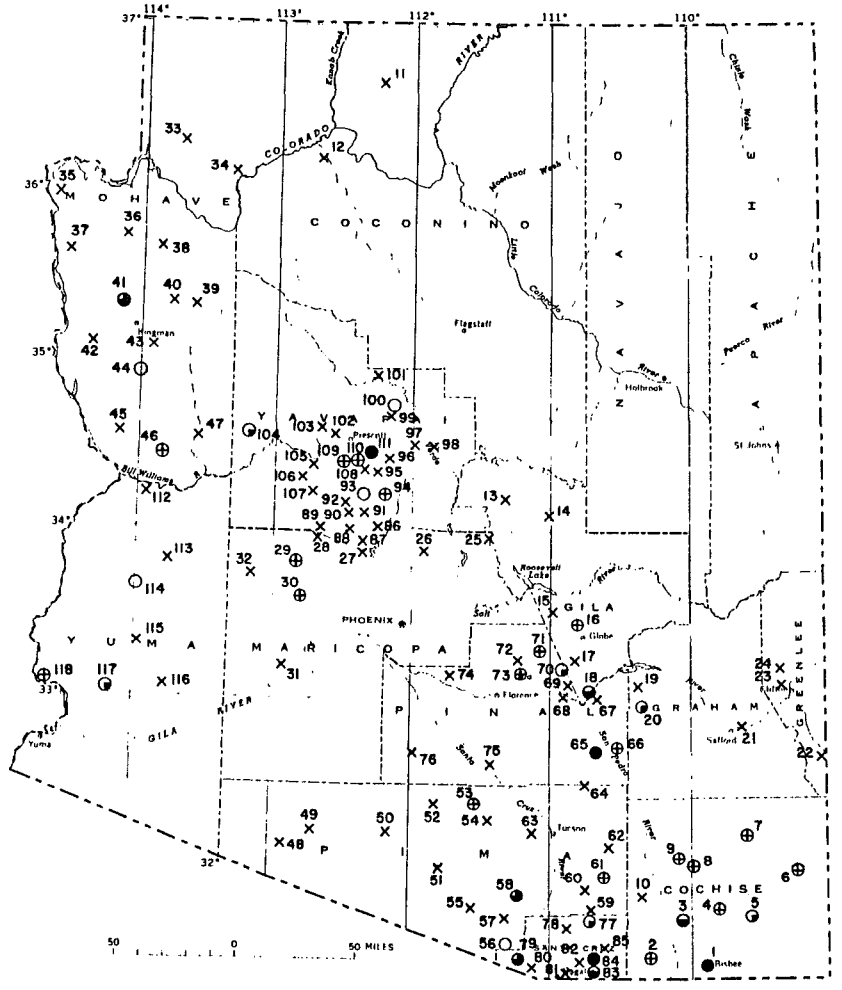
Below, listed in order, are the 10 top ranking lead-producing and zinc-producing districts in Arizona. Six of the districts are leaders in the production of both metals, an indication of the close association of lead and zinc in Arizona deposits.

Rank	Lead districts and locality numbers [1]	Zinc districts and locality numbers [1]
1	Bisbee (1)	Bisbee (1).
2	Mammoth (65)	Big Bug (111).
3	Big Bug (111)	Wallapai (41).
4	Harshaw (84)	Harshaw (84).
5	Wallapai (41)	Pima (58).
6	Pima (58)	Mammoth (65).
7	Oro Blanco (79)	Superior (71).
8	Tombstone (3)	Cochise (9).
9	Patagonia (83)	Verde (100).
10	Banner-Dripping Spring (18)	Bagdad (104)

[1] See figs. 27 and 28 and table 16.

Types of Deposits

A brief geologic description of each of the 118 mining districts recognized as producing either lead, or lead and zinc is given in table 16. In general, the deposits can be broadly categorized as being either vein deposits, or replacement deposits.



EXPLANATION

Production in short tons

More than 50,000	5,000 to 12,500
25,000 to 50,000	500 to 5,000
12,500 to 25,000	250 to 500
Less than 250	

(Numbers refer to districts listed in table 16 and mentioned in text)

Figure 27.—Lead in Arizona

TABLE 16.—*Lead and zinc districts in Arizona*

Locality No. in figs. 27 and 28 and county and district	Principal lead and zinc mines, date of discovery ( ), and years of principal production 1/	Mode of occurrence	References to mode of occurrence
Cochise			
1. Bisbee (Warren)	Campbell, Junction, Shattuck, Southwest, Gardner, Uncle Sam (1877): Lead, 1908-30, 1939-53; Zinc, 1917-27, 1939-53.	Massive sulfide replacement bodies in Paleozoic limestone. Deposits occur: (1) along structural breaks and in association with favorable zones or beds; (2) peripheral to barren siliceous-pyritic bodies; (3) intimately associated with, or peripheral to, massive pyrite-copper ore bodies; and (4) in veinlets, stockworks and replacements in porphyry dikes.	Hogue and Wilson, 1950, p. 26.
2. Huachuca (Hartford)	State of Texas, Eureka, Panama (ca 1877): Lead, 1925-28, 1940-49; Zinc, 1943-47.	Sphalerite, galena, minor pyrite and chalcopyrite, garnet, and other silicates as replacement bodies in favorable zones in Paleozoic limestone. Ore localized near the crest of a low anticline where intersected by vertical fissures (State of Texas), and along a northeast-trending fissure cutting a klippe of limestone resting on Cretaceous clastic sedimentary rocks (Panama).	Wilson, 1951b, p. 39, 40.
3. Tombstone	Numerous mines (1877): Lead, 1879-1952; Zinc, 1908-09, 1913-15, 1925, 1947-52.	Silver-lead, copper, and zinc sulfide replacement bodies along northeast-trending fissures in Paleozoic and Mesozoic limestone and in Laramide dikes. Anticlinal rolls in favorable host rocks important as local traps for mineralizing solutions. Oxidized minerals important in near-surface ore bodies.	Butler and others, 1938.
4. Turquoise (Courtland-Gleeson)	Tom Scott, Silver Bill, Mystery, Defiance, Last Chance (1877): Lead, 1907-28, 1939-57; Zinc, 1926-55.	Oxidized lead-silver and zinc ore and some sulfide bodies as replacements in impure Carboniferous limestone along steeply dipping faults and beneath low-angle faults, particularly where intersected by northeasterly trending fissures.	Wilson, 1927; 1951a, p. 13-20.
5. Swisshelm	Mountain Queen, Chance (ca 1880): Lead, 1918-53; Zinc, 1948-53.	Lead-silver sulfides and oxidized minerals, carrying some zinc in irregular replacement bodies in fractured, impure limestones of the Naco Group. Ore bodies occur above, and near the contact of a diorite porphyry dike, intrusive into the Paleozoic formations along a low-angle reverse fault.	Galbraith and Loring, 1951, p. 34, 35.
6. Chiricahua (California)	Hilltop (ca 1875): Lead, 1911-18, 1924-27, 1938-53; Zinc, 1948-54.	Lead-silver, lead-copper-silver, and lead-zinc replacement deposits in irregular masses associated with monzonitic to dioritic dikes that are intrusive into Paleozoic limestone. Locally, pipes or chimneys of massive sulfides, 1 to 6 feet in diameter, follow fractures into the limestone wall rock for distances of 50 feet from the dikes.	Ariz. Bur. Mines file data.

TABLE 16.—*Lead and zinc districts in Arizona*—Continued

Locality No. in figs. 27 and 28 and county and district	Principal lead and zinc mines, date of discovery ( ), and years of principal production 1/	Mode of occurrence	References to mode of occurrence
Cochise--Continued			
7. Dos Cabezas-Teviston	Numerous mines (1890): Moderate amounts of lead and zinc produced as byproducts of gold mining.	Base-metal sulfides in gold-silver-quartz fissure veins that cut metamorphosed, black Cretaceous shale.	Wilson and others, 1934, p. 117-120.
8. Dragoon	Abril, San Juan, Golden Rule (ca 1883): Lead, 1908-23, sporadic since 1940; Zinc, sporadic since 1943.	Zinc, copper, and lead sulfides in garnet tactite replacement bodies in impure, shaly limestone of Permian age. Ore bodies are localized beneath low-angle, bedding-plane faults, and are associated with northeast-trending fissures. Locally, as at Golden Rule, production has come from quartz veins in limestone containing sulfides and oxidized minerals of lead, zinc, copper, and silver, and free gold.	Wilson, 1951a, p. 20-29.
9. Cochise (Johnson, Winchester)	Republic, Mammoth, Peabody, Copper Chief (1881): Zinc, 1944-63; Lead, comparatively small.	Copper and zinc sulfides in tactite replacement bodies in the form of chimneys and mantos at or near the intersections of mineralized faults and fractures with shaly and impure limestone units in both the Naco Formation (Permian) and the Abrigo Formation (Cambrian).	Cooper, 1950, p. 36-37; 1964, p. 133-183.
10. Whetstone (Benson)	Mainly from old smelter cleanup (ca 1890): Lead, about 450 tons prior to 1929.	Minor production from fissure veins.	Ariz. Bur. Mines file data.
Coconino			
11. Jacobs Canyon	Minor production of lead in 1933 and 1942.	No data.	----------
12. Havasu Canyon	Ninety-two tons of lead produced in 1943-44.	No data.	----------
Gila			
13. Green Valley (Payson)	Approximately 4 tons of lead, and less than 1 ton of zinc produced, mainly between 1933 and 1952 (ca 1875).	Argentiferous galena in quartz fissure veins that occupy east-trending fault zones.	Lausen and Wilson, 1925.
14. Young (Spring Creek)	One small shipment of lead ore in 1941.	No data.	----------
15. Pinto Creek (Pinto Valley)	Small shipment of lead ore in 1934.	No data.	----------
16. Globe-Miami	Defiance, Irene, Albert Lea (1874): Lead, 1911-50; Zinc, 1916, 1925, 1937, 1941-42, 1951-53.	Lead, zinc, and copper sulfides and oxidized minerals carry gold and silver in fissure veins and replacement veins in breccia zones. Faults containing the veins strike generally northeast and dip steeply. Wall rocks mainly Precambrian quartzite and diabase.	Peterson, 1950; 1962, p. 118-133.
17. Pinal Mts.	Denial claim: Lead, 1934-49, intermittent.	No data.	----------

TABLE 16.—*Lead and zinc districts in Arizona*—Continued

Locality No. in figs. 27 and 28 and county and district	Principal lead and zinc mines, date of discovery ( ), and years of principal production 1/	Mode of occurrence	References to mode of occurrence
Gila--Continued			
18. Banner-Dripping Spring	Seventy-Nine, London-Arizona (1879): Lead, 1913-30, 1933-38, 1941-51; Zinc, 1917, 1937-47, 1951-52.	Galena, sphalerite, pyrite, and quartz in replacement bodies in shattered, alternating, thin-bedded shale and impure limestone members of the Naco Formation, and as small, discontinuous vein replacements in fractured and brecciated parts of a prominant rhyolite porphyry dike.	Kiersch, 1951, p. 73-74.
Graham			
19. Stanley	Stanley Butte, Starlight (1886): Lead, 1945-53.	Galena, anglesite, cerussite, and various copper minerals in small irregular replacement masses in Paleozoic limestone.	Ross, 1925a, p. 113-114.
20. Aravaipa	Grand Reef, Iron Cap, Head Center (ca 1870): Zinc, 1923-28, 1942-57; Lead, 1915-20, 1923-31, 1937-55.	Lead and zinc sulfides and oxidized minerals in fissure veins and replacement bodies in intrusive rhyolite and brecciated Pennsylvanian limestone. Vein deposits occur in low-angle fault zones and bedding-plane slips, and in steeply dipping fissures.	Wilson, 1950b, p. 56; Ross, 1925a; Simons, 1964, p. 119-127, 131-149.
21. Lone Star	Small lots of lead-gold ore shipped in 1934.	No data.	----------
Greenlee			
22. Ash Peak	Ash Peak (ca 1900): Lead, 1936-39.	Lead produced as a byproduct of silver mining. Argentite, pyrite, and some galena in a gangue of quartz, calcite, and rhodochrosite fill a fissure vein that strikes N. 60° W. and dips 80° N. Vein cuts Tertiary rhyolitic to andesitic tuffs and flows.	Lines, 1940, p. 3-4.
23. Morenci (Copper Mtn.)	Several small mines (1872): Lead, 1934-50.	Galena in quartz-filled fissure veins which follow porphry dikes. Veins cut more or less metamorphosed Paleozoic and Mesozoic sedimentary rocks.	Lindgren, 1905, p. 200.
24. Metcalf	Several small mines (ca 1872): Zinc, 1939-41; Lead, 1939-48.	Galena and sphalerite in quartz gangue fills fissure veins that trend northeasterly and dip steeply. Veins cut granite and porphyry.	Lindgren, 1905, p. 200-201.
Maricopa			
25. Sunflower	Tri-Metals: Lead, 1947, 1949.	No data.	----------
26. Cave Creek	Approximately 1-1/2 tons lead produced during 1934-39, as byproduct of gold mining.	Copper, gold, silver, and lead minerals occur in veins that consist of fine-grained, grayish quartz in silicified brecciated zones of northward strike and steep dip. Country rock is altered schist, intruded by dikes of granite porphyry and rhyolite porphyry.	Lewis, 1920; Wilson and others, 1934, p. 164.
27. Pikes Peak	Three or four small lead-silver mines. Total lead production less than 5 tons.	No data.	----------

TABLE 16.—*Lead and zinc districts in Arizona*—Continued

Locality No. in figs. 27 and 28 and county and district	Principal lead and zinc mines, date of discovery ( ), and years of principal production 1/	Mode of occurrence	References to mode of occurrence
Maricopa--Continued			
28. Wickenburg-San Domingo	Small production of lead, 1942-50, as byproduct of gold mining.	No data.	----------
29. Vulture	Montezuma (1863): Lead, variable production, 1936-50.	Lead-silver minerals in quartz gangue fill fissure veins in Precambrian granite and schist and Cretaceous(?) andesite.	Ariz. Bur. Mines file data.
30. Osborn	Belmont-McNeill, Moon Anchor: Lead, 1926-30, 1937, 1941-44.	Lead and copper sulfides and oxidized minerals carry gold and silver in a siliceous vein that strikes N. 60° E. and dips vertically. Vein occupies a brecciated zone in volcanic rocks that ranges from 1 foot to 20 feet wide.	Do.
31. Gila Bend Mts.	One mine: Lead, 1 to 2 tons produced in 1935 and 1946.	No data.	----------
32. Big Horn	Lead Dyke: Lead, about 7 tons, 1942-49; Zinc, 500 lbs., 1949.	No data.	----------
Mohave			
33. Bentley	Grand Gulch (ca 1853): Lead, small shipments, 1942-43 and 1957.	Oxidized lead minerals occur in very small quantities with copper sulfides and oxidized minerals along the periphery of a pluglike body of unstratified sandstone, intrusive(?) into Supai Sandstone.	Hill, 1915, p. 48-49.
34. Copper Mtn. (Andrus Canyon)	Copper King: Lead-zinc, 1949.	Oxidized lead and zinc minerals occur sparingly with oxidized copper minerals that also carry gold and silver. Minerals are localized along northwest-trending fissures which dip steeply and cut flat-bedded Supai formation.	Hill, 1915, p. 56.
35. Minnesota (Eldorado Pass)	Several mines (ca 1900): Small shipments of rich gold-silver-lead ore, 1934-42.	Gold, silver, and lead minerals in quartz veins that cut Precambrian granite.	Schrader, 1909, p. 218.
36. Gold Basin	Several small mines (ca 1870): Lead, less than 20 tons, as byproduct of gold mining, 1937-41.	Galena and cerussite in gold-bearing quartz fissure veins that cut Precambrian granite, gneiss, and schist.	Schrader, 1909, p. 118-127.
37. Weaver	Several small operations (1892): Lead, less than 5 tons, as byproduct of gold mining, 1934-48.	Galena and free gold in quartz gangue occur as stringers and irregular masses along the walls of low-angle faults in andesite	Schrader, 1909, p. 216; Wilson and others, 1934, p. 79.
38. Music Mtn.	Several small mines (ca 1880): Lead, less than 15 tons, as byproduct of gold mining, 1935-48.	Galena in gold-quartz fissure veins which strike N. 40°-50° W. and dip 75° to vertical. Veins cut Precambrian granite, gneiss, and schist and younger granite and diabase of uncertain age.	Schrader, 1909, p. 142-151.
39. Cottonwood	Lead, about 2 tons, as byproduct of gold mining, 1934-41.	No data.	----------

