**STATE OF NEW MEXICO**
**BEFORE THE WATER QUALITY CONTROL COMMISSION**

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| **In the Matter of:** | ) | |
| **PROPOSED AMENDMENT TO 20.6.2 NMAC (Copper Rule)** | ) | **No. WQCC 12-01(R)** |

# EXHIBIT LANDE – 3

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# Copper in New Mexico

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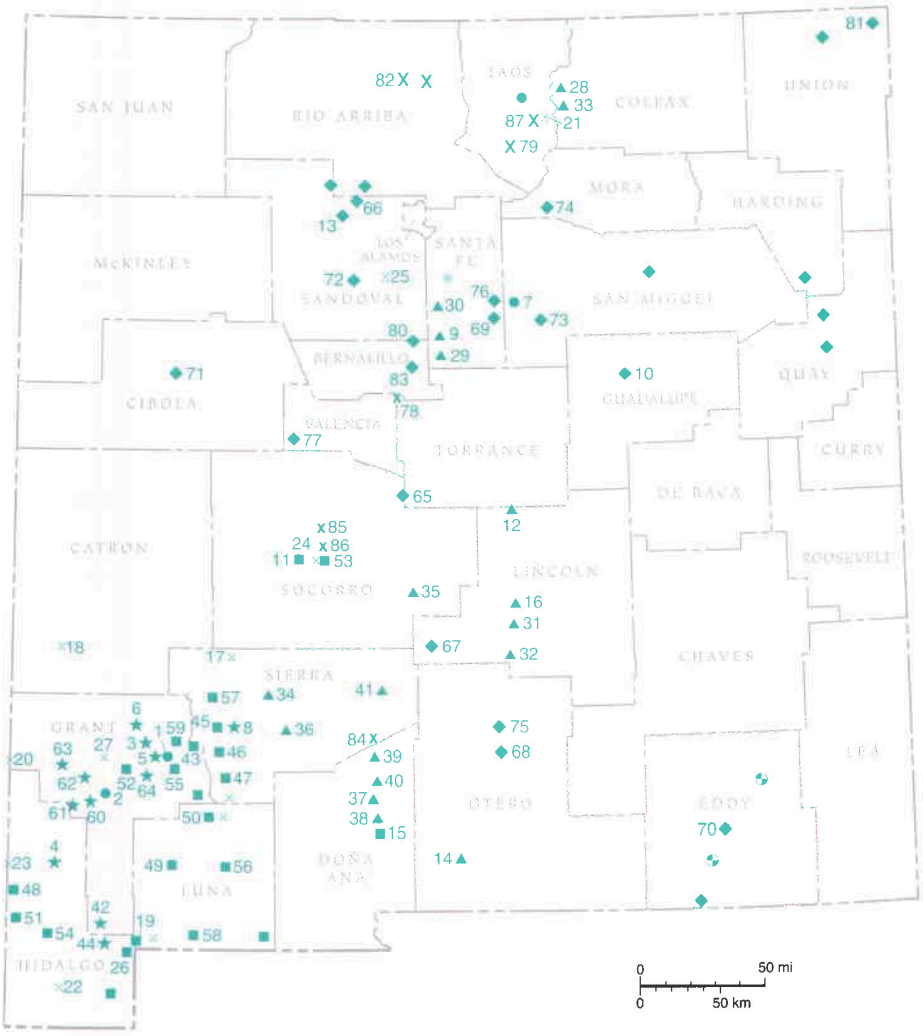


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FIGURE 1—Mining districts with reported copper production. Symbols refer to type of deposit; some districts have more than one type, but only the predominant type is shown. Not all districts with copper occurrences are shown.


## Abstract

Copper has been produced in New Mexico since prehistoric times, but actual production records were not kept until 1804. From 1804 to 1994, nearly 8.4 million tons of copper were produced, worth approximately $10 billion. Three districts account for 93% of the total copper production (Santa Rita, Burro Mountains, Fierro–Hanover). Copper in New Mexico is found in 13 types of deposits; the most important are porphyry copper and Laramide skarn deposits. Today, three mines are in production with copper as the primary product: Chino, Tyrone, and Continental. Recoverable reserves at Santa Rita are reported as 315.4 million tons of concentrator ore grading 0.67% Cu and 720.5 million tons of leach ore grading 0.24% Cu. Recoverable reserves at Tyrone (Burro Mountains district) are estimated as 230.2 million tons of leach ore grading 0.35% Cu. Cobre Mining Co. reports minable reserves at the Continental mine (Fierro–Hanover district) of more than 10 million tons of 0.92% Cu. Minable reserves at the Copper Flat porphyry copper deposit are estimated as 60 million tons of 0.42% Cu and 0.012% Mo. Additional deposits in these and other areas are likely to be discovered, especially in districts with potential for porphyry copper deposits and copper skarns.