TABLE 16.—*Lead and zinc districts in Arizona*—Continued

Locality No. in figs. 27 and 28 and county and district	Principal lead and zinc mines, date of discovery ( ), and years of principal production[1/]	Mode of occurrence	References to mode of occurrence
Mohave--Continued			
40. Peacock	Old Hackberry (ca 1875): Lead less than 2 tons, 1935-36.	Lead produced as a byproduct of silver mining in siliceous fissure veins in granite.	Schrader, 1909, p. 141.
41. Wallapai	(Tennessee-Schuylkill, Golconda (ca 1860): Zinc-lead, 1911-17, 1936-48.	Lead-zinc-silver sulfides and oxide minerals in steeply dipping siliceous fissure veins which strike north or N. 60° W. and cut Precambrian igneous and crystalline metamorphic rocks.	Dings, 1950, 1951; Schrader, 1909, p. 51-118.
42. San Francisco	Vivian (ca 1860): Lead, small quantity produced in 1938 and 1949 as byproduct of gold mining.	Gold in calcite and quartz gangue which fills a fissure vein that carries minor amounts of silver and lead. Vein strikes N. 75° W., dips about 80°-85° S., and cuts green chloritic andesite. Vein ranges in thickness from a fraction of an inch to 3 or 4 feet.	Schrader, 1909, p. 196.
43. Maynard	Great Eastern, Enterprise (1865): Small intermittent production; 1937 best single year with 10 tons lead and 7 tons zinc produced.	Argentiferous galena and sphalerite with quartz gangue in northwest-trending fissure veins that cut Precambrian granite.	Schrader, 1909, p. 139-141.
44. Cedar Valley	Antler, Copper World (1879): Lead, 1935-56, Zinc, 1945-54.	Sphalerite, chalcopyrite, and galena in massive sulfide replacement bodies and as open-space vein-filling material in northeast-trending zones, which are parallel to schistosity of enclosing Precambrian schist. Ore shoots are closely related, spatially, to pegmatite dikes and lenses.	Romslo, 1988, p. 5. p. 5.
45. Chemehuevis	Mohawk: Lead, small shipments, 1934-51, aggregate less than 5 tons.	Galena and pyrite, which carry gold and silver, occur in veins of coarse-textured, brecciated white quartz in schist. Veins trend northeastward and range from less than an inch to about 1-1/2 feet in thickness.	Wilson and others, 1934, p. 116.
46. Owens	McCracken (1874): Lead, 1933-41, 1947-49, 1951-57; Zinc, 1949, 1957.	Argentiferous galena and minor gold in a gangue of calcite, siderite, quartz, and barite, which cement fragments of schist and quartz in fissure veins; veins cut a complex of schistose diorite and pink pegmatite, and strike north, dip about 65° E., and range from 6 to 20 feet in width.	Bancroft, 1911 p. 125.
47. Signal (Greenwood)	Small shipment of lead in 1941.	No data.	----------
Pima			
48. Growler	Several small shipments of lead in 1939.	No data.	----------
49. Gunsight (Meyer)	Gunsight (1878): Lead, 1881-84, 1936, 1943.	Oxidized lead-silver minerals in siliceous veins that cut granite. Veins strike N. 20°-30° E. and dip 50°-60° NW.	Ariz. Bur. Mines file data.
50. Quijotoa	Tres Metals, and other mines (1883): Lead, small shipments in 1934-35, 1939, 1942.	No data.	----------

TABLE 16.—*Lead and zinc districts in Arizona*—Continued

Locality No. in figs. 27 and 28 and county and district	Principal lead and zinc mines, date of discovery ( ), and years of principal production[1/]	Mode of occurrence	References to mode of occurrence
Pima--Continued			
51. Cobabi (Comobabi)	Several small producers (1850): Shipments in 1934, 1938-42, 1952 total about 40 tons lead and 1 ton zinc.	Silver-lead-gold minerals in fissure veins in granite and andesite.	Ariz. Bur. Mines file data.
52. Santa Rosa	Several small shipments of lead, 1934-35.	No data.	----------
53. Silver Bell	El Tiro, Atlas, Arizona-Indian (1865): Lead, 1909, 1916-19, 1923-29, 1941-50, 1956-64; Zinc, 1915, 1947-64.	Argentiferous lead, zinc, and copper sulfides and carbonates in veins and irregular replacement bodies in Paleozoic sedimentary rocks.	Ruff, 1952; Ariz. Bur. Mines file data.
54. Roskruge-Waterman	Silver Hill (ca 1880): Lead, 1941-47.	Lead, copper, and silver sulfides and oxide minerals in fissure veins and tabular replacement bodies in Paleozoic limestone and quartzite.	Ariz. Bur. Mines file data.
55. Baboquivari	Two or three small mines in southern part of district: Lead, 1931-35, 1938-39, 1951-52.	Galena, pyrite, and chalcopyrite in a coarse-grained quartz-calcite gangue in fissure veins that cut unmetamorphosed, to schistose Cretaceous clastic sedimentary rocks, which are intruded by dikes of granite and diorite porphyry. Deposits primarily worked for gold.	Wilson and others, 1934, p. 180.
56. Arivaca	Liberty, Tiger, Tunquepata (ca 1700): Lead, 1880-90, 1934, 1936-40, 1948-55; Zinc, 1949-50.	Lead-silver minerals in quartz veins that cut andesite and granite.	Ariz. Bur. Mines file data.
57. Cerro Colorado	Mary G., Oreona (ca 1700): Lead, intermittent, 1934-50.	do.	Do.
58. Pima	San Xavier, Pima, Mission (ca 1870): Zinc, 1912-17, 1943-67; Lead, 1876-1907, 1912-17, 1943-59.	Zinc-copper ore in tactite replacement bodies in limestone and arkose along faults and fractures, and near a granite intrusive. Lead-zinc and zinc-lead ore bodies occur as massive sulfide replacement deposits in limestone and brecciated andesite in strong fault zones, and as fissure vein deposits in arkosic and andesitic rocks.	Cooper, 1960; Wilson, 1950a.
59. Greaterville	Several small mines (ca 1870): Lead, about 160 tons since 1927; Zinc, 5 or 6 tons in 1946.	Argentiferous galena, sphalerite, and lead carbonate in banded quartz-calcite gangue in fissure veins that cut granite and sedimentary rocks.	Schrader, 1915, p. 152-158.
60. Helvetia (Rosemont)	Several small mines and prospects (ca 1860): Zinc, 1913, 1918, 1943-50; Lead, 1913, 1916-20, 1923-29, 1941-50.	Argentiferous galena in quartz-fluorite gangue in fissure veins that cut granite; chalcopyrite and sphalerite in tactite replacement bodies in Paleozoic limestone.	Schrader, 1915, p. 98-115.
61. Empire	Total Wreck (1879): Lead, 1881-82, 1907-10, 1917-18, 1922-28, 1937-42, 1946-50; Zinc, 1918, 1925, 1942-43.	Oxidized, siliceous lead-silver and zinc ore in fissure veins, and in replacement bodies in Permian limestone. Veins strike east and N. 30° E. and dip steeply. Replacement bodies extend outward from veins along bedding planes into wall rock.	Wilson, 1951c, p. 53.

TABLE 16.—*Lead and zinc districts in Arizona*—Continued

Locality No. in figs. 27 and 28 and county and district	Principal lead and zinc mines, date of discovery ( ), and years of principal production[1]	Mode of occurrence	References to mode of occurrence
Pima—Continued			
62. Rincon	Small shipments of lead in 1950.	No data.	----------
63. Amole	Palo Verde, Old Yuma (ca 1850): Lead-zinc, 1880-83, 1916, 1924, 1937, 1941-47, 1955.	Argentiferous galena, cerussite, and sphalerite in fissure veins and replacement bodies in limestone, volcanic rocks, and granite.	Jenkins and Wilson, 1920.
64. Control	Hartman: Lead, 1937, 1947-48, 1951, 1956-57; Zinc, 1948, 1951, 1956.	Zinc, lead, and copper sulfides in veins, and as replacement bodies at the contact between limestone and diorite. Copper has been principal metal.	Ariz. Bur. Mines file data.
Pinal			
65. Mammoth (Old Hat)	St. Anthony (Mammoth, Collins, Mohawk-New Years) (1879): Lead, 1935-57; Zinc, 1942-52.	Galena and sphalerite as fissure-filling material, and in wall rock replacement bodies. Principal veins cut rhyolite and quartz monzonite, strike between N. 50° W. and west, and dip steeply northeast. Considerable oxidation and development of several rare lead minerals above 900-foot level. Postmineral faulting has offset vein into at least two major segments.	Creasey, 1950a, 1965, 1967.
66. Bunker Hill	Blue Bird (1863): Lead, 1863-70, 1926-38, 1940-48.	Argentiferous galena in veinlets and streaks in quartz fissure vein that cuts granodiorite. Vein strikes N. 40°-60° E., dips 80°-85° SE., and ranges from 2 to 5 feet in width.	Kuhn, 1951, p. 63.
67. Saddle Mtn.	Adjust, Saddle Mtn., Little Treasure (ca 1875): Lead, 1922-27, 1934-36, 1953.	Argentiferous galena in quartz-barite-calcite gangue that fills fissure veins in Cretaceous andesite.	Ross, 1925b.
68. Ripsey	Florence Lead-Silver: Lead, Several small shipments, 1930-31 (primarily for silver), and in 1950.	Argentiferous lead, zinc, and copper sulfides and oxidized minerals fill fissures in a prominent fault zone.	Ariz. Bur. Mines file data.
69. Riverside	Lucky Strike, and other mines: Lead, small shipments, 1937.	Gold-silver-copper-lead minerals in a 4-foot-wide vein that cuts granite.	Do.
70. Mineral Creek (Ray)	Ray Silver-Lead, Lead Queen, Phillips (ca 1870): Lead, 1917-30, 1936-40, 1946-57; Zinc, 1949, 1952-57.	Lead-silver-oxide ore in fissure veins and chimneys localized along fractures in limestone.	Ariz. Mining Jour. 1918; Ransome, 1919.
71. Pioneer (Superior)	Magma, Belmont, Silver King (1873): Zinc, 1916, 1938-45, 1950-52; Lead, 1875-89, 1916, 1923-28, 1938-45, 1950-52.	Early lead production mainly from silver ore that occurred in a stockwork of quartz and lead-silver-copper sulfides in altered porphyry at the Silver King. Zinc-lead production from fissure veins and replacement veins along east-trending faults that cut Paleozoic limestone and Precambrian diabase and schist at both the Magma and Belmont, and, more recently, from irregularly shaped, bedded replacement deposits in impure limestone at Magma.	Blake, 1883; Short and others, 1943; Wilson, 1950c.

TABLE 16.—*Lead and zinc districts in Arizona*—Continued

Locality No. in figs. 27 and 28 and county and district	Principal lead and zinc mines, date of discovery ( ), and years of principal production[1]	Mode of occurrence	References to mode of occurrence
Pinal—Continued			
72. Mineral Hill	Several small mines (ca 1885): Lead, 1936-37, 1940-53, 1956; Zinc, 1948-52.	Argentiferous galena and sphalerite in manganiferous quartz gangue filling fissure veins that cut Precambrian mica schist.	Ariz. Bur. Mines file data.
73. Martinez Canyon	Silver Bell-Martinez (ca 1870): Lead, 1926-28, intermittent, 1937-52.	Argentiferous galena in a fault zone, 30 feet wide, that cuts granite and schist.	Do.
74. Blackwater (Sacaton Mts.)	One or two small shipments of lead ore in 1939.	No data.	----------
75. Picacho	Better Pay: Lead, 27 tons of ore shipped in 1940.	No data.	----------
76. Casa Grande	Jack Rabbit, Orizaba, Silver Reef, Hilltop (ca 1880): Lead, 1908-26 (sporadic), 1934-56; Zinc, 1917, 1950-51.	Argentiferous galena and minor sphalerite occur in narrow replacement bodies and in fissure veins with quartz gangue in faults and fractures. Faults and fractures cut limestone, granite porphyry, and, at the Silver Reef, volcanic flows.	Tenney, 1934.
Santa Cruz			
77. Tyndall	Montosa, Wandering Jew, Clove (ca 1700): Lead, 1911, 1913-14, 1916-17, 1924-28, 1941-59; Zinc, 1911, 1914, 1925, 1942, 1946-54.	Argentiferous galena, sphalerite, and copper sulfides in quartz-barite gangue, fill fissure veins in granitic rocks, and occur as massive sulfide replacement and contact-metamorphic deposits in Paleozoic limestone.	Schrader, 1915, p. 180-220.
78. Wrightson	Several small mines (ca 1880): Lead, 1935-39, 1942-47.	Lead and copper sulfides in quartz fissure veins and replacement bodies in monzonitic and andesitic rocks.	Schrader, 1915, p. 220-239.
79. Oro Blanco	Montana, Coctaw, Lucky Shot (1873): Lead, 1909-30, 1934-50; Zinc, 1917-18, 1928-30, 1934-50.	Galena, sphalerite, and quartz masses form ore shoots in the Montana shear zone, and form replacement bodies in conglomerate in the hanging wall of the shear zone.	Fowler, 1951.
80. Pajarito	Big Steve: Lead, 1934-35, intermittent 1941-53.	No data.	----------
81. Nogales	Several small mines: Lead, as byproduct of gold mining.	Gold, lead, silver minerals in quartz gangue fill fissure veins which cut quartz monzonite.	Schrader, 1915, p. 348-355.
82. Palmetto	Domino, Jarilla (ca 1880): Lead, intermittent, 1880-1905, intermittent, 1934-56.	Argentiferous galena and cerussite, in a gangue of banded quartz, fill fissure veins in quartz monzonite.	Schrader, 1915, p. 279-292.
83. Patagonia	Duquesne, Mowry, Pride of the West (ca 1700): Lead, 1858-1900, 1915-31; Zinc, 1915-17, 1930, 1940-59.	Argentiferous galena and oxidized lead minerals in quartz gangue, which fills fissure veins in granitic to monzonitic intrusive rocks, and in veins, massive sulfide replacement bodies, and tactite deposits in Paleozoic sedimentary rocks.	Schrader, 1915, p. 292-348.

TABLE 16.—*Lead and zinc districts in Arizona*—Continued

Locality No. in figs. 27 and 28 and county and district	Principal lead and zinc mines, date of discovery ( ), and years of principal production[1]	Mode of occurrence	References to mode of occurrence
Santa Cruz--Continued			
84. Harshaw	Alta, Flux, Hardshell, Josephine, Trench (ca 1850): Lead, 1882-1900, 1916-19, 1926-31, 1936-64; Zinc, 1939-64.	Siliceous lead-silver ore in large fissure veins that cut granitic and rhyolitic rocks, and that are generally associated with dikes and plugs of younger intrusive rocks.	Schrader, 1915, p. 245-279.
85. Redrock	Minor production of lead from prospects.	Galena and oxidized lead minerals in quartz fissure veins, which cut andesite, rhyolite, and conglomerate.	Schrader, 1915, p. 239-245.
Yavapai			
86. Tip Top	Tip Top and several other small silver mines (1875): Lead, 7 or 8 tons, 1935-43.	Argentiferous galena and various oxidized minerals in quartz gangue occur as a filling in sharply defined fissure veins which cut granite and pegmatite. Major veins trend northeast and dip steeply northwest.	Lindgren, 1926, p. 179-182.
87. Humbug	Several small mines: Lead, about 15 tons, intermittent.	Lead-silver-gold minerals in quartz gangue fill east-northeast-trending fissure veins which cut schist and granite.	Lindgren, 1926, p. 178-179.
88. Castle Creek-White Picacho	Lead Vein(?) (ca 1880): Lead, 1938-51.	Argentiferous galena and anglesite in manganiferous barite gangue in a breccia zone in granitic and andesitic rocks.	Lindgren, 1926, p. 186.
89. Blue Tank	Small shipments of lead in 1937.	No data.	----------
90. Black Rock	Gold Bar: Lead, intermittent 1934-50.	Gold-bearing lead, copper, and iron sulfide in veins that cut Precambrian igneous and metamorphic rocks. Mine worked chiefly for gold.	Ariz. Bur. Mines file data.
91. Silver Mtn.	Several prospects: Lead, about 10 tons.	Argentiferous galena and sphalerite occur in glassy quartz gangue in veins that cut granite.	Lindgren, 1926, p. 177.
92. Walnut Grove	Five or six small mines and prospects: Lead, several small shipments, 1937-41, 1949-51.	No data.	----------
93. Pine Grove-Tiger	Gladiator-War Eagle, Del Pasco, Crown King-Wildflower (1874): Zinc, 1905, 1913, 1915-17, 1942-50; Lead, 1908, 1910-1, 1916-18, 1921, 1934-50, 1955.	Sphalerite, galena, chalcopyrite, and tetrahedrite, carrying gold and silver, occur in quartz gangue in fissure veins that cut Precambrian granitic and crystalline metamorphic rocks. Vein systems trend north-northeast and dip steeply.	Lindgren, 1926, p. 164-175.
94. Black Canyon	Several small mines and prospects (ca 1870): Lead, 1908-13, 1917-19, 1921, 1934-42; Zinc, 1944-53.	Argentiferous galena and sphalerite in quartz gangue occur as fissure filling in nearly horizontal veins that cut Precambrian amphibolite and granite.	Lindgren, 1926, p. 152-159.