## Introduction

Copper has been produced in New Mexico since prehistoric times, but actual production records were not kept until 1804. From 1804 to 1994 nearly 8.4 million

## Also in this issue



## Coming soon

La Bajada uranium mine
Stratigraphy of Tr-4 unconformity
Pecos River valley vertebrates

tons of copper were produced in the state, amounting to approximately $10 billion (Table 1). The major copper districts are shown in Fig. 1. Three districts account for 93% of the reported copper production in New Mexico (Santa Rita, Burro Mountains, Fierro–Hanover; Table 2).

TABLE 1—Estimated copper production from New Mexico, 1804–1994 (from Lindgren et al., 1910; Anderson, 1957; U. S. Geological Survey, 1902–1927; U. S Bureau of Mines, 1927–1994; Energy, Minerals and Natural Resources Department, 1994).

| Years of Production | Copper (short tons) | Value ($) |
|---|---|---|
| 1804–1880 | 15,003 | 6,001,205 |
| 1881–1903 | 23,554 | 6,831,500 |
| 1904–1920 | 338,425 | 138,857,559 |
| 1921–1940 | 601,346 | 151,850,186 |
| 1941–1960 | 1,316,268 | 613,905,615 |
| 1961–1980 | 2,686,467 | 3,072,497,160 |
| 1981–1994 | 3,379,866 | 6,002,137,421 |
| Est. total 1804–1994 | 8,360,929 | 9,992,080,646 |

Today copper is widely used in the electrical and communications industries, building construction, consumer products, machinery, transportation, and military applications. New Mexico has ranked third in the U. S. in copper production since 1992 (Energy, Minerals and Natural Resources Department, 1994). Approximately 2,540 people were employed by the copper industry in New Mexico in 1994 with a payroll of more than $88 million (New Mexico Energy, Minerals and Natural Resources Department, press release, May 24, 1995).

The purpose of this paper is to present a brief summary of the copper resources in New Mexico. Best available information on copper production from the state since 1804 is summarized in Table 1 and by major district in Table 2. These production figures were obtained from a variety of published and unpublished sources, including the U. S. Geological Survey (1902–1927), the U. S. Bureau of Mines (1927–1994) Mineral Yearbooks, and various company annual reports, most of which are on file at the New Mexico Bureau of Mines and Mineral Resources. However, some of these production figures are subject to change, as new data are obtained. Mining and, especially, production statistics are generally poorly recorded, particularly in the earliest times, and many of those early records are conflicting.

## History of copper production in New Mexico

The first use of copper was by American Indians, for ornaments and tools. Later, Francisco Vasques de Coronado led a Spanish expedition into New Mexico in 1540 looking for gold (Jones, 1904). Instead Coronado found turquoise; early Spanish mining for turquoise and copper in New Mexico occurred in Cerrillos and Old Placers districts in Santa Fe County, Placitas in Sandoval and Bernalillo Counties, and Santa Rita near Silver City.

One of the first known copper operations was at Santa Rita. In 1798 an Apache

TABLE 2—Major copper districts in New Mexico (compiled by V. T. McLemore from U.S. Geological Survey, 1902–1927; U.S. Bureau of Mines, 1927–1994; and various published and unpublished sources, including company annual reports). District number refers to Fig. 1.