TABLE 16.—*Lead and zinc districts in Arizona*—Continued

Locality No. in figs. 27 and 28 and county and district	Principal lead and zinc mines, date of discovery ( ), and years of principal production[1]	Mode of occurrence	References to mode of occurrence
Yavapai--Continued			
95. Peck	Swastika, De Soto (1875): Lead, 1875-85, 1906, 1911-21, intermittent 1934-51.	Argentiferous lead and copper sulfides in a sideritic carbonate gangue filling fissure veins in Yavapai schist. Veins strike and dip essentially parallel to foliation of schist which ranges from north to N. 24° E. with steep dip.	Lindgren, 1926, p. 162-16 .
96. Agua Fria	Two prospects: Zinc, 4 tons and lead 2 tons, 1951-52.	No data.	----------
97. Ash Creek	Prospect: Lead, small shipment, 1934.	No data.	----------
98. Squaw Peak	About 25 tons of lead, 1935-37.	No.data.	----------
99. Black Hills	Shylock, Brindle Pup(?) (1890): Lead, intermittent, pre-1926, 1949-50.	Tetrahedrite, galena, and sphalerite in massive white quartz gangue, in a vein that cuts Precambrian bedded tuff.	Anderson and Creasey, 1958, p. 177.
100. Verde (Jerome)	United Verde, U.V.X. (1585): Zinc, 1948-53; Lead, 1917-18, 1949-56.	Zinc, lead, and copper in massive sulfide deposits which occur as tabular, lenticular, or pipelike replacement bodies in Precambrian tuff, rhyolite, quartz porphyry, and andesitic intrusive rocks.	Anderson and Creasey, 1958, p. 95-155.
101. Mineral Point	Four mines: Lead, small shipments, 1937.	No data.	----------
102. Thumb Butte	Last Chance Extension: Lead, several small lots of ore shipped in 1936 and 1954.	No data.	----------
103. Copper Basin	Boston-Arizona, Silver Gulch: Zinc, 1937, 1942-52; Lead, 1937-53.	Galena and sphalerite, carrying some gold and silver, occur in veins that cut Precambrian crystalline rocks.	Ariz. Bur. Mines file data.
104. Eureka (Bagdad)	Hillside, Copper King, Old Dick (ca 1880): Lead, 1887-99, 1909-12, 1914, 1917-18, 1920, 1925-27, 1934-67; Zinc, 1917-20, 1925-27, 1937-67.	Sphalerite, galena, and chalcopyrite occur in quartz gangue in fissure veins that cut mica schist, and occur as massive sulfide replacement bodies in chlorite and biotite schist derived from metamorphism of tuff and nonvolcanic clastic material.	Anderson, 1950; Anderson and others, 1955, p. 83-96.
105. Kirkland	Several small mines and prospects: Lead, small shipments in 1934, 1937, and 1953.	Lead and copper sulfides in quartz gangue in veins.	Ariz. Bur. Mines file data.
106. Martinez	Two or three mines (ca 1870): Lead, small shipments in 1936 and 1939.	Argentiferous galena, pyrite, and gold in coarse-textured quartz gangue in veins that occupy northward-dipping fault zones, which cut biotite granite and greenstone dikes. Ore shoots form flat lenses near footwall of veins. Deposits worked chiefly for gold.	Wilson and others, 1934, p. 69-73.

TABLE 16.—*Lead and zinc districts in Arizona*—Continued

Locality No. in figs. 27 and 28 and county and district	Principal lead and zinc mines, date of discovery ( ), and years of principal production[1/]	Mode of occurrence	References to mode of occurrence
Yavapai--Continued			
107. Weaver (Octave)	Octave (ca 1865): Lead, 1908, 1911, 1916, 1928-29, 1932-42, 1950.	Galena and pyrite in coarse-textured, grayish-white quartz gangue in fissure veins that cut granitic rocks. The main Octave vein occurs within a fault fissure that strikes N. 70° E. and dips 20°-30° NW.	Wilson and others, 1934, p. 66-67.
108. Turkey Creek	Several small mines and prospects (1872): Lead, intermittent, 1907-55; Zinc, one small shipment, 1947.	Argentiferous galena, tetrahedrite, and sphalerite in drusy comb-quartz gangue that fills steeply dipping fissure veins. Veins strike north to N. 20° E. and cut Yavapai Schist.	Lindgren, 1926, p. 149-152.
109. Hassayampa	Cash, Dos Oris, Blue Dick (1874): Lead, 1900-05, 1912-18, 1925-30, 1934-52; Zinc, 1911-13, 1916, 1926-30, 1943-54.	Argentiferous galena, sphalerite, and oxidized lead minerals in massive quartz and quartz-barite gangue, fills fissure veins which cut schist and greenstone.	Lindgren, 1926, p. 114-126.
110. Walker	Sheldon, New Strike, Emma, Oro Plata (ca 1865): Lead, 1908-19, 1923-27, 1930-55; Zinc, 1911, 1913, 1942-55.	Galena, sphalerite, chalcopyrite, and tetrahedrite in quartz-calcite gangue fill fissure veins which cut granodiorite. Veins strike predominantly northeast and dip steeply.	Lindgren, 1926, p. 109-113.
111. Big Bug	Poland, Silver Belt, Arizona National, Lelan-Dividend, McCabe-Gladstone (ca 1870): Lead, 1870-1931; Zinc, 1915-26. Iron King: Zinc-lead, 1906-67.	Zinc, lead, and copper in massive sulfide deposits in veins that occupy a mylonitic sheared zone in Precambrian foliated volcanic rocks.	Anderson and Creasey, 1958, p. 156; Creasey, 1950b.
Yuma			
112. Planet	Townsend: Lead, about 3 tons, 1936-40.	No data.	----------
113. Ellsworth	Several small mines: Lead, 80-85 tons, intermittent, 1900-1952.	Quartz veins contain galena and generally follow the schistosity of the enclosing rock.	Bancroft, 1911, p. 101
114. Plomosa	Lucky Lead (ca 1900): Lead, 1942-55; Zinc, 1948-51.	Galena in quartz gangue occurs within a vertical fissure vein that strikes S. 15° E. and cuts silicified rhyolite(?).	Bancroft, 1911, p. 90-91.
115. Kofa Mts.	(ca 1900): One or two small shipments of lead in 1948.	Galena, disseminated in a gangue of fluorspar and calcite, occurs in a vein within a monzonite-porphyry dike that is intrusive into Precambrian(?) metamorphic rocks.	Jones, 1916, p. 164.
116. Neversweat	Silver Prince: Lead, small production, 1912, 1944.	Argentiferous galena, anglesite, and cerussite with a gangue of barite and gypsum occur in veins within a brecciated fault zone in schist.	Wilson, 1933, p. 128.

TABLE 16.—*Lead and zinc districts in Arizona*—Continued

Locality No. in figs. 27 and 28 and county and district	Principal lead and zinc mines, date of discovery ( ), and years of principal production[1/]	Mode of occurrence	References to mode of occurrence
Yuma--Continued			
117. Castle Dome	Flora Temple, Senora, Castle Dome (ca 1860): Lead, 1870-83, 1890-96, intermittent 1904-42, 1942-57; Zinc, less than 1 ton.	Argentiferous galena, in a gangue of fluorite, calcite, barite, and some quartz, fills fissure veins in steeply dipping fault zones which strike from north-northwest to northwest. Ore shoots are generally best where diorite porphyry forms one or both of the vein walls. Some productive veins cut Cretaceous(?) shale.	Wilson, 1951e, p. 101-102.
118. Silver-Eureka	Red Cloud, Black Rock (ca 1860): Lead, 1880-85, 1887-89, 1934-37, 1941, 1947-49; Zinc, 1947-49.	Oxidized minerals of lead, silver, and zinc in a gangue of quartz, fluorite, calcite, barite and various iron and manganese oxides fill fissure veins in granitic and andesitic rocks at the Red Cloud, and in sericite schist at the Black Rock. Veins strike north-northwest to west-northwest and dip from 35° NE. to vertical. Locally, argentiferous galena occurs as nodules and stringers.	Wilson, 1951d, p. 90-94.

[1/] Data on history and production abstracted from Elsing and Heineman (1936); U. S. Bureau of Mines, Minerals Yearbook, annual volumes; and Arizona Bureau of Mines file data.

VEIN DEPOSITS

Siliceous fissure veins carrying lead minerals, principally galena, and to a lesser extent minerals of zinc, copper, and silver, are numerous in the southwestern half of Arizona. With few exceptions, however, they have contributed little lead-zinc production. Primary ore minerals are galena, sphalerite, chalcopyrite (copper-iron sulfide), tennantite (copper-arsenic sulfide), and proustite (silver-arsenic sulfide); the gangue is predominantly quartz. In some districts the quartz is accompanied by various amounts of calcite, fluorite, barite, and rhodochrosite. The quartz ranges in texture from fine to coarse grained and in color from gray to white with some veins containing glassy-appearing varieties. In some districts the quartz is banded but in most places it tends to be massive. Although veins in different districts vary in strike, the majority trend either northwest, north, or northeast. Host rocks also differ in different areas. In the Morenci district (fig. 27, No. 23), Greenlee County, veins cut Paleozoic and Mesozoic limestone, sandstone, and shale, and in the Baboquivari Mountains (No. 55), Pima County, coarse-grained Mesozoic clastic sediments contain mineralized veins. Igneous and metamorphic crystalline rocks form the host rocks in parts of Mohave (Nos. 35, 36, 38, 40, 45), Pima (Nos. 49, 57), and Yavapai Counties (Nos. 86, 87, 90, 91, 99, 106, 107); and rhyolitic to andesitic flows and tuffaceous units predominate at the Ash Peak deposit (No. 22), Greenlee County, Vulture district (No. 29), Maricopa County, and in several other districts in Maricopa, Mohave,

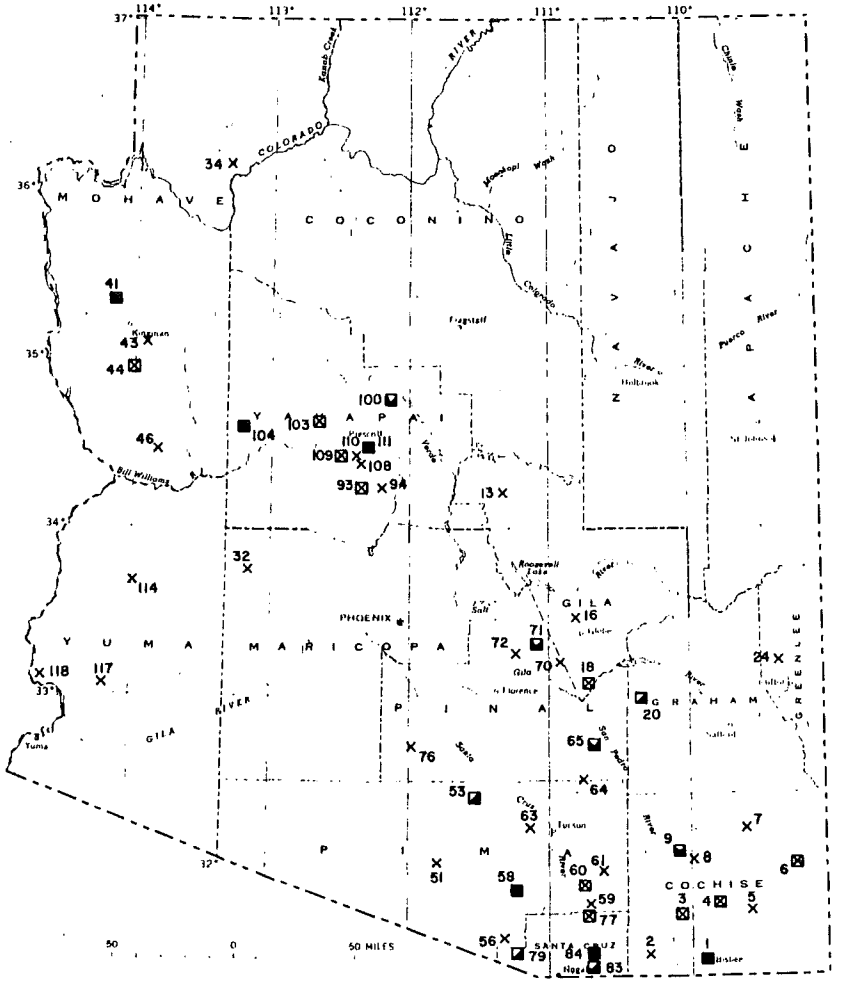


FIGURE 28.—Zinc in Arizona.

Pima, Pinal, Santa Cruz, and Yuma Counties (Nos. 30, 37, 42, 51, 56, 57, 63, 67, 76, 78, 85, 114).

Many of the siliceous fissure veins in Mohave and Yavapai Counties contained rich concentrations of gold and silver in their upper, oxidized parts, and were worked chiefly for those metals, lead and zinc being produced only as byproducts. The veins were abandoned when the rich, near-surface, precious-metal deposits had been exhausted. Notable exceptions to this, however, include the Wallapai district (No. 41), Mohave County, and the Pine Grove-Tiger district (No. 93), Yavapai County. In these districts, large quantities of lead and zinc were mined from the lower mine levels after the precious metals in the enriched upper parts of the veins had been essentially mined out. The Wallapai district ranks fifth among the lead-producing districts and third among the zinc-producing districts in the State, and the Pine Grove-Tiger district ranks 18th among the zinc-producing districts.

Fissure veins containing argentiferous galena, cerussite, and anglesite in a gangue of fluorite, barite, calcite, and gypsum, with variable amounts of iron and manganese oxides, although not as numerous as the siliceous veins, have been important producers of lead in the Castle Dome (No. 117) and Silver-Eureka (No. 118) districts, Yuma County, and have been moderately productive of lead in the Castle Creek (No. 88) and Peck (No. 95) districts, Yavapai County.

REPLACEMENT DEPOSITS

Lead and zinc replacement deposits occur in Arizona both as massive sulfide bodies and as tactite deposits. Although fewer in number than the vein type, the replacement deposits are by far the most important. Of the 10 top ranked lead-producing districts, 8 contain predominantly massive sulfide replacement deposits, and of the 10 leading zinc-producing districts, replacement deposits predominate in 8, of which 6 are massive sulfide deposits and 2 are tactite replacement deposits (see p. 187 and table 16).

The massive sulfide replacement deposits generally are rather simple mineralogically. Ore minerals consist of galena and sphalerite, usually with lesser amounts of chalcopyrite and pyrite. The sulfide masses occure peripherally to barren, siliceous, pyritic bodies and massive pyritic copper ore bodies, as at Bisbee (No. 1); at the intersections of northeast-trending fissures with other favorable structures, such as the anticlinal rolls at Tombstone (No. 3) and the low-angle faults in the Turquoise district (No. 4); or as wall-rock replacement masses in shear zones, as in the Mammoth (No. 65), Oro Blanco (No. 79), Eureka (Bagdad) (No. 104), and Big Bug (No. 111) districts. Favorable host rocks include shale and impure limestone of Paleozoic and Mesozoic ages, as in the Bisbee (No. 1), Tombstone (No. 3), Turquoise (No. 4), and Swisshelm (No. 5) districts; Precambrian schist and metavolcanics, as in the Cedar Valley (No. 44), Pioneer (No. 71), Eureka (Bagdad) (No. 104), and Big Bug (No. 111) districts; and various intrusive and extrusive igneous rocks, as in the Mammoth (No. 65) and Verde (No. 100) districts. The replacement bodies occur as tabular, lenticular, or pipelike masses, and are either flat-lying manto deposits, essentially

parallel to the replaced beds, or are steeply dipping, veinlike masses which follow shatter zones that cut across the favorable beds.

In the tactite replacement deposits lead is of minor importance; the chief metals are copper and zinc. The principal ore minerals, which are chalcopyrite, sphalorite, bornite, and pyrite, are disseminated throughout a silicate replacement mass that consists of various proportions of garnet, epidote, diopside, tremolite, and other lime silicates. Important deposits of this type occur in the Pima district (No. 58), which ranks fifth among the zinc districts, and in the Cochise district (No. 9), which ranks eighth among the zinc districts. In the Cochise district, the tactite bodies occur in the form of chimneys and mantos at or near the intersections of mineralizing faults and fractures with shaly and impure limestone units of Paleozoic age (Cooper, 1950). In the Pima district the tactite replaces limestone and arkose along faults and fractures near a granite intrusive (Wilson, 1950a).

Resources and Outlook

It is estimated that Arizona's lead resources total 500 million pounds and that zinc resources amount to about 1,000 million pounds. The greater proportion of the known lead and zinc occurrences are in the Jerome-Wickenburg area, which is part of a broad belt of deposits that extends northwesterly from Cochise County, through central Yavapai County to the vicinity of Kingman, Mohave County, and thence northerly to Lake Mead (figs. 27 and 28). Within this belt, two notable concentrations of deposits are apparent. In central Yavapai County, a large cluster of lead-bearing fissure vein cuts Precambrian granitic and metamorphosed sedimentary and volcanic rocks (see "Geologic map," fig. 5) and several zinc-lead replacement bodies occur in the metamorphic units. The second concentration of deposits is centered in Cochise, Santa Cruz, and eastern Pima Counties (figs. 27 and 28) and consists mainly of replacement deposits in Paleozoic and Mesozoic sedimentary rocks (fig. 5).

Under present (1968) market conditions, lead is not particularly attractive from an economic standpoint to the Arizona mining industry. However, the frequent association of silver with lead in Arizona deposits should stimulate the search for deposits from which both metals might be produced. (See "Silver," p. 251.) Zinc, on the other hand, enjoys a more stable market and, thus, the search for new deposits continues, and the observed relations of the lead and zinc deposits to the geologic conditions within the mineralized areas, as outlined in the paragraph above, should serve as useful guides for further prospecting.

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LITHIUM

(By James J. Norton, U.S. Geological Survey, Washington, D.C.)

Introduction

Arizona has produced only a negligible quantity of lithium minerals, but lithium has been found at several places. Industry has shown interest chiefly in the pegmatite area near Wickenburg (Jahns, 1952) and a clay deposit northwest of Kirkland (Norton, 1965).

Lithium, the lightest weight alkali metal, has experienced a vigorous growth in its industrial use since 1950. The opening of large new mines in various parts of the world has vastly increased supply and revolutionized the lithium mining industry. Until 1950 most mining was in small pegmatites from which spodumene and other minerals listed in table 17 were hand sorted; later the supply came chiefly from pegmatites suited to large-scale mechanized operations; and now the industry is centering its efforts on lithium in brines. These changes have not been without pitfalls, nor has publicity about new uses and new deposits always seemed cautious in the light of later events.

TABLE 17.—COMPOSITIONS OF LITHIUM MINERALS MINED FROM PEGMATITES

Mineral	Formula	Maximum theoretical content of Li_2O (weight percent)	Li_2O content of commercial concentrates (weight percent)
Spodumene	$LiAlSi_2O_6$	8.0	4–7.5
Lepidolite	$KLi_2AlSi_4O_{10}F_2$*	7.7	3–4.5
Petalite	$LiAlSi_4O_{10}$	4.9	†3.6–4.7
Amblygonite	$LiAlPO_4(F,OH)$	10.2	7.5–9.5
Eucryptite	$LiAlSiO_4$	11.9	†5.5–6.5

*Formula for polylithionite end member. Natural lepidolite has various proportions of muscovite molecule.
†For Bikita, Southern Rhodesia (Cooper, D. G., 1964, p. 460).

Lithium companies convert most of their raw material to lithium hydroxide or lithium carbonate before selling it, but several other compounds as well as lithium metal and alloys are manufactured. Lepidolite and petalite and smaller quantities of other lithium minerals go directly into some kinds of glass, ceramics, and porcelain enamel. The foremost uses of lithium compounds are in greases, ceramics and glass, welding and brazing, air conditioning, and alkaline storage batteries. A host of lesser uses and potential uses of lithium are mentioned by Schreck (1961, p. 3–9) and Eilertsen, 1965, p. 533).

Prior to 1950 there were few years in which consumption exceeded 1 million pounds of lithium carbonate or its equivalent. Eigo, Franklin, and Cleaver (1955, p. 83) said that total domestic consumption in 1951 was 3.02 million pounds, and they estimated the consumption for all except military uses in 1953 at 5.75 million pounds and in 1955 at 8.95 million pounds. Purchases by the Atomic Energy Commission were a major stimulant to production in the 1950's, but when they ended late in the decade, production dropped sharply. An increase resumed in the 1960's, and by 1966 consumption was 14 to 15 million pounds of lithium carbonate or its equivalent (Luckenbach, 1967, p. 153).

The modest needs of the lithium industry in its early years were met by small mines in zoned pegmatites from which spodumene, amblygonite, and lepidolite were hand sorted. The largest source for many years was the Etta spodumene mine, S. Dak. This pegmatite, which is circular and about 200 feet in diameter, has a quartz core surrounded by units containing about 22 percent spodumene, and these in turn are surrounded by zones containing quartz, feldspar, and mica without lithium minerals. Published maps (Norton and others, 1964, plate 25) show that it is similar to the Wickenburg pegmatites (Jahns, 1952).

After 1950 lithium minerals were obtained mostly from large mines and concentrated by milling techniques. Kings Mountain, N.C., became the center of activity in the United States. Its foremost mine, described most fully by Kesler (1961), has remarkably large unzoned spodumene pegmatites with about 1.5 percent Li_2O. Similar deposits were mined at Barraute, Quebec, and an extraordinarily large zoned pegmatite at Bikita, Southern Rhodesia, was worked mainly for lepidolite and petalite.

Another turning point seems to have appeared in 1966. In that year the Foote Mineral Co. began extracting lithium from subsurface brine at Silver Peak, Nev., and the Lithium Corp. of America was preparing to process brine at Great Salt Lake (Luckenbach, 1967, p. 152). Such sources are not totally new or surprising: lithium has long been one of the many products obtained by the American Potash and Chemical Co. at Searles Lake, Calif., and other brines and certain clays of the Southwest have promising amounts of lithium. The new feature is the indication that the preeminence of spodumene pegmatites is disappearing.

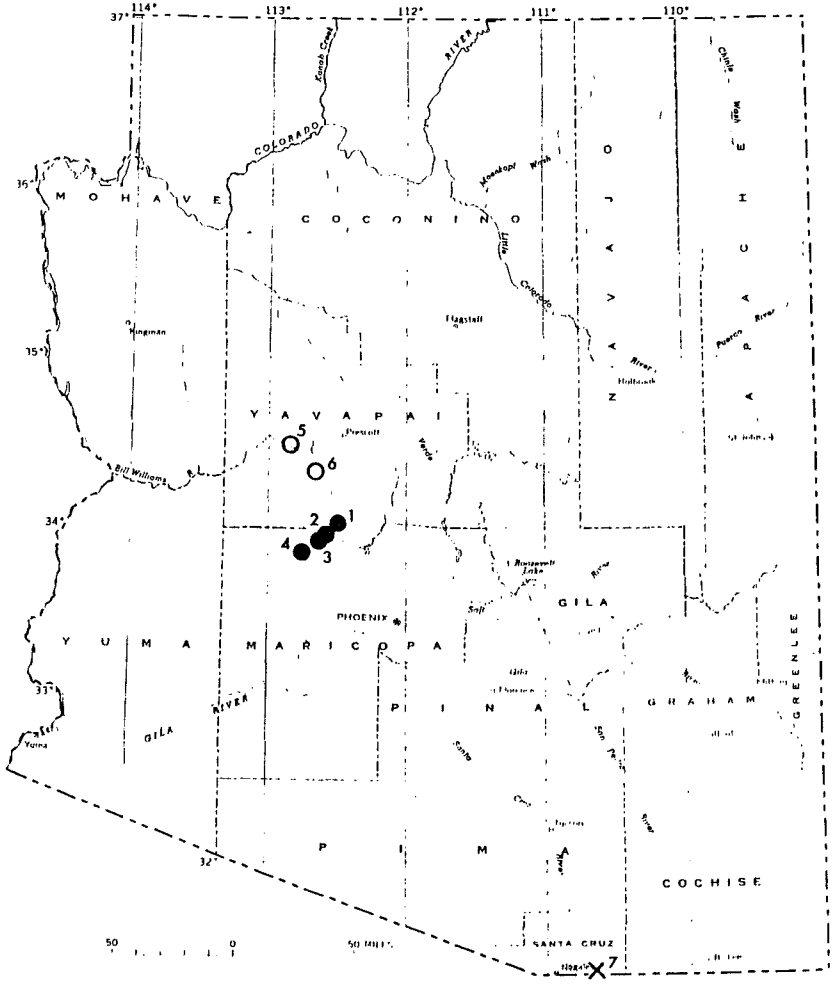
Reserves at Silver Peak, Nev., are estimated at 5–10 billion pounds of lithium, against previously known world reserves of about 2 billion pounds (Foote Mineral Co., 1967, p. 23). This estimate reinforces earlier statements (Kesler, 1960, p. 528; Norton and Schlegel, 1955, p. 325) that resources of lithium are enormous relative to the rate of consumption. Lack of need to find new deposits is one reason for the small interest shown by industry in Arizona's lithium.

Arizona Occurrences

The lithium deposits discovered near Wickenburg in the late 1940's are a part of the Arizona pegmatite belt. According to Jahns (1952, fig. 1), this belt extends from Lake Mead south to Kingman and thence over a broad area southeast to Wickenburg, and ultimately tapers to its end near the northwest corner of Pinal County. The pegmatites are in Precambrian rocks, and can be observed only where the widespread cover of younger sediments and volcanics is absent.

The locality attracting the most interest is about 10 miles east of Wickenburg in the White Picacho district. From field studies in the period 1948–52, Jahns (1952) has written a detailed, lengthy, and excellent modern description of the geology of these pegmatites. Only a brief summary can be presented here, supplemented by personal observations based on notes made during a visit to the district in October 1951.

The chief deposits are the Midnight Owl (see fig. 29, locality No. 1), near the divide between Independence Gulch and Trilby Wash, and the North Morning Star and Lower Jumbo (locality No. 2) on San Domingo Wash near the boundary between Yavapai and Maricopa Counties. All of these, as well as smaller lithium deposits in the same



EXPLANATION

● 1 Lithium-bearing pegmatite

○ 6 Lithium-bearing clay

× 7 Lithium-bearing mica

(Numbers refer to localities described in text)

Figure 29.—Lithium in Arizona.

localities, are in zoned pegmatites. Jahns (1952, p. 77) says the reserves of lithium minerals "probably amount to at least 8,000 tons." Recorded production is 88 tons of amblygonite and 75 tons of spodumene (Jahns, 1952, table 5).

Spodumene is more abundant in the deposits than amblygonite. Spodumene that has been altered, and its Li_2O content reduced to less than 5 percent, is common enough to have been of real concern to mine operators active in the district in 1951. Yet the importance of the problem can be exaggerated, for Jahns (1952, table 3) reports one analysis of a soft, weathered crystal that had 8.02 percent Li_2O. Lepidolite is widely distributed, but in amounts that in any one place rarely exceed 10 tons (Jahns, 1952, p. 67). Eucryptite has also been observed (J. W. Adams, oral commun., 1953).

The lithium minerals occur with feldspar and quartz in the inner parts of the pegmatites, surrounded by barren outer zones consisting of feldspar, quartz, and muscovite. Several pegmatites also have quartz cores.

Lithium-bearing inner zones are in the thicker parts of the pegmatites. Some pegmatites are of irregular shape, thick in some places and thin in others, and even of branching form; such a pegmatite may have lithium minerals at several different locations. Jahns illustrates complexities of this kind on his map of the Midnight Owl, but his ingenious diagram of the Lower Jumbo shows that the structure of such deposits is not as puzzling as it seems to be.

Scattered exposures of Precambrian rocks elsewhere in the Wickenburg region, but outside the area of Jahns' report, contain at least a few lithium pegmatites. One locality is near San Domingo Peak, in the southeast part of T. 7 N., R. 4 W., where the Spodumene Nos. 1 and 2 claims (locality No. 3) were being explored in October 1951. Another locality east of the center of T. 6 N., R. 5 W., contains the Vulture spodumene deposit (No. 4) (F. F. Clarke, written commun., 1951). Precambrian rocks to the north, in Yavapai County, are not known to contain lithium pegmatites except at Bagdad, where sparse lepidolite and amblygonite have been reported (Anderson and others, 1955, p. 21).

A lithium clay deposit occurs in Yavapai County about 9 miles N. 60° W. of Kirkland (No. 5) (Norton, 1965). Its content of 0.3 to 0.5 percent Li_2O led to cursory exploration in the middle and late 1950's. A hint that other such deposits exist in the region is furnished by a lithium occurrence southeast of Kirkland shown on two published mineral resource maps (McCrory and O'Haire, 1961; Stipp and others, 1967). Samples brought to the Arizona Bureau of Mines in the mid-1950's "appeared to be a light colored volcanic ash which showed a low lithium content, not more than 0.5 percent Li, on the spectrograph"; the location, though not exactly known, is probably "on the east side of Peebles Valley in the northeast quarter of T. 11 N., R. 4 W." (No. 6) (S. B. Keith, written commun., 1968). The description is reminiscent of the clay northwest of Kirkland.

Elsewhere in Arizona little effort has been expended to find lithium minerals, and even where they have been found, information is scanty. Olson and Long (1957) said that lithium minerals have been found in the Sierrita Mountains, Pima County, but did not give the names

of the minerals or any other information. Localities with zinnwaldite, which is a lithium mica rarely if ever used commercially, have been reported by Galbraith and Brennan (1959, p. 105). They and others have particularly mentioned zinnwaldite at the Line Boy mine, about 2 miles south of Duquesne (No. 7), Santa Cruz County. A description of this mine by Schrader (1915, p. 347) contains a statement that white mica is abundant in quartz monzonite country rock near the contact of a granite porphyry dike. This white mica is almost surely the mineral identified as zinnwaldite, but the mineralogic and chemical data on which the identification was based can no longer be found (S. B. Keith, written commun., 1968).

Outlook

Lack of evidence for lithium-bearing brines in Arizona may reflect only incomplete knowledge. The lithium content of a brine is likely to be so small that it escapes notice, yet the brine may have commercial value, especially if other products can be recovered. Luckenbach (1967, p. 152) reports 0.04 percent lithium at Silver Peak, Nev., where the brine is processed for its lithium alone, and 0.006 percent lithium at Great Salt Lake, where other constituents are to be extracted with lithium. Anyone testing a brine in Arizona for its economic value should ascertain its lithium content.

The most encouraging aspect of lithium in Arizona is that it has been detected in so many places. Unfortunately the lithium industry now has little interest in small zoned pegmatites, and it never has looked with favor on lithium clays. Yet the possibility is still open that a lithium deposit will be found in Arizona that can compete with sources elsewhere.

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MANGANESE

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Review of Industry

Manganese is an essential raw material in the making of steel, being used primarily as a desulfurizer and deoxidizer and secondarily as an alloying element. About 95 percent of manganese consumption is by the steel industry. It is also used in the chemical, paint, and fertilizer industries and as a depolarizer in the common dry battery.