| District | County | Estimated copper production (lbs) | Type(s) of deposit | Major commodities |
|---|---|---|---|---|
| 1. Santa Rita (Chino) | Grant | 9,080,000,000 | Porphyry copper | Cu (Ag, Au, Mo) |
| 2. Burro Mountains (Tyrone) | Grant | 5,240,000,000 | Porphyry copper, Laramide vein | Cu (Ag, Au) |
| 3. Fierro–Hanover | Grant | 1,250,000,000 | Laramide skarn, prophyry copper | Cu, Zn, Pb |
| 4. Lordsburg | Hidalgo | 229,577,000 | Laramide vein | Cu, Au, Ag, Pb, Zn |
| 5. Bayard | Grant | 110,000,000 | Laramide vein | Zn, Cu, Ag, Pb |
| 6. Pinos Altos | Grant | 59,500,000 | Laramide skarn, Laramide vein | Cu, Zn, Pb, Ag (Au) |
| 7. Willow Creek | San Miguel | 18,687,426 | Volcanogenic massive sulfide | Zn, Pb, Cu, Ag |
| 8. Hillsboro | Sierra | 17,000,000 | Laramide vein, porphyry copper | Cu, Au (Ag, Pb) |
| 9. New Placers | Santa Fe | 17,000,000 | Great Plains margin | Cu, Au, Ag (Pb, Zn) |
| 10. Pastura | Guadalupe | 13,578,214 | Sedimentary copper | Cu (Ag, Pb) |
| 11. Magdalena | Socorro | 12,000,000 | Carbonate-hosted Pb-Zn replacement | Zn, Pb, Cu (Ag) |
| 12. Gallinas | Lincoln | 8,000,000 | Great Plains margin, sedimentary copper | Cu, Pb (Ag, Zn) |
| 13. Nacimiento | Sandoval | 7,561,567 | Sedimentary copper | Cu (Ag) |
| 14. Orogrande | Otero | 5,700,000 | Great Plains margin skarn | Au, Cu (Ag, Pb, Zn) |
| 15. Organ Mountains | Doña Ana | 4,636,000 | Carbonate-hosted Pb-Zn replacement | Pb, Zn, Cu, Ag (Au) |
| 16. Jicarilla | Lincoln | 4,201,474 | Great Plains margin | Au, Ag, Cu |
| 17. Chloride | Sierra | 3,060,000 | Volcanic epithermal | Ag, Pb (Au, Cu) |
| 18. Mogollon | Catron | 1,500,000 | Volcanic epithermal | Ag, Au, Pb, Cu |
| 19. Apache No. 2 | Hidalgo | 1,300,000 | Carbonate-hosted Pb-Zn replacement | Ag (Pb, Zn, Cu) |
| 20. Steeple Rock | Grant | 1,200,000 | Volcanic epithermal | Ag, Au, Pb, Zn, Cu |
| Estimated total New Mexico | all | 16,720,000,000 | all | — |

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Indian led Col. Manuel Carrasco, a Spanish officer, to these copper deposits, and by 1804 copper was being mined at Santa Rita and transported by mule to Mexico City. Actual production records are lacking, but Christiansen (1974) estimates 200 mule trains were sent annually, amounting to approximately 6,000,000 lbs (3,000 short tons) of copper per year. Lindgren et al. (1910) estimates total production from 1804 to 1879 as 15,000 short tons of copper. Mining at Santa Rita diminished after 1809 as a result of increasing costs, difficult transportation, Indian uprisings, declining copper demands in Mexico, and finally the Mexican Revolution in 1810. The records are conflicting as to who owned and operated the mines after 1809, and the mines finally closed in 1834. They were still inactive when General Kearney and the U. S. Army visited the area in 1846 (Jones, 1904; Milbauer, 1982).

In 1848 New Mexico Territory became part of the United States and gold and silver mining began in earnest. Numerous districts were discovered and mined for precious metals in the 1800s (North and McLemore, 1986; McLemore, in press a); copper was recovered wherever it was possible. Copper mining at the Hanover mine in the Fierro–Hanover district occurred 1858–1861 (Hillesland et al., 1995). However, most mining in the state ceased in 1862 with the invasion of New Mexico by the Confederate forces.

The end of the Civil War brought tremendous change to mining in New Mexico. Settlers and prospectors fled the war-torn East to start new lives in the West. Prospectors from the California gold fields moved eastward into New Mexico as the California placers were exhausted or claimed. Soldiers were sent to eliminate interference by Indians and later became prospectors themselves. Exploration throughout New Mexico for gold and silver deposits soared. Southwest New Mexico was one of the last areas in the United States to be rid of the threat of Indian attacks, and many mining districts there were not discovered until 1890–1900.

The Federal Mining Act of 1866 established rules and regulations governing prospecting and mining with provisions for obtaining private ownership of federal land containing valuable mineral resources. The act was subsequently amended in 1870 and 1872 and in the years since. The mining act further encouraged mining and prospecting in the state, and the mining boom of 1870–1890 began. Many districts began production as the Indian threat was subdued. Copper and turquoise were found in the Burro Mountains in 1871 (Kolessar, 1982). The telegraph and then the railroad improved conditions in the state as mining continued to flourish. New metallurgical techniques were developed, and copper became an important commodity. Times were exciting for the miner in the late 1800s as metal prices, including copper, soared.

In 1904 Daniel C. Jackling opened the first large, open-pit mine to produce low-grade copper ore (less than 2% Cu) by bulk-mining methods at Bingham Canyon, Utah. At the same time, John M. Sully arrived at Santa Rita and recognized the similarity of ore at Santa Rita to that mined at Bingham Canyon. Sully acquired the mineralized area and attempted to obtain backers (Sully, 1908). Finally, in 1909 he obtained the financial backing, and in 1910 production began. The first concentrator was erected at Hurley in 1911; flotation concentration was added in 1914. The facilities at Hurley have been modernized several times since. Smelter operations at Hurley continue today as does mining at Santa Rita. In 1909 Phelps Dodge Corp. purchased the mines and concentrator at Tyrone in the Burro Mountains district.

New Mexico became a state in 1912 and in 1914 World War I began. Metal prices and production increased as metals were needed for the war effort. In 1918 World War I ended and was followed by a depression that closed many mines, including the underground mines at Tyrone.

New selective-flotation metallurgical techniques were developed in the 1920s that improved recovery of massive lead and zinc sulfide ore. In 1927 production began at the Pecos volcanogenic massive-sulfide deposit in the Willow Creek district in San Miguel County by the American Metal Co. (now AMAX Resource Conservation Co.). This was the largest lead- and zinc-producing mine in the state at the time; copper was recovered as a byproduct. Significant production continued through 1939 when the mine closed. Reprocessing of the dumps occurred 1943–1944.

World War II saw an increase in copper production, because the metal was needed for war materials (Table 1), and was followed by a depression. Copper prices gradually increased and copper production from the porphyry copper and skarn deposits steadily increased, with a few slumps from year to year caused by price fluctuations and labor disputes. Extensive exploration worldwide for porphyry copper deposits occurred from about 1955 to the early 1980s and resulted in discovery of several deposits in New Mexico. In 1962–1964 the U. S. Smelting, Refining, and Mining Co. discovered the large deposits now being mined at the Continental mines by Cobre Mining Company, Inc. (Hillesland et al., 1995). Production at the Continental mines began in 1967 and ceased in 1982 as a result of declining copper prices. In 1967 Phelps Dodge Corp. began development of the Tyrone open-pit mine in the Burro Mountains district. In 1974 Phelps Dodge Corp. built the Playas smelter in the Animas Valley in Hidalgo County; the smelter is still operating. In January 1992 the Tyrone mill closed and the Tyrone mine became a mine-for-leach operation, the first in the state. Cobre Mining Company, Inc. resumed production at the Continental mines in July 1993.

In the 1980s solvent extraction–electrowinning (SX–EW) technology was developed that enabled economic recovery of high-purity copper from very low grade copper deposits. Two SX–EW plants currently operate in New Mexico: Tyrone, begun in April 1984, and Chino, begun in August 1988. Solvent extraction removes copper from a pregnant leach solution, by mixing it with an organic extractant, into a solution of sulfuric acid and copper sulfate. The resulting electrolyte solution is pumped into the electrowinning tanks. Copper is plated onto cathodes. A very high purity copper is produced in this manner as opposed to concentration, but no gold, silver, or molybdenum can be recovered. SX–EW enables leaching of very low grade copper ores (as low as 0.1% Cu) that contain easily leached copper minerals such as chalcocite, chrysocolla, and copper carbonates.

Today three mines are in production with copper as the primary product: Santa Rita, Tyrone, and Continental. Pinos Altos, operated by Cyprus Pinos Altos Corp., closed in 1995. In terms of copper production by state in the United States, New Mexico ranked 2nd from 1984 to 1991 and 3rd from 1992 to 1994. In 1994, of the 42 producing copper mines in the United States, Chino ranked 4th, Tyrone 10th, Continental 16th, and Pinos Altos 20th (Daniel Edelstein, U.S. Bureau of Mines, oral comm. October 17, 1995). A small amount of copper, as silica flux, was reported from the Lordsburg mine in the Lordsburg district, which ranked 37th in 1994.

## Types of deposits

Copper is found in 13 types of deposits in the state (Table 3). Economically, the most important type is the porphyry copper deposit. The classification used in this report is described by North and McLemore (1986, 1988) and McLemore (in press a).

### Volcanic-epithermal vein deposits

Volcanic-epithermal vein deposits in New Mexico include deposits that were formed by ascending waters at shallow to moderate depths (<1,500 m) and low to moderate temperatures (50°–300°C) and that are typically associated with intrusive and/or volcanic rocks in structurally com-

TABLE 3—Classification of copper deposits of New Mexico arranged by perceived age of the deposits (North and McLemore, 1986, 1988; McLemore, in press a). *, deposits where copper is a major commodity; ?, uncertainty in age. U.S. Geological Survey classification from Cox and Singer (1986).