Manganiferous material and ores are widespread in Arizona; 723,675 long tons of ore, concentrate, and manganiferous material have been produced in the State since manganese mining began in 1915. Most of this material was produced during the 1951–59 subsidy stockpiling program and has not been consumed. Some was produced for fluxing material in the smelting of base-metal ores, minor quantities were used for fertilizer, and some was shipped for direct use in making steel.

In 1966 the world produced about 18 million long tons of manganese ore. In that year, the United States produced about 10,000 short tons. The average annual import for consumption by the United States for 1964–66 was 2.5 million short tons of ore averaging 47.4 percent manganese. In addition, during the same period we imported annually for consumption about 240,000 short tons of ferromanganese containing 76.5 percent manganese.

The steel industry uses manganese as ferromanganese, to a much lesser extent as speigeleisen, and to a minor extent, manganiferous iron ore containing between 5 and 35 percent manganese. To make ferromanganese (an alloy containing about 10–15 percent iron and 70–80 percent manganese), the manganese-iron ratio of the ore must be about 7:1 or higher; a lower ratio is permissible in making speigeleisen (an alloy containing about 20 percent manganese) but the use of this alloy is uncommon owing to the increased costs it imposes on steelmaking. Manganiferous iron ore is not common; most produced in the United States comes from the Cayuna Range in Minnesota

Principal sources of manganese ore used in the United States are Gabon, Brazil, South Africa, Ghana, and India. There is no shortage of high-grade (plus 46 percent manganese) manganese ore in the world but the U.S.S.R., China, Brazil, and the Republic of South Africa are the only major industrial nations with adequate domestic sources of such ore. Relatively little manganese ore containing less than 40 percent manganese is imported.

The nominal price in 1966 was about $0.73 per long ton unit (22.4 pounds contained manganese) for ore containing 48–50 percent manganese, and about $0.68 per long ton unit for ore containing 46–48 percent manganese. The unit price times percentage of contained manganese gives value of ore per long ton. Prices were rather stable between 1956 and 1966, for supply was ample and the larger consumers had developed their own sources of supply. In earlier decades, however, prices—particularly for domestic ores—fluctuated greatly. Our dependence on foreign sources made it essential to produce during wartime as much as possible from our small and high-cost deposits; during depressions demand was so small and prices fell so low that only the lowest-cost producers could ship ore. During the 1950's, the Government acquired large stocks of high-grade imported ore and smaller stocks of low-grade manganiferous rock and of concentrate containing more than 40 percent manganese produced in the United States at subsidized prices. These stocks are still being held. There is little chance that another critical wartime stringency will recur as long as these stocks are maintained.

In 1951, acting under Congressional direction, the General Services Administration set up a manganese-purchasing depot at Deming, N. Mex. and in 1953 another at Wenden, Ariz. These depots accepted material containing as little as 15 percent manganese and paid more than $2.00 per contained long ton unit, more than twice the world price, for ore containing 48 percent manganese. From 1951 until 1955, when the depots were closed, they received from Arizona mines 349,521 tons of material containing less than 35 percent manganese and 17,210 tons of ore and concentrates containing more than 35 percent manganese (Farnham and others, p. 3). Most of the material contained between 15 and 20 percent manganese; such material is not usable unless concentrated.

After this program of purchasing low-grade material was stopped, a "carlot" purchasing program was established and continued until 1959. In this program only ore and concentrate containing more than 40 percent manganese were accepted and no more than 10,000 tons of ore or concentrate per year could be sold from each mine. The price was more than $2.00 per long ton unit. The subsidized price stimulated miners to concentrate their low-grade ore; thus, more than 230,000 long tons of plus 40 percent ore and concentrates were produced in Arizona during the carlot program. This material is quite usable by industry, although it cost the Government much more than imported ore of better grade would have cost. With the termination of the subsidized price, production of manganese ore from Arizona essentially ceased and no production has been recorded after 1961.

Annual production of manganese ores from Arizona for 1915–65 is shown in figure 30. Material containing less than 35 percent manganese was used primarily for smelter flux until the 1951–55 stockpiling episode. The responsiveness of manganese production to high prices during wartime is apparent.

Technology of beneficiation of low-grade manganiferous materials has progressed enormously since 1940 owing to research carried on by the U. S. Bureau of Mines and by industry. However, at present and foreseeable world prices for manganese, it is unlikely that concentra-

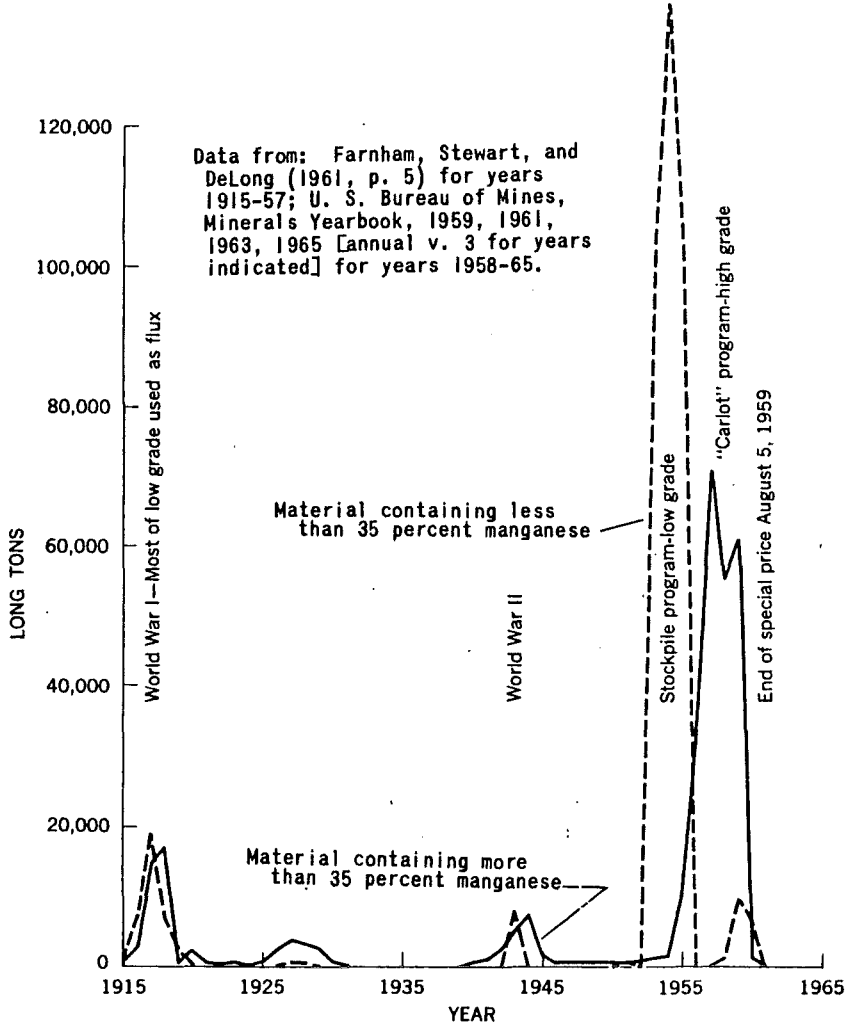


FIGURE 30.—Manganese production in Arizona, 1915–65.

tion of these ores will be economic except under emergency conditions. Because the overall domestic resource is small, many believe that low-grade ore is best left in the ground until needed. The graph shows that, after the first spurt under artificial stimulus, production declined even with the high prices after easily won ore was extracted.

TYPES OF MANGANESE DEPOSITS

Commercial concentrations of manganese occur in various environments and have various origins. Characteristics such as size and shape of deposit, mineralogy and grade of ore, continuity in depth, and

amenability to mining and concentration result from the environment and origin. Ideal ores from an economic viewpoint are those that occur in large high-grade deposits of regular shape that either need no concentration or can be concentrated by simple methods.

Most manganese deposits can be classified into three types, as determined by their manner of formation: (1) Sedimentary deposits, many modified by metamorphism and supergene enrichment; (2) vein and replacement deposits, which are hydrothermal in origin; and (3) spring deposits, which are hydrothermal in origin but form at or near the surface.

Most of the major deposits of the world (those containing more than 10 million tons of ore) are sedimentary in origin. These are *syngenetic*, that is, they formed at the same time as the enclosing rocks. Such deposits tend to have uniform grade, regular shape, and are simple to mine. Only washing and sizing is needed to yield a high-grade concentrate. Also, most have no serious contaminants such as arsenic, alkalis, lead, copper, tungsten, or zinc, all of which are deleterious in steelmaking, and many have extremely favorable manganese-iron ratios. In the past, only deposits of the manganese oxides have been mined but at present sedimentary deposits of the manganese carbonates are becoming economically interesting because the carbonates can easily be converted to manganese oxide by roasting.

A number of major deposits of sedimentary manganese carbonate rocks, high, medium, and low grade, have been oxidized and concentrated under tropical weathering conditions into large high-grade oxide ore deposits. In many, the sedimentary rocks have been modified by metamorphism, complicating the mineralogy and distorting the structure so that the deposits are more difficult to mine. Such deposits are generally confined to the zone between lats. 30° N. and 30° S., where tropical and subtropical weathering has been intense.

Spring deposits are formed by the subaerial or subaqueous deposition of manganese minerals, commonly the oxides, from hot waters. This type of deposit may be relatively large but the admixture of rock debris generally leaves the grade so low that the manganese cannot be economically extracted. This type may grade into the sedimentary type and is of course closely related to the vein type. These ores are syngenetic.

Vein and replacement deposits generally occur as veins, impregnations, and irregular replacement bodies. They are *epigenetic*, that is, they were formed after the host rocks. The manganese was introduced by waters or gases from deep within the earth. In few places are such bodies large enough to be of significance, but there are literally thousands of them and they aggregate a considerable tonnage of manganese. The ore minerals are intimately mixed with the gangue in most such deposits and separation of ore minerals into a salable concentrate may be difficult. Furthermore, many deposits contain an appreciable percentage of base metals and penalties are assessed against such ore, as it must be mixed with other ore or purified before it can be used to make steel. Deposits of this type characteristically occur in small irregular bodies which range widely in grade and shape. They often are complicated to mine and the material from them is costly to process.

Weathering and the oxidation of manganiferous carbonate or sulfide minerals and migration of oxide minerals under near-surface condi-

tions in all these types of deposits results in mobilization of manganese and redeposition in oxide form with resulting secondary enrichment. This may extend to depths of several hundred feet or more. The amount of such enrichment depends primarily upon the nature of the original manganiferous material, upon the physiographic history of the area, and upon the past and present climates. A humid tropical climate promotes enrichment.

At least 80 percent of the manganese of world commerce is won from sedimentary deposits, much from original sedimentary oxides, the balance from manganese oxides that have been concentrated by the weathering of lower-grade sedimentary manganese carbonate and manganiferous carbonate and oxide rocks. Other types of manganese deposits are of minor economic significance.

World reserves of manganese ores are ample, totaling more than 3 billion tons of material minable at present or slightly higher prices. The principal known deposits are in South Africa, U.S.S.R., India, Australia, central Africa, and South America. It is expected that more major deposits will be found. Furthermore, enormous quantities of low-grade manganiferous nodules occur on the sea floor at depths of 3,000 feet or more. Although these nodules cannot be mined economically today, expected improvements in technology might make them recoverable at some future time.

Arizona Manganese

Jones and Ransome (1920) published an excellent résumé of the manganese industry in Arizona as it was known about the end of World War I and described the geologic features of the major deposits. This work later was supplemented by a general study by Wilson and Butler (1930), updating Jones and Ransome's work. Just before and during World War II, many geologists of the U.S. Geological Survey and engineers of the U.S. Bureau of Mines worked in Arizona to evaluate the deposits and stimulate production. A significant part of the work in the Artillery Mountains was reported by Lasky and Webber (1944; 1949). Later examinations made in the mid-fifties were reported by Farnham and Stewart (1958) for western Arizona, and by Farnham, Stewart, and DeLong (1961) for eastern Arizona. Because manganese mining essentially ceased with the end of the subsidy program in 1959, the work of Farnham and Stewart (1958) and of Farnham, Stewart, and DeLong (1961) provides up-to-date information on the productivity of the deposits, mining methods and the metallurgy of manganese in the State and are a primary source of much information about the individual deposits. For additional information, the reader is referred to the bibliographies in the above-cited publications and in particular to the excellent bibliography by Moore and Wilson (1965, p. 252–253), which lists 50 titles on manganese deposits in Arizona. Some additional references are cited in the text that follows.

Table 18 presents general information on the major groups of deposits as well as separate mines in Arizona that have shipped more than 100 tons of ore or manganiferous rock to stockpile or market. These deposits are identified by locality numbers in figure 31. Some mines that produce more than 100 tons may have been omitted for lack of information. Most of the output went to stockpiles and did not enter

TABLE 18.—*Principal manganese-producing districts and mines in Arizona*

Locality No. in fig. 31	County and district or mine	Approx. total production (long tons) of ore (O) or concentrate (C)	Approx. grade of shipments (percent Mn)	Approx. remaining resource (long tons)	Approx. grade in ground (percent Mn)	Type of occurrence and remarks	References
	Cochise						
1	Bisbee	35,000 (O)	± 40	± 30,000	< 30(?)	Vein and replacement. Contains 0.25-2 percent copper.	Farnham and others, 1961, p. 9-24; Wilson and Butler, 1930, p. 46; Jones and Ransome, 1920, p. 119.
2	Courtland	± 250 (O)	15-35	< 1,000	<15-30(?)	Vein and replacement. Contains silver.	Farnham and others, 1961, p. 37-42.
3	Tombstone	8,800 (O) 206 (C)	±35 ±35	< 10,000	<15-30	do.	Farnham and others, 1961, p. 24-37; Needham and Storms, 1956.
	Coconino						
4	Heber	> 600 (O)	35-45	< 2,000(?)	<15(?)	Residual.	Farnham and Stewart, 1958, p. 11-12.
5	Johnson and Hayden	> 300 (O)	28	< 1,000	<15	Breccia.	Farnham and Stewart, 1958, p. 12-13.
6	Long Valley	700 (C) >3,300 (O)	32-42 >40	< 2,000(?)	±10	Replacement and residual.	Farnham and Stewart, 1958, p. 7-11.
	Gila						
7	Apache	302 (O) 1,540 (C)	45-49 47-50(?)	±5,000	5.5	Breccia. Contains >0.25 percent copper.	Farnham and others, 1961, p. 81-84.
8	Black Point	224 (O)	16-28	(?)	3-5(?)	Breccia.	Farnham and others, 1961 p. 79-80.
9	Giant Cactus	185 (O)	6.8	(?)	6	do.	Farnham and others, 1961 p. 80-81.
10	Globe	±25,000 (O)	17-45	±20,000	±6-10	Vein, breccia, and replacement. Ores contain base metals and silver.	Farnham and others, 1961, p. 46-77.

11	Ireland	140 (O)	24	< 1,000	< 10(?)	Breccia.	Farnham and others, 1961, p. 78-79.
12	Sunset	110 (O)	25	< 1,000	< 10(?)	do.	Farnham and others, 1961, p. 86-87.
	Graham						
13	Black Hawk	220 (C) 16 (O)	43 47	< 1,000	< 10(?)	Vein; breccia.	Farnham and others, 1961, p. 91-92.
	Greenlee						
14	Black Rock	775 (O)	10-37(?)	< 1,000	± 10(?)	Replacement(?).	Farnham and others, 1961, p. 101-102.
15	Denton	> 1,000 (C) and (O)	±39	< 2,000	±10(?)	Breccia.	Farnham and others, 1961, p. 99-101.
16	Oliver	160 (O)	19	< 1,000	±10(?)	do.	Farnham and others, 1961, p. 96-97.
	Maricopa						
17	Aguila	> 15,000 (O) 15,000 (O) 4,300 (O)	<15 >15 35-43	> 2,000(?)	±10(?)	do.	Farnham and Stewart, 1958, p. 15-25.
	Mohave						
18	Artillery Mtn.	> 295,000 (O) 77,000 (O)	<15 >15	± 175,000,000	±3.9	Sedimentary. Much of enriched ore already extracted.	Farnham and Stewart, 1958, p. 25-36.
19	Black Burro	820 (O)	18	(?)	± 10	Sedimentary.	Farnham and Stewart, 1958, p. 54.
20	Black Diamond	135 (O)	29	< 1,000	± 10(?)	Breccia	Farnham and Stewart, 1958, p. 56.
21	Mesa Manganese	± 300 (O)	16.5	< 1,000	± 15(?)	do.	Farnham and Stewart, 1958, p. 52-53.
22	Oversight	1,360 (O)	15	(?)	± 10	Sedimentary.	Farnham and Stewart, 1958, p. 52.
23	Pilot Rock	± 500 (O)	35(?)	< 1,000	± 15(?)	Vein.	Farnham and Stewart, 1958, p. 54.
24	Yucca	± 400 (O)	20-40	< 1,000	± 15(?)	Sedimentary(?).	Farnham and Stewart, 1958, p. 55.