| Classification (this report) | Perceived age | USGS classification |
|---|---|---|
| Volcanic-epithermal vein deposits | Eocene–Pliocene | 25b,c,d,e |
| Supergene copper-uranium (silver) deposits | Miocene–Pliocene? | none |
| Great Plains margin (alkaline-related) deposits | Eocene–Miocene | 22b,c, 21a, 18b,c,d, 39a |
| Rio Grande rift barite-fluorite-galena (copper, silver) deposits (formerly sedimentary hydrothermal deposits) | Paleozoic?–early Tertiary | 32a, 19a |
| Carbonate-hosted lead-zinc (copper, silver) replacement deposits | Eocene–Oligocene | 19a |
| Carbonate-hosted silver-manganese (lead) replacement deposits | Paleocene–Oligocene? | 19b |
| *Laramide lead-zinc and copper skarn deposits | Late Cretaceous–Eocene | 18b,c,d |
| *Laramide vein deposits (polymetallic veins) | Late Cretaceous–Eocene | 22c |
| *Porphyry copper (gold, molybdenum) deposits | Late Cretaceous–Eocene | 21a,b |
| Mississippi Valley-type (MVT) deposits (here restricted to Permian Basin) | Permian?–Miocene | 32a |
| *Sedimentary copper deposits | Pennsylvanian–Triassic | 30b |
| Vein and replacement deposits (here restricted to Permian Basin) | Precambrian–Tertiary | 22b,c, 26b |
| *Precambrian volcanogenic massive-sulfide deposits (VMS) | Precambrian | 24a,b, 28a |

TABLE 4—Volcanic-epithermal vein deposits with reported copper production in New Mexico. Number refers to Fig. 1.

| District, County | Year of discovery | Period of reported production | Estimated copper production (lbs) |
|---|---|---|---|
| 17. Chloride, Sierra | 1879 | 1934–1992 | 3,060,000 |
| 18. Mogollon, Catron | 1875 | 1875–1988 | 1,500,000 |
| 20. Steeple Rock, Grant | 1860 | 1880–1993 | 1,200,000 |
| 21. Red River-Rio Hondo, Taos | 1826 | 1902–1956 | 17,000 |
| 22. Gillespie, Hidalgo | 1880 | 1880–1950 | 15,000 |
| 23. Kimball, Hidalgo | 1875 | 1875–1953 | 12,000 |
| 24. Hop Canyon, Socorro | 1880 | 1913–1941 | 7,000 |
| 25. Cochiti, Sandoval | 1880 | 1894–1983 | 2,500 |
| 26. Fremont, Hidalgo | 1860 | 1880–1951 | 2,000 |
| 27. Cora Miller, Grant | 1880 | 1940–1941 | withheld |

plex areas. The characteristics of these deposits and a model for their formation are outlined by Buchanan (1981). The volcanic-epithermal vein deposits of New Mexico formed usually in Oligocene to Miocene volcanic rocks, commonly adjacent to calderas, but typically formed much later than the caldera (Elston, 1994; Rytuba, 1981; McLemore, 1994a) although other volcanic settings, such as silicic domes and andesitic stratovolcanoes, are not uncommon for these deposits. Typical volcanic-epithermal vein deposits in the state occur as siliceous vein fillings, breccia pipes, disseminations, and replacement deposits along faults and fractures.

The mineralogy and metal associations of these deposits are diverse and typically vary from one deposit to another. District zoning is also diverse, and in some districts precious metals occur in the upper levels and grade into base metals at depth (Buchanan, 1981; McLemore, 1994a, in press b). Common ore minerals include auriferous pyrite, native gold, acanthite, chalcopyrite, bornite, argentiferous galena, native silver, and sphalerite. Quartz, calcite, and pyrite are common gangue minerals. Copper minerals occur in most districts (Fig. 1), but only three districts have yielded significant copper production (Table 4): Chloride, Mogollon, and Steeple Rock. Ore shoots, less than 2 m wide, form at the intersection of faults or at areas with a change in strike and/or dip. Typical deposits are a few hundred thousand tons or less with variable copper grades (0.1–20%). These deposits provide excellent silica flux material for local smelters and will be in continued demand as long as such undesirable elements as fluorine and bismuth are low.

### Supergene copper-uranium (silver) deposits

Two deposits in New Mexico, La Bajada and Jeter (Ladron Mountains), are classified as supergene copper-uranium (silver) deposits. These deposits were formed at low temperatures, near the surface, and along Tertiary faults. Copper, silver, molybdenum, and uranium are found in both deposits. Copper production from La Bajada consisted of 5,345 pounds Cu; uranium, vanadium, and silver were also produced (McLemore and North, 1984). Only uranium and vanadium were produced from the Jeter mine (Chamberlin et al., 1982). Copper occurs in variable amounts in both deposits. It is unlikely that these small, low-grade deposits would be mined conventionally for their copper contents.