TABLE 18.—*Principal manganese-producing districts and mines in Arizona*—Con.

Locality No. in fig. 31	County and district or mine	Approx. total production (long tons) of ore (O) or concentrate (C)	Approx. grade of shipments (percent Mn)	Approx. remaining resource (long tons)	Approx. grade in ground (percent Mn)	Type of occurrence and remarks	References
	Pima						
25	Stella Maris claims	± 7,000 (O)	26-48	± 2,000(?)	25-48	Replacement. Some excellent ore from this group.	Farnham and others, 1961, p. 109.
	Pinal						
26	Black Prince	± 250 (O)	21-31	< 1,000	10(?)	Vein; breccia.	Farnham and others, 1961, p. 157.
27	Crescent	1/650 (O) 2,825 (O)	40 20	< 1,000(?)	10(?)	Breccia-replacement.	Farnham and others, 1961, p. 144.
28	Superior	± 30,000 (O) 10,157 (C)	28 28	>50,000(?)	10-20(?)	Vein-replacement. Base metals and silver in ore.	Farnham and others, 1961, p. 125.
29	Zig Zag	± 500 (O)	(?)	> 1,000	10-20(?)	Vein; breccia. Copper in ore.	Farnham and others, 1961, p. 150.
	Santa Cruz						
30	Bender	> 3,900 (O) and (C)	20	> 2,000(?)	20(?)	Replacement. Silver in ore.	Farnham and others, 1961, p. 165.
31	Mowry	7,500 (O)	25	> 5,000	20(?)	Vein; breccia. Silver in ore.	Farnham and others, 1961, p. 159.
	Yavapai						
32	Black Buck	> 600 (O)	21	< 2,000(?)	10(?)	Vein.	Farnham and Stewart, 1958, p. 61.
33	Blue Tank	1,400 (O)	17	< 1,000	10(?)	Vein; breccia.	Farnham and Stewart, 1958, p. 60.
34	Box Canyon	± 1,000 (O)	< 20	< 1,000	10(?)	Breccia.	Farnham and Stewart, 1958, p. 59.
35	Burmister	>'3,400 (O)	50-53	< 2,000(?)	+ 40(?)	Hot spring.	Farnham and Stewart, 1958, p. 63-64.

36	Harris	>1,300 (O)	28-41	<1,000(?)	20(?)	Vein.		Farnham and Stewart, 1958, p. 57-59.
	Yuma							
37	ABC	±300 (O)	41	<1,000	30(?)		do.	Farnham and Stewart, 1958, p. 81.
38	Black Beauty	±360 (O)	16	<1,000	5-10(?)		do.	Farnham and Stewart, 1958, p. 77.
39	Black Dahlia	230 (O)	27	<1,000	10(?)	Breccia.		Farnham and Stewart, 1958, p. 84-85.
40	Black Top	384 (O)	26	<1,000	10(?)	Vein.		Farnham and Stewart, 1958, p. 85.
41	Bouse	800 (O) +3,000 (C)	17-36 23	<1,000	5-10(?)	Vein; breccia.		Farnham and Stewart, 1958, p. 71-77.
42	Cibola	>3,000 (O)	25-30	<2,000	10-20(?)		do.	Farnham and Stewart, 1958, p. 79-80.
43	Doyle	±70,000 (O)	15-16	>100,000(?)	5-10(?)	Sedimentary.		Farnham and Stewart, 1958, p. 68-70.
44	Hovater	230 (O)	18	<1,000	5-15(?)	Vein; breccia.		Farnham and Stewart, 1958, p. 87.
45	La Angora	>150 (O)	44	<2,000	20-30(?)	Replacement.		Farnham and Stewart, 1958, p. 82-83.
46	Lucky	97 (C) 275 (O)	34 20	<1,000	10-20		do.	Farnham and Stewart, 1958, p. 67.
47	Matate	>230 (O)	20	<1,000	10-20		do.	Farnham and Stewart, 1958, p. 82.
48	National Debt	±812 (O)	20	<2,000	10-20	Vein; breccia.		Farnham and Stewart, 1958, p. 83.
49	Spring	90,000 (O)	4-5	>100,000	3-4	Sedimentary.		Farnham and Stewart, 1958, p. 70.

1/Questionable figure

22-299 O—69——15

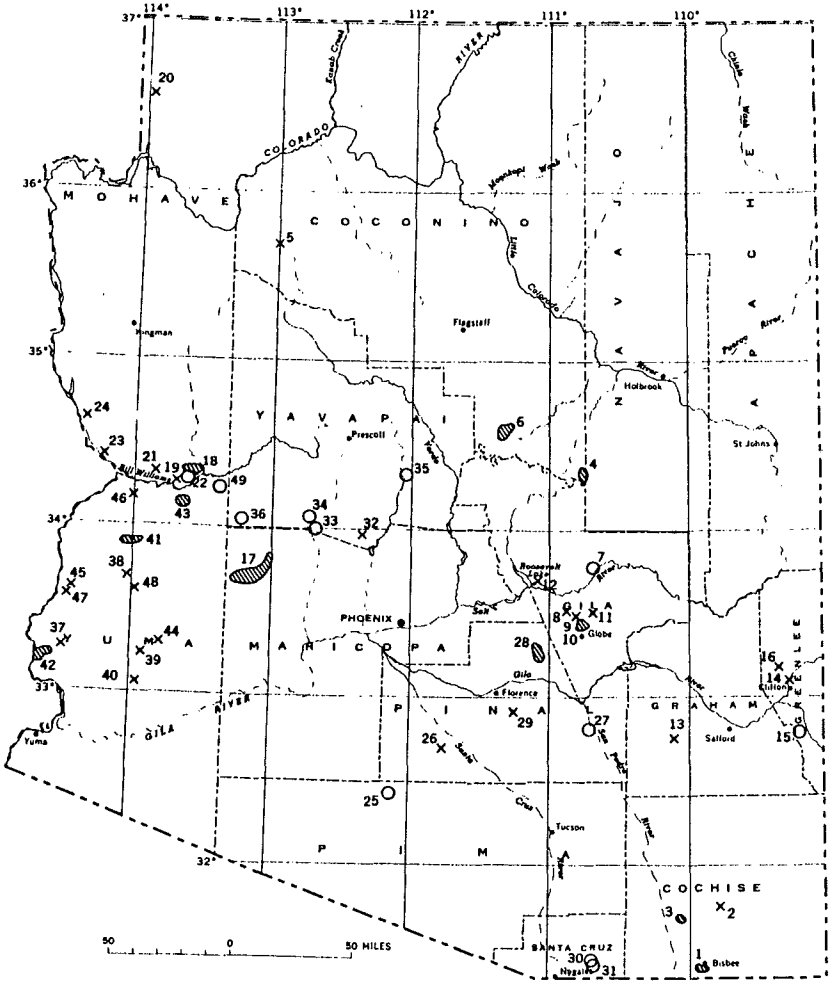
into commerce. Details may be found in Farnham and Stewart (1958) and in Farnham, Stewart, and DeLong (1961) and in their cited references on the specific location, access, and names of the individual mines, amenability and beneficiation of the ores, and recovery of silver and base metals from the ores.

SYNGENETIC DEPOSITS

Manganese deposits in the vicinity of the Artillery Mountains have been known for many years and are among the more important syngenetic deposits in the United States from the viewpoint of total contained manganese oxide. These deposits occur north of Aguila and south of Kingman, on both sides of the Bill Williams River near the confluence of the Big Sandy River (see locality 18, fig. 31). The primary manganese oxides occur in the Chapin Wash Formation of Pliocene(?) age. This formation is a playa and alluvial fan deposit formed in a fault basin; it is composed of lenticular beds of conglomerate, sandstone, clay, tuff, and other clastic sediments, the whole aggregating probably at least 1,350 feet in thickness (Lasky and Webber, 1949, p. 31). Two zones of manganiferous material are known in the formation, a lower one which has not been well explored and does not crop out extensively, and an upper one, the target of most of the exploration and development work. Manganese oxides in the upper zone in the Artillery Mountains are present in an interval as much as 350 feet thick, but, according to Lasky and Webber (1949), they are concentrated in a zone 65 feet thick. This zone has been explored by drill holes as much as a mile back from the outcrop. The bulk of the manganiferous zone may average between 3 and 4 percent manganese, about the same in iron, and slightly more than 1 percent barium oxide. Some concentrate from the manganiferous material contains more than 2 percent lead.

The manganese occurs as wad interstitial to fragments of coarser clastic material. It is believed by some to have been derived from hot springs of volcanic origin draining into the playa basin, although direct evidence of such springs is not known (Lasky and Webber, 1949, p. 69). Wilson (1950) states that some geologists believe that the manganese may have been derived from the erosion of an extensive ferruginous manganese deposit of hypogene origin, now destroyed by erosion or covered by later rocks. Lasky and Webber believed that the manganese was deposited in finely and coarsely particulate form. The origin of these deposits is also discussed by Hewett (1966, p. 457).

The low-grade (3–4 percent manganese) syngenetic deposits of wad have been reworked near the outcrop and near certain faults by supergene solutions. This action has enriched the original lower-grade material by replacement of clay and other minerals by manganese oxides and in general has hardened the rock. M. D. Crittenden (oral commun., 1968) believes that much of this modification, particularly near faults, is the result of hydrothermal solutions. The enrichment is only a few percent in most of the area as presently known but locally the rock may contain from 10 to 20 percent manganese. Such material also has a much more favorable manganese-iron ratio. The enrichment probably occurred at several periods in the past and may be continuing today.



EXPLANATION

10
District

Mines, showing relative size in total long tons of ore or concentrate produced

O7 More than 1,000	X11 100 to 1,000

(Numbers refer to localities listed in table 18)

FIGURE 31.—Manganese in Arizona.

Much of the ore mined in this district during the 1950's came from such areas of secondary enrichment.

Lasky and Webber (1949, p. 81), basing their estimates on boreholes and other exploratory work done before 1939, estimated the total amount of manganiferous rock in the Artillery Mountains deposits as shown below:

Manganese (percent)	*Tons*
More than 20	70,000
15 to 20	460,000
10 to 15	2,250,000
5 to 10	17,000,000
Less than 5	175,000,000

(Cutoff about 1.5 percent; average grade 3–4 percent)

Thus the total amount of elemental manganese present in the upper zone is about 7.5 million tons, which is contained in about 200 million tons of rock which would have to be mined and milled to recover the manganese. The manganiferous material is overlain in most places by tens to hundreds of feet of overburden which would have to be removed before the zone could be mined by open-pit methods.

Subsequent to Lasky and Webber's work, manganiferous rocks similar to the Chapin Wash Formation have been found in a much wider area and include those at the Doyle mine (No. 43, fig. 31) south of the Bill Williams River. During the subsidy period of mining, much of the easily accessible higher-grade material in the Chapin Wash Formation was removed and future mining will be forced to depend to a large extent on the lower-grade resources.

According to Farnham and Stewart (1958, p. 31), between the time the Lasky and Webber (1949) estimate was made (June 1941) and January 1956, 372,000 tons of ore were mined from the Artillery Mountains area, of which 77,000 tons containing 15 percent or more manganese was shipped to the Wenden purchasing depot. The balance, containing less than 15 percent manganese, was concentrated in local mills to a grade of more than 15 percent until the low-grade purchasing plan stopped; thereafter the materials were concentrated to a grade of more than 40 percent manganese.

The lower manganiferous zone, about 700 to 1,000 feet stratigraphically below the upper zone, is still relatively unknown, although on the basis of present knowledge the grade of the unenriched manganiferous material is expected to be similar to that in the upper zone. Because of the physical position of the zone, however, secondary enrichment probably will not be as extensive as in the upper zone.

A syngenetic manganese deposit of entirely different type is at the Burmister mine (No. 35, fig. 31) in Yavapai County, about 14 miles southeast of Mayer, Ariz. Here manganese oxide occurs in disconnected pods and lenses as much as 2 feet in thickness in tufa deposits. The tufa ranges from 1 to 10 feet in thickness and is overlain by basalt. Production from 1917 through August 1954 totaled 3,485 tons of ore averaging nearly 52 percent manganese.

A similar but lower-grade deposit, the Black Duke (not shown in fig. 31 or table 18) occurs in the same travertine (tufa) deposit about a mile from the Burmister mine, according to Farnham and Stewart (1958, p. 64). The manganese oxide in these deposits was a chemical

precipitate rather than a clastic sediment as in the Artillery Mountains. According to M. D. Crittenden (written commun., 1942) the manganese and tufa probably originated in hot springs.

EPIGENETIC DEPOSITS

Epigenetic vein and replacement deposits are widely scattered throughout the State. They occur as fissure fillings and as irregular replacement bodies in a wide variety of rocks. In some districts the manganese minerals occur associated with or as the gangue of base-metal and silver ores, as in the vicinity of Tombstone (No. 3) and Bisbee (No. 1), Cochise County, near Globe (No. 10), Gila County, and near Superior (No. 28), Pinal County. With few exceptions, the grade of the manganese ore is low and the production of manganese has been insignificant compared to that of the associated metals. The principal concentrations of manganese are at the borders of the mining districts, indicating that the mineralizing fluids had dropped much of their base-metal and silver contents before the manganese was precipitated.

The manganese minerals are either the oxides, pyrolusite, psilomelane, hausmannite, hetaerolite, and braunite, or the carbonates rhodochrosite and black calcite (calcite containing finely divided manganese oxide), and, in Bisbee and a few other localities, the sulfide alabandite. Hewett and Fleischer (1960, p. 49) suggest that the primary minerals at Bisbee and Tombstone were alabandite and rhodochrosite; because manganese oxides were found at depths of 500 feet at the Shattuck mine and 1,300 feet at the Junction mine at Bisbee (associated with pyrite, sphalerite, and galena), and as deep as 2,000 feet in the Superior district, some oxides may have been primary. Hausmannite is generally considered to be a hypogene or metamorphic mineral; other common oxides may be either hypogene or supergene (Hewett and Fleischer, 1960, p. 51). In the Globe and Tombstone districts the manganese ores contain appreciable amounts of silver, lead, copper, and locally zinc. Much manganiferous material containing less than 35 percent manganese was shipped from Tombstone for the silver content; where the silver content was low, the manganiferous material was used as a flux at smelters.

Most of the material that was rich enough in manganese to be shipped as manganese ore was the product of secondary enrichment of the leaner primary protores. Writing of the Bisbee district, J. B. Tenney, *in* Wilson and Butler (1930, p. 46) states that the medium- and high-grade deposits of manganese oxides ". . . are commonly associated with nearly all the oxidized caps of the larger ore bodies of the camp, usually at a higher horizon than the typical limonite-silica gossans cut by the upper development levels."

In deposits in other mining districts, ore was rarely found deeper than 100 feet below the surface and most ore bodies played out at a depth of 50 feet or less. In the Bisbee, Tombstone, and Superior districts, the country rock of most of the deposits is limestone; in the Globe district, the country rocks are limestone, diabase, and quartzite. The ore bodies in these areas are controlled by faults and fissures which served as channelways for the mineralizing fluids.

Perhaps the most widespread, although not the most productive, type of manganese deposit in Arizona is interstitial fillings in breccia zones. These deposits are characterized by closely spaced fissures and shattered wall rocks, the voids being filled by manganese oxides. The deposits are typically small, low grade, and lack continuity. In most of the explored shatter zones, manganese oxides form 1.5 to possibly 10 percent of the total rock mass. Recovery of the ore minerals is effected by crushing and removal of waste by sink-float processes or other means. The degree of adherence of the manganese minerals to the barren rock varies greatly from deposit to deposit and within individual deposits and is a significant factor in recovery of the valuable minerals. The manganese oxides tend to be quite pure in many places, although locally they contain base metals and much black calcite.