### Great Plains margin deposits

Some of the state's largest gold deposits occur along a north-south belt roughly coinciding with the Great Plains physiographic margin with the Basin and Range (Rio Grande rift) and Rocky Mountains physiographic provinces. These deposits have similar characteristics that, when compared with their tectonic setting, define a class of ore deposits referred to as Great Plains margin deposits, also known as alkaline-related gold deposits (North and McLemore, 1986, 1988; McLemore, in press c). Copper occurs in most districts, and four have yielded significant production (Fig. 1; Table 5): New Placers, Gallinas, Orogrande, and Jicarilla.

The Great Plains margin deposits contain both precious and base metals, but precious metals, especially gold, are typically high. These deposits consist of seven styles of mineralization: (1) polymetallic, epithermal to mesothermal veins, (2) gold-bearing breccia pipes and quartz veins, (3) porphyry copper-gold and porphyry gold, (4) copper-lead-zinc skarns or carbonate-hosted replacements, (5) iron skarns and replacement bodies, (6) placer gold, and (7) rare-earth element (REE)-fluorite epithermal veins and breccias. Alkaline igneous rocks, typically Oligocene, are found in most districts, but mineralization is usually associated with silica-saturated (monzonite) or oversaturated (quartz monzonite) rocks. The veins have high gold to base-metal ratios (Thompson, 1991a; McLemore, in press c). Although porphyry gold deposits, such as

the Fort Knox deposit in Alaska, have similar mineralization and alteration styles as porphyry copper deposits, the porphyry gold deposits differ in that they contain less than 1% total sulfides, have a low Cu to Au ratio, and have a typical metal association of gold, bismuth, tungsten, and molybdenum (Hollister, 1992). Although porphyry copper deposits have been found in some districts, none have produced. (Alkaline-related porphyry copper deposits are described separately in this report.) Most copper production in Great Plains margin deposits in New Mexico has come from copper skarns and carbonate-hosted replacements. Only one alkaline-related skarn deposit in New Mexico has been extensively studied; the Lukas Canyon copper-gold skarn in Old Placers district contains a resource of 6 million tons of 0.25% Cu and 0.03 oz/ton Au (Maynard, 1995). Copper will be produced from these deposits only as a byproduct of gold production.

TABLE 5—Great Plains margin deposits with reported copper production in New Mexico. Number refers to Fig. 1. *, includes production from sedimentary copper deposits. Age dates are from Atkinson (1961), Perhac (1970), Beane et al. (1975), Bloom (1975), Marvin and Dobson (1979), Scott et al. (1990), Bachman and Mehnert (1978), Thompson (1991a, b), and Allen and Foord (1991).

| District, County | Year of discovery | Period of reported production | Age of igneous intrusives | Estimated copper production (lbs) |
|---|---|---|---|---|
| 9. New Placers, Santa Fe | 1839 | 1839–1968 | 47.1±3.9 | 17,000,000 |
| 12. Gallinas, Lincoln* | 1885 | 1909–1954 | 30.7 | 8,000,000 |
| 14. Orogrande, Otero | 1879 | 1879–1966 | 43.7–49.5 | 5,700,000 |
| 16. Jicarilla, Lincoln | 1850 | 1912–1957 | 39.2±1.5 | 4,201,474 |
| 28. Elizabethtown–Baldy, Colfax | 1866 | 1866–1968 | 29.1±1.4 | 329,231 |
| 29. Cerrillos, Santa Fe | 1680 | 1879–1957 | 28.7–48.2 | 229,395 |
| 30. Old Placers, Santa Fe | 1828 | 1828–1986 | 26–48.2 | 1,570 |
| 31. White Oaks, Lincoln | 1850 | 1850–1951 | 29.8–36.1 | 1,000 |
| 32. Nogal–Bonito, Lincoln | 1865 | 1868–1955 | 26.5–38.3 | withheld |
| 33. Cimarroncito, Colfax | 1896 | 1896–1940 | 29.1±1.4 | withheld |

TABLE 6—Rio Grande rift deposits with reported copper production in New Mexico. Number refers to Fig. 1. *, districts with minor copper production from veins and replacements in Precambrian rocks.

| District, County | Year of discovery | Period of production | Estimated copper production (lbs) |
|---|---|---|---|
| 34. Hot Springs, Sierra | 1930 | 1930–1950 | 16,650 |
| 35. Hansonburg, Socorro | 1872 | 1937–1957 | 12,600 |
| 36. Caballo Mountains, Sierra* | 1881 | 1937–1957 | 2,800 |
| 37. Bear Canyon, Doña Ana | 1900 | early 1900s | <10,000 |
| 38. Black Mountain, Doña Ana* | 1883 | 1883–1900s | <10,000 |
| 39. San Andrecito–Hembrillo, Doña Ana* | 1890s | 1914–1930 | <10,000 |
| 40. San Andres Canyon, Doña Ana | 1900 | 1900–1904 | <10,000 |
| 41. Salinas Peak, Sierra | 1930s | 1935–1948 | 100 |

### Rio Grande rift barite-fluorite-galena deposits

Barite-fluorite-galena (silver, copper) deposits, formerly called sedimentary hydrothermal deposits (North and McLemore, 1986, 1988), are found throughout New Mexico along the Rio Grande rift (Fig. 1; Table 6; McLemore and Barker, 1985; Van Alstine, 1976; North and McLemore, 1985; McLemore and Lueth, 1995; McLemore et al., 1996). These deposits are low-temperature, open-space fillings with local replacement and are not obviously associated with any magmatic activity. Rio Grande rift deposits in New Mexico are predominantly barite-fluorite-galena vein and replacement deposits; locally they may contain significant amounts of silver, copper, and zinc (Table 6).

The deposits typically occur as veins, breccia cements, cavity fillings, and minor replacement bodies in carbonate rocks adjacent to or within Basin and Range-related faults (i.e. Hansonburg, Salinas Peak; Kottlowski and Steensma, 1979; Smith, 1981; McLemore, 1994b; McLemore et al., 1996). Previous workers have attributed these deposits to the Tertiary (Allmendinger, 1975; Beane, 1974; Seager et al., 1971). Most Rio Grande rift deposits in New Mexico are small, typically less than a few thousand tons of ore. Widths as much as tens of feet occur and some deposits can be traced along strike for several thousand feet.

These deposits are similar to Mississippi Valley-type (MVT) deposits and were formed by low-temperature basin brines that were ejected along fractures, faults, and unconformities during early diagenesis or later compaction of sedimentary basins (Hanor, 1979; Ohle, 1980; Hill, 1993). The formation waters or basin brines accumulated in local basins and were heated by high heat flow, magmatic activity, or radiogenic heat from Precambrian plutons. The warm convicting waters leach ions from source rocks such as arkosic sediments, evaporites, Precambrian rocks, and Precambrian mineral deposits. In central New Mexico, these basins are continental instead of marine, as in the classic Mississippi Valley area, and are associated with extensional tectonics. The mineralized waters were ejected along open spaces such as faults and fractures. Precipitation occurred as a result of cooling of the fluids, decrease in pressure, and/or mixing of the mineralized hydrothermal fluids with subsurface brines or meteoric water.

It is unlikely that many of these deposits will be mined solely for their copper content. Most of these deposits are also too small to be exploited for barite, fluorite, or lead.

### Carbonate-hosted lead-zinc replacement deposits

Carbonate-hosted lead-zinc replacement deposits occur in southwest New Mexico and were formed approximately 50–20 Ma (Fig. 1, Table 7; McLemore et al., 1996; McLemore and Lueth, 1995). The deposits include replacements in carbonate rocks with little or no calc-silicate minerals, minor skarns with few calc-silicate minerals, and minor veins. Skarn deposits do occur in some districts, such as Magdalena and Apache No. 2, but the skarn minerals are neither as abundant nor mineralogically zoned as in the Laramide skarns. The host rocks are predominantly Paleozoic and Cretaceous carbonate rocks and adjacent intrusive rocks. Many deposits are structurally controlled along extension-related fault, fracture, and contact zones. The localization of many deposits is also stratigraphically controlled. They are typically lead and zinc dominant, with byproduct copper, silver, manganese, and gold. Galena and sphalerite are the predominant ore minerals with lesser amounts of chalcopyrite.

The deposits vary in size and grade, ranging from a few thousand tons to a few hundred thousand tons and typically grading 5–30% combined lead and zinc; the amount of copper varies (0.1–20%; McLemore and Lueth, 1995). Fluid-inclusion data from five deposits indicate temperatures of formation between 147 and 367°C and low to moderate salinities (<10 eq. wt% NaCl; McLemore et al., 1996).