Fissures in the shatter zones that are filled by oxides range from hairline cracks to as much as a foot or more in width. Pods of manganese oxides form at the intersection of major fissures and cracks. Some fissures are incompletely filled, whereas in others the manganese oxide is in the form of solid plates. In some localities the wall rock has been replaced to a minor degree, in others it is somewhat altered adjacent to the fissures, and in still others the wall rock shows no apparent sign of alteration. The gangue minerals are mostly calcite, black calcite, and quartz, and some deposits contain minor base metals. Secondary enrichment is locally important.

The breccia-zone type of deposit is gradational into typical vein deposits, in which the manganese is confined as a fissure filling in relatively unshattered rocks. The veins may be as much as 10 feet thick, although generally much thinner. The vein-filling material generally is a mixture of manganese oxide, calcite, black calcite, quartz, gouge, and fragments of wall rock. Few vein deposits have been minable below a depth of 75 feet; in most the ore is limited to a few tens of feet or less from the surface, where it has been concentrated by secondary enrichment. Vein deposits, however, tend to be longer along strike than the breccia deposits, and to have wider or richer shoots. In some vein deposits short ore shoots occur at intervals along a single vein which may be traced for hundreds of feet along strike.

In Arizona, oxide vein deposits are found in quartzite, granite, schist, limestone, tuff, and volcanic rocks. The most important host rocks are limestone and volcanic rocks. Most vein-type deposits are so irregular in form and erratic in grade that it is impossible to block out substantial quantities of ore before mining and therefore proved reserves are negligible.

An unrelated type of epigenetic manganese deposit is found in a few places in Arizona. It consists of manganese nodules that occur as concretions in soil. The nodules range from a fraction of an inch to several inches in maximum dimension and the material is easily confused with detrital ore. Tests in 1944 by the Reconstruction Finance Corp. of such ore from the Cummings claims (not shown in fig. 31 or table 18), Yavapai County, showed that the soil contained about 34 pounds of manganese in cleaned nodules per cubic yard (Farnham and Stewart, 1958, p. 62). The Long Valley deposits (No. 6, fig. 31), Coconino County, are

said to have produced ore both from a mineralized bed in the Kaibab Limestone and detrital ore derived from these beds. From the description of Farnham, Stewart, and DeLong (1961, p. 7–11), the manganese in the soil and gravels may be not only detrital but possibly also concretionary in origin. An analysis of a bed of gray limestone in the Kaibab Limestone at the Denison mine in Long Valley showed a content of 6.4 percent manganese (D. F. Hewett, written commun., 1968). Weathering of this limestone probably released large quantities of manganese to ground water, from which the manganese was precipitated as oxide concretions in the soil. The minable ore in the limestone was found in thin beds and nodular masses, the latter containing as much as a hundred tons of ore in exceptional cases. Concretionary ore is higher grade than most manganese ore in Arizona.

Outlook

Manganese production from Arizona will require subsidized prices substantially above present commercial levels. Although the Artillery Mountains area is one of the major sources of easily treated manganiferous material in the United States, the grade of the material is low in comparison with deposits mined elsewhere in the world. The low grade, the thick cover of overburden, and the large outlay of capital needed for large-scale mining and processing equipment make open-pit mining of the deposits uneconomic. The multitude of small deposits scattered widely through the state might support sporadic small-scale operations under conditions of high prices and national scarcity. It is possible that new deposits may be discovered, but it is unlikely they will be of great importance.

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MERCURY

(By E. H. Bailey, U.S. Geological Survey, Menlo Park, Calif.)

Introduction

Mercury, often referred to as quicksilver, is the only metal that at normal room temperature is liquid. Because of its liquidity and other nearly unique physical and chemical properties, it has thousands of industrial uses, and for many of these no satisfactory substitute has been found. Thus, with increasing industrialization throughout the United States and the world, there is an ever increasing demand for mercury (Bailey and Smith, 1964), which in recent years has resulted in it becoming a quite valuable metal. In 1967 it was worth about $6.50 a pound.

The use of mercury in fever thermometers and as an alloy in dental fillings is widely known, but it has much larger use in electrical apparatus, in bactericides and fungicides, medicines, and mercury batteries. Less well known is its major use in plants making chlorine, which is basic to the manufacture of plastics and detergents. Initially a single chlorine plant installation may require 150,000 pounds of mercury, and the amounts needed for new plants have in recent years markedly increased the U.S. consumption of mercury. Theoretically the mercury is not consumed in making chlorine, but actually there are small operating losses. The number of plants now in existence in the United States has recently become so large that the mercury needed to replace these unavoidable losses now forms a significant part of our annual domestic mercury consumption.

The liquid metal is marketed in steel flasks, about the size of half-gallon milk bottles, containing a standard 76 pounds of mercury, and the worldwide units of trade are these standard flasks. World production in recent years has been at a rate of a little more than 250,000 flasks annually, and U.S. consumption has been about 75,000 flasks, or almost a third of the world production. The production from domestic mines, however, is only about 20,000 flasks, or a fourth of our requirements. A part of our production-consumption gap is filled by secondary recovery, but generally more than half our consumption is supplied by imports, chiefly from Spain and Italy.

The domestic production of mercury has been, and is, chiefly from mines in the Coast Ranges of California. Of the total domestic production of about 3,500,000 flasks, Arizona mines have yielded less than 8,000 flasks. However, the recent increase in the price of mercury may result in Arizona gaining a greater proportionate share of the production. Mercury mining in Arizona has always been held down by the overall low grade of its deposits, but the higher price should now permit profitable exploitation of deposits that were previously too low in grade to be economic.

The recovery from the ore of the final product is more readily and cheaply done for this metal than for any other, with the possible exception of free gold. Consequently, the final product, which is 99.9 percent pure mercury, is typically made at the producing deposit, or perhaps at a nearby mine. The ore mineral, which is generally a bright-

red mercury sulfide called cinnabar, occurs sparsely scattered as crystals, grains, or veinlets through a large quantity of useless rock. To extract the mercury, the ore is placed in a container and heated enough to vaporize and release the mercury; then the vapor is moved to a place cool enough to condense it to the liquid metal. For the heating, two basic types of equipment are used—retorts and furnaces. Retorts are essentially stills in which the fuel gases do not mix with the mercury vapor; furnaces are fired internally, and the gases from the burning fuel are mixed with the mercury. Retorts are generally small, and after a batch of ore is treated they must be emptied and reloaded. Furnaces, on the other hand, are large and are fed and operated continuously. Either is capable of extracting more than 95 percent of the mercury in the ore, and the choice of installation is generally made on the basis of the quantity and quality of ore available for treatment. Retorts are much less expensive to install and are used to treat small amounts of rich ore, whereas furnaces are used to process large quantities of lower-grade ore. Both kinds of extractive equipment have been used at mines in Arizona.

Mercury also can be recovered from ore by a variety of other processes which are either used alone or in conjunction with concentrating equipment. Leaching with a sulfide or chloride solution is relatively simple, and the dissolved mercury can be easily precipitated on aluminum or some other metals, either with or without the aid of electric current. Ores to be leached are generally ground to a fine size. After grinding, flotation may be employed to greatly increase the cinnabar concentration prior to leaching, thereby decreasing the loss of reagents. Costs of treatment by these methods usually are considerably greater than by direct retort or furnace treatment, and generally processes involving concentration or leaching are used on ores so low in grade that normal heat processing is obviously uneconomic.

Most of the mercury deposits of the world are confined to a broad belt of quite young mountain building and volcanic activity, a part of which extends through the western United States (Bailey, 1962). Within the belt the deposits are found in a great variety of structural settings and in rocks of nearly all kinds and ages. Most of the deposits in Arizona occur along fault zones in Precambrian schists. The mercury was carried in solution in warm waters ascending along fractures, and it was deposited in the interval between 2,000 feet of depth and the surface, generally as cinnabar. As deposits formed near the surface are quickly eroded, geologically speaking, the deposits still available for mining are those young enough to have escaped erosion, generally those deposited in late Tertiary or Quaternary time. Thus, there is no relation between the age of the host rocks and the age of the mercury deposits in Arizona and elsewhere.

Although mercury minerals were first discovered in Arizona about a century ago, very little mercury was extracted until the late 1920's. The productive peak was achieved in 1929, when over a thousand flasks was recovered, and during the period of high prices related to World War II the annual production was only a little less. Since 1945 the annual output has never exceeded 500 flasks, and for several years no production was recorded.

Arizona Mercury

The first mercury discovery was made in the Dome Rock Mountains district (see fig. 32, locality No. 7) in 1875, and although the mine was developed to a depth of 600 feet by 1914 only a few hundred flasks seem to have been recovered. The deposit is reported to contain, in addition to cinnabar, some free gold, wulfenite, and various copper minerals (Lausen and Gardner, 1927, p. 30). The ore occurred in a shoot 2–3 feet wide and less than 50 feet long in a brecciated quartz vein paralleling the foliation in schist.

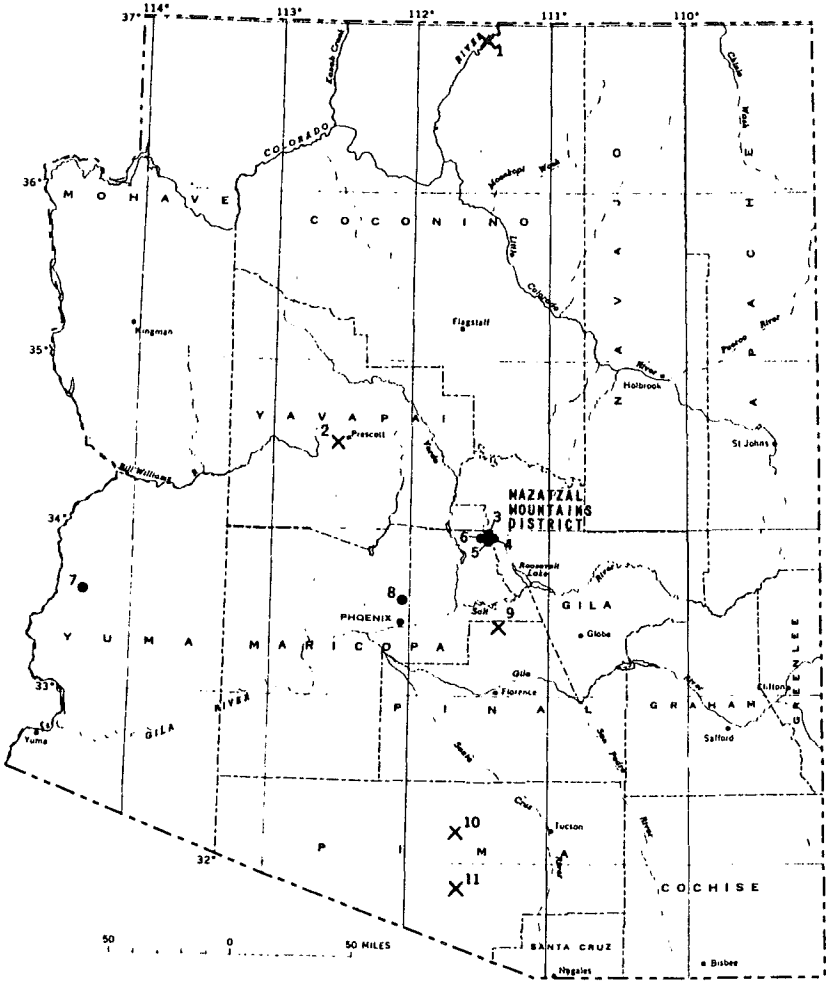
About 95 percent of the mercury recovered in Arizona has come from mines in the Mazatzal Mountains district (fig. 32) about 60 miles northeast of Phoenix. This district includes the Ord mine (No. 4) (Faick, 1958) with a production of about 3,000 flasks, the slightly less productive Pine Mountain mine (No. 3), the Sunflower mine (No. 6) with a production of more than a thousand flasks, the Rattlesnake mine (No. 5) with production included with the Ord mine, and a dozen prospects with production records of less than a hundred flasks. The larger ore bodies are along steep faults that nearly parallel the foliation of sericitized Precambrian schist. Where unaltered the schist is gray or maroon, but along the veins it is conspicuously bleached. Cinnabar is disseminated as minute crystals in the schist, in some places making the bleached schist pink, or it occurs as slightly larger crystalline masses in lenticular quartz carbonate veinlets. A very little native mercury and mercurian tennantite is also locally present. Pyrite, some copper minerals, and hematite accompany the ore in places. Tourmaline, once thought to have been deposited with the ore, is more likely a premercury component of the schists. The ore treated has generally contained less than 10 pounds of mercury to the ton.

In the Phoenix Mountains district (No. 8), 7 miles north of Phoenix, are several small mercury deposits. They were first noted in 1916 and have since had a production of less than a hundred flasks. The Phoenix Mountains consist of Precambrian metamorphic rocks, such as quartzite, slate, marble, and sericite and chlorite schist, intruded by dikes of diabase, and overlain on the northwest by much younger flows of basalt. Cinnabar occurs with quartz in pockets in quartz-sericite schist, and according to Schrader (1918), the black mercury sulfide, metacinnabar, was also found here.

At a few places in the Copper Basin district (No. 2), 7 miles southwest of Prescott, some cinnabar has been found. It is not certain if mercury was recovered here, but there are rumors that retorting yielded some, which was used in amalgamation at the nearby Mint mine. Cinnabar occurs with a little pyrite or limonite in silicified zones in Precambrian granite or along the edges of rhyolite dikes cutting the granite. The wall rocks near the ore shoots tend to be leached, silicified, argillized, or sericitized.

Mercury minerals have been noted in small amounts in several other parts of Arizona (see fig. 32, Nos. 1, 9–11). For data on most of these see U.S. Bureau of Mines (1965) and Wilson (1941).

Mercury has been found and mined in enough places in Arizona to indicate the State is one of the few with mercury potential. The



EXPLANATION

●6 Deposit or district with recorded production

X1 Occurrence with no recorded production

(Numbers refer to localities listed below and referred to in text)

1 Lees Ferry
2 Copper Basin district
3 Pine Mountain mine
4 Ord mine
5 Rattlesnake mine
6 Sunflower mine
7 Dome Rock Mountains district
8 Phoenix Mountains district
9 Nations Mercury
10 Roadside
11 Cerro Colorado

Figure 32.—Mercury in Arizona.

prevalent low grade of most of the ore has discouraged development, but the high price that has prevailed since early 1965 should encourage the further development of known deposits and stimulate limited search for new ones.

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MOLYBDENUM AND RHENIUM

(By Robert U. King, U.S. Geological Survey, Denver, Colo.)

Review of Industry

Molybdenum is a silvery white metal, somewhat softer than steel, having a melting point of 4,730° F. which is higher than all other metals except tungsten, rhenium, osmium, and tantalum. It has a specific gravity of 10.2, about as heavy as silver or bismuth.

Molybdenum is a metal of primary importance to our modern industrial and scientific community chiefly because of its superior properties as an alloying element in the iron and steel industry, but also because of its versatility in applications to the electric and electronics, missiles and aircraft, metal working, nuclear energy, chemical, glass, and metalizing industries as well as in such uses as lubricants, pigments, catalysts, and agricultural products. Somewhat over 85 percent of the molybdenum produced in the United States is used in the manufacture of high-temperature alloy steels, stainless steel, castings, and special alloys to which it imparts such beneficial properties as increased hardness, toughness, resistance to corrosion and wear, and high-temperature strength.

Commercial production began in the United States at about the close of the past century but it was small and intermittent until about 1914. Probably the first successful industrial application of molybdenum was its use as alloy in steel by the German military during World War I. Since that time production has increased yearly with few exceptions from an annual rate of about 200,000 pounds to the current annual rate of about 90 million pounds. During the first part of this century the United States produced only a fraction of the world's molybdenum supplies, but since 1925 has ranked first in world production with the development of the large molybdenite deposit at Climax, Colo., and the recovery of molybdenum as a byproduct from the large porphyry copper deposits in the Southwestern States.