The association between carbonate-hosted lead-zinc replacement deposits

TABLE 7—Carbonate-hosted lead-zinc replacement, carbonate-hosted silver-manganese replacement, and Laramide skarn deposits in New Mexico with copper production. Number refers to Fig. 1.

| District, County | Year of discovery | Period of production | Estimated copper production (lbs) | Type(s) of deposit |
|---|---|---|---|---|
| 3. Fierro-Hanover, Grant | 1850 | 1890–present | 1,250,000,000 | Laramide skarn |
| 6. Pinos Altos, Grant | 1860 | 1890–1995 | 59,500,000 | Laramide vein, Laramide skarn |
| 11. Magdalena, Socorro | 1866 | 1866–1977 | 12,000,000 | Carbonate-hosted Pb-Zn replacement |
| 15. Organ Mountains, Doña Ana | 1830s | 1849–1961 | 4,636,000 | Carbonate-hosted Pb-Zn replacement |
| 19. Apache No. 2, Hidalgo | 1870s | 1880–1956 | 1,300,000 | Carbonate-hosted Pb-Zn replacement |
| 42. Eureka, Grant | 1871 | 1880–1961 | 500,000 | Laramide skarn |
| 43. Carpenter, Grant | 1891 | 1891–1969 | 310,000 | Carbonate-hosted Pb-Zn replacement |
| 44. Sylvanite, Hidalgo | 1871 | 1902–1957 | 130,000 | Laramide skarn, Laramide vein |
| 45. Kingston, Sierra | 1880 | 1880–1957 | 111,950 | Carbonate-hosted Mn-Ag replacement; carbonate-hosted Pb-Zn replacement |
| 46. Lake Valley, Sierra | 1878 | 1880–1957 | 100,000 | Carbonate-hosted Mn-Ag replacement; carbonate-hosted Pb-Zn replacement |
| 47. Tierra Blanca, Sierra | 1900s | 1919–1955 | 92,784 | Carbonate-hosted Mn-Ag replacement |
| 48. McGhee Peak, Hidalgo | 1894 | 1894–1956 | 85,000 | Carbonate-hosted Pb-Zn replacement, Laramide skarn, porphyry-copper |
| 49. Victorio, Luna | 1870s | 1880–1959 | 41,000 | Carbonate-hosted Pb-Zn replacement |
| 50. Cooke's Peak, Luna | 1876 | 1876–1965 | 23,000 | Carbonate-hosted Pb-Zn replacement |
| 51. Granite Gap, Hidalgo | 1897 | 1897–1955 | 20,400 | Carbonate-hosted Pb-Zn replacement |
| 52. Chloride Flat, Grant | 1871 | 1873–1946 | 20,000 | Carbonate-hosted Mn-Ag replacement |
| 53. Water Canyon, Socorro | 1868 | 1905–1956 | 15,377 | Carbonate-hosted Pb-Zn replacement |
| 54. Rincon, Hidalgo | 1880 | 1940–1949 | <10,000 | Carbonate-hosted Pb-Zn replacement |
| 55. Lone Mountain, Grant | 1871 | 1871–1950 | 5,000 | Carbonate-hosted Mn-Ag replacement |
| 56. Florida Mountains, Luna | 1876 | 1880–1956 | 5,000 | Carbonate-hosted Pb-Zn replacement |
| 57. Hermosa, Sierra | 1930 | 1879–1956 | 1,850 | Carbonate-hosted Mn-Ag replacement |
| 58. Tres Hermanas, Luna | 1881 | 1885–1957 | 550 | Laramide vein, Laramide skarn |
| 59. Georgetown, Grant | 1866 | 1866–1983 | withheld | Carbonate-hosted Mn-Ag replacement |

and igneous activity is uncertain. Poorly developed skarns are present in some districts, suggesting magmatic fluids are involved with ore fluids. Tertiary intrusive rocks with veins and/or disseminations of sulfides ranging from 50 to 20 Ma crop out in most districts. The carbonate-hosted lead-zinc replacement deposits are similar in form, texture, age, tectonic setting, and temperature to the volcanic-epithermal vein deposits in New Mexico (McLemore et al., 1996); the main differences between the two are the differences in host rock and mineralogy. Similarities in texture, mineralogy, and temperature of alteration and mineralization between altered Carboniferous carbonate rocks from the Valles caldera (1.12 Ma; Gardner et al., 1986) and the Magdalena district (Socorro caldera, 32 Ma and Sawmill–Magdalena caldera, 28.9 Ma; McIntosh et al., 1990) provide additional evidence supporting an epithermal origin of the carbonate-hosted Pb–Zn replacement deposits in New Mexico (Armstrong et al., 1995; Renault et al., 1995). Many of the deposits in New Mexico occur along the ring-fracture zones of calderas (McLemore et al., 1996). These deposits are also similar to the chimney, manto, and pod carbonate-hosted Ag–Pb–Zn(Cu) deposits in northern Mexico (Megaw et al., 1988). Geochemical data suggest that the Mexico deposits were formed by mixing of variable amounts of magmatic and meteoric fluids (Megaw et al., 1988), and a similar epithermal origin is reasonable for the New Mexico deposits.

The carbonate-hosted lead-zinc replacement deposits in New Mexico are not a significant source of copper, but copper could be recovered