Since 1925 from two-thirds to nine-tenths of the world's molybdenum has been produced in this country. Molybdenum, today, is produced in quantities sufficiently in excess of domestic consumption to supply a sizable part of the free world demand and is our country's only surplus commodity in the steel alloy field. U.S. consumption of molybdenum in 1966 amounted to slightly more than 75 million pounds whereas mine production was just over 90 million pounds of contained molybdenum (U.S. Bur. Mines, 1967, p. 331). A continued rise in both production and demand for molybdenum is foreseen for the remainder of this century.

Molybdenum is marketed chiefly in the forms of molybdenite concentrates ($1.62 per pound of contained molybdenum, at 95 percent MoS_2) or roasted concentrates (molybdenum trioxide) (Eng. Mining Jour., 1968, p. 24). Concentrates, however, are not normally marketable in small or individual lots, thus limiting the economic potential of small deposits.

Ore-grade molybdenum deposits in the United States range from 0.2 to 0.5 percent molybdenite in large ore bodies mined primarily for their molybdenum content, but molybdenum is profitably extracted as a byproduct from copper, uranium, and tungsten ores in which the molybdenum content ranges from 0.01 to 0.1 percent.

Molybdenum is widespread in the crustal rocks of the earth, but concentrations of commercial interest are found chiefly in igneous rocks of granitic composition or in volcanic and sedimentary rocks in close proximity to intrusive granitic rocks. The abundance of molybdenum in the crustal rocks is variously estimated to be from 1 to 2.5 parts per million (0.0001 to 0.00025 percent). It is present in trace amounts in the oceans, in ground water, soils, and in plant and animal tissues in which it apparently plays a vital role in many organic processes. It does not occur in its native or metallic state, but only in combination with other metallic elements such as arsenic, bismuth, calcium, cobalt, lead, magnesium, tungsten, and vanadium, and the nonmetallic elements sulfur and oxygen.

About 12 molybdenum-bearing minerals are known, but only two, molybdenite (molybdenum disulfide, MoS_2) and wulfenite (lead molybdate, $PbMoO_4$) have been the source of most of the molybdenum produced to date. Recently, however, two other molybdenum minerals, ferrimolybdite ($FeMoO_3 \cdot nH_2O$) and jordisite (amorphous molybdenum disulfide, MoS_2) have been found to occur in sufficient concentrations to be of commercial value for their molybdenum content. Also, as the demand for molybdenum continues to rise, powellite (calcium molybdate, $CaMoO_4$, generally with tungsten) and ilsemannite (blue, water-soluble molybdenum oxysulfate) are receiving more than passing interest either for their molybdenum content or geologic significance.

Rhenium, one of our scarcest metallic elements, has been intensively investigated since its rather recent discovery in 1925. Rhenium metal is silvery white, has a melting point of 3,180° C., the second highest of all metals, and has a specific gravity of 21, the fourth highest of metals. It is ductile, extremely hard, and has a high tensile strength. Although current production is small, and domestic consumption amounts to

less than 1,000 pounds per year, there is considerable interest in this metal for its potential applications in science and industry. In powder form, rhenium sells for $580 to $650 per pound (U.S. Bur. Mines, 1968, p. 124). Rhenium is used today in thermocouples, in filaments for mass spectrographs and ion gages. Potential uses of rhenium metal and rhenium alloys include electrical contacts, lamp filaments, metallic coatings, heat- wear- and corrosion-resistant alloys, and catalysts. Except for the one rare mineral dzhezkazganite, a rhenium-copper sulfide, discovered recently in copper ores in Russia, other rhenium minerals are not known. Molybdenite in general contains more rhenium than any other mineral. Rhenium is found in molybdenite in amounts ranging from traces to a few tenths of one percent, but rhenium has been found in trace amounts in copper, iron, silver, and in several base-metal sulfides as well as in wulfenite, powellite, uraninite and in complex niobium (columbium) and tantalum oxides.

The rhenium content of molybdenite in copper porphyry deposits ranges from a few times to as much as 100 times the content in molybdenite from other types of deposits. Small amounts ranging from a few parts per million to more than 100 parts per million of rhenium have been found in bedded molybdenum-uranium deposits in sedimentary rocks.

Rhenium is recovered from the roasting of molybdenite concentrates derived as a byproduct from the mining of copper and molybdenum sulfide ores in Arizona, Nevada, New Mexico, and Utah. Current U.S. production accounts for about 80 percent of the free world's supply, and amounted to about 2,000 pounds of metal in 1965. Significant increases in the rate of production of rhenium can be expected in the near future as additional rhenium recovery facilities are installed.

Molybdenum in Arizona

Molybdenum production began in Arizona in about 1915 and reached a maximum of about 500,000 pounds in 1917 (see fig. 33). From 1919 to 1932 little molybdenum was produced in Arizona; since then the gradual growth has brought production from less than 100,000 pounds in 1933 to just over 10 million pounds of metal in 1966. Early production of molybdenum came from deposits yielding molybdenum as a primary product from wulfenite ores of the Mammoth-St. Anthony district and copper-molybdenum sulfide ores from the Copper Creek district. Later molybdenum production, from about 1940 to the present, has been a byproduct of the recovery of copper from the large porphyry copper deposits. Arizona over the years has consistently ranked third in U.S. production of molybdenum, after Colorado and Utah.

The productive deposits of molybdenum and the accompanying rhenium are entirely associated with porphyry copper deposits, which are described under "Copper" (see p. 139). Both the molybdenum and rhenium are recovered solely as byproducts of copper mining. Mineral occurrences of molybdenum, however, are known in every county of Arizona except Yuma. Figure 34 shows the principal molybdenum deposits in Arizona; these occurrences are briefly described in table 19.

The molybdenum occurs most commonly as the mineral molybdenite, but also as wulfenite, ferrimolybdite, jordisite, and ilsemannite.

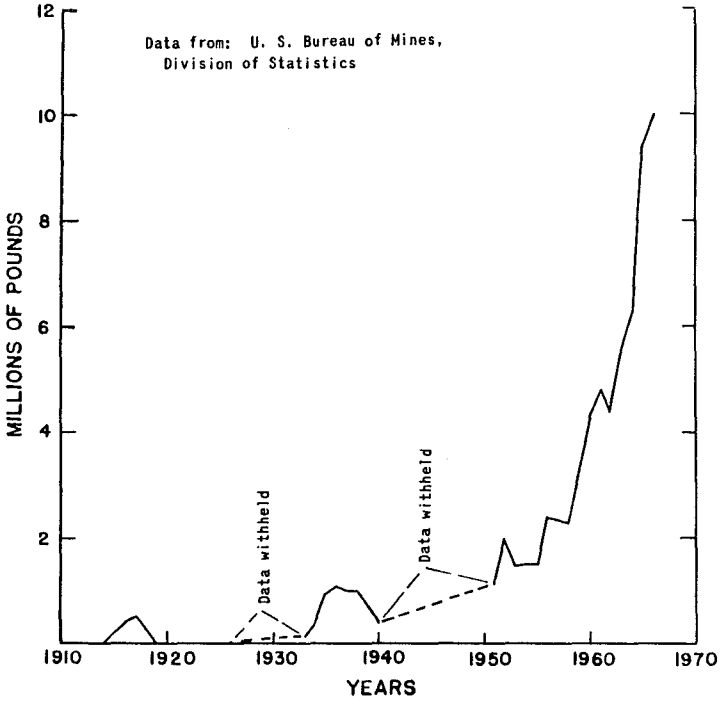


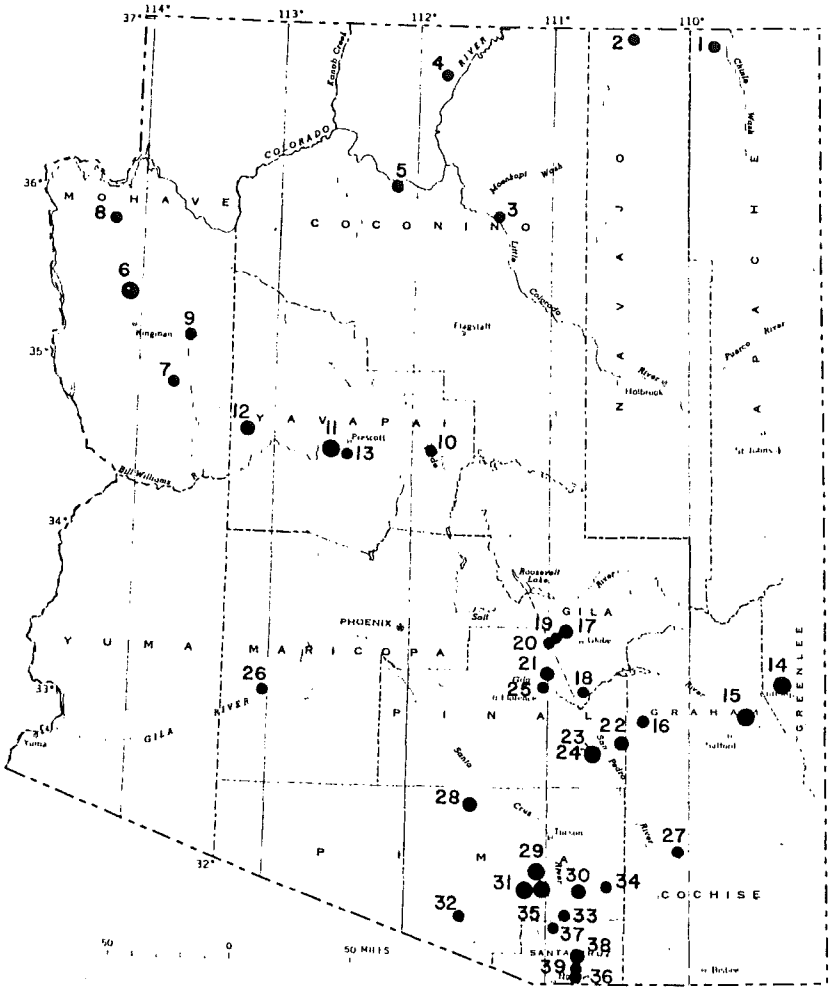
FIGURE 33.—Molybdenum production in Arizona, 1914–66.

The molybdenite occurrences are chiefly in vein deposits in granitic rocks or in metasedimentary or volcanic rocks that are closely associated with granitic intrusives.

Wulfenite occurs in oxidized parts of lead-zinc vein deposits and in replacement deposits in limestone. Ferrimolybdite is rare in Arizona but occurs in near-surface parts of some vein deposits. Jordisite and ilsemannite occur with uranium minerals in some of the bedded uranium deposits in sandstone in the Colorado Plateau of northern and northeastern Arizona.

RESOURCES

The known reserves of molybdenum in Arizona are about 450,000 tons of metal chiefly in copper-molybdenum ores containing from 0.005 to 0.05 percent molybdenum. Potential resources of molybdenum are estimated to equal the known reserves for total molybdenum resources of about 900,000 tons of metal. These resources, which chiefly are in low-grade copper-molybdenum ores, are largely in Graham, Greenlee, Mohave, Pima, Pinal, Santa Cruz, and Yavapai Counties. The annual rate of production of molybdenum in Arizona is expected to increase along with an expected rise in the output of copper. While few data are available on which to base an estimate of the total



EXPLANATION

Deposit or deposits showing relative size in tons of molybdenum (production plus estimated content)

●11	●38	●4
More than 50,000	1,000 to 50,000	Less than 1,000

(Numbers refer to localities listed in table 19)

FIGURE 34.—Molybdenum in Arizona.

TABLE 19.—*Molybdenum occurrences in Arizona*

Locality No. in fig. 34	County, district, mine, or property	Mode of occurrence	References
	Apache		
1	Monument No. 2 mine	Molybdenum with uranium in sandstone.	U. S. Geol. Survey file data.
	Navajo		
2	Monument No. 1 and Mitchell Mesa mines	do.	Do.
	Coconino		
3	Alyce Tolino mine	Umohoite and ilsemannite with uranium minerals in sandstone.	Hamilton and Kerr, 1959, p. 1248-1260.
4	Sun Valley mine	Ilsemannite and jordisite(?) with uranium minerals in sandstone.	Peterson and others, 1959.
5	Orphan Lode mine	Wulfenite with uranium in breccia pipe.	Granger and Raup, 1962.
	Mohave		
6	Ithaca Peak mine	Molybdenite in veins and disseminated in granite.	Dings, 1951.
7	Leviathan mines	Molybdenite in quartz veins cutting quartz diorite.	Hess, 1924, p. 14.
8	O.K. claims	Molybdenite and wolframite in quartz veins.	Schrader, 1909.
9	Telluride Chief mine (Standard Minerals)	Molybdenite with wolframite and scheelite in quartz veins.	U. S. Geol. Survey file data.
	Yavapai		
10	Squaw Peak mine	Molybdenite in quartz veins and disseminated in quartz diorite.	Kirkemo and others, 1965.
11	Copper Basin district	Molybdenite in veins in breccia pipes.	Johnston and Lovell, 1961.
12	Bagdad mine	Molybdenite with disseminated copper sulfides.	Anderson, Scholz, and Strobell, 1955.
13	Twin Ledge prospect	Molybdenite with pyrite in quartz veins cutting granite.	U. S. Geol. Survey file data.
	Greenlee		
14	Morenci mine	Molybdenite with disseminated copper sulfides.	Reber, 1916.
	Graham		
15	Lone Star district	Molybdenite with copper sulfides in disseminated deposits.	U. S. Geol. Survey file data.
16	Grand Reef mine	Wulfenite in veins.	Do.
	Gila		
17	Inspiration mine	Molybdenite with disseminated copper sulfides.	Peterson, 1962, p. 133-134.
18	Christmas mine	Molybdenite with copper sulfides in pyrometasomatic replacement of limestone.	Peterson and Swanson, 1956.
19	Roscoe group	Molybdenite with copper in veins in granite.	U. S. Geol. Survey file data.
20	Bronx property	Molybdenite and ferrimolybdite in quartz sulfide veins cutting granite.	Do.

TABLE 19.—*Molybdenum occurrences in Arizona*—Continued

Locality No. in fig. 34	County, district, mine, or property	Mode of occurrence	References
	Pinal		
21	Ray mine	Molybdenite with disseminated copper sulfides.	Ransome, 1915.
22	Copper Creek area	Molybdenite in mineralized breccia pipe.	Kuhn, 1941.
23	San Manuel mine, Kalamazoo property	Molybdenite in disseminated copper sulfide deposit.	Schwartz, 1953.
24	Mammoth-St. Anthony mine	Wulfenite and vanadinite in base-metal veins.	Creasey, 1950.
25	Rare Metals deposit	Molybdenite in quartz veins.	U. S. Geol. Survey file data.
	Maricopa		
26	Rowley mine	Wulfenite and ferrimolybdite in quartz veins cutting andesite.	Heikes, 1921, p. 352; Hess, 1921, p. 799.
	Cochise		
27	Republic mine	Molybdenite in pyrometasomatic deposit in limestone.	Cooper, 1950.
	Pima		
28	Silver Bell property	Molybdenite in disseminated copper deposit.	Richard and Courtright, 1954.
29	Pima mine and Mission mine	Molybdenite in disseminated copper deposits and in pyrometasomatic replacement deposits.	Thurmond and others, 1958; Kinnison, 1966, p. 281-287.
30	Leader mine	Molybdenite in tactite in fault zone.	Creasey and Quick, 1955, p. 316-318.
31	Esperanza mine (New Year's Eve)	Molybdenite with disseminated copper sulfides.	U. S. Geol. Survey file data.
32	Gold Bullion mine	Molybdenite in quartz veins cutting granite.	Do.
33	Sun Lode claims	Molybdenite in quartz along fault and in quartz veins in diorite.	Do.
34	Total Wreck mine	Wulfenite in fractured limestone.	Do.
35	Twin Buttes mine	Molybdenite with copper sulfides in disseminated deposit.	Do.
	Santa Cruz		
36	Santo Nino mine	Molybdenite in veins in feldspathized zone in quartz monzonite.	Do.
37	Glove mine	Wulfenite in oxidized lead-zinc-silver veins in quartz monzonite.	Olson, 1966.
38	Ventura property	Molybdenite with copper sulfides in breccia deposit.	U. S. Geol. Survey file data.
39	Red Hill mine	Molybdenite with copper sulfides disseminated in breccia pipe.	Do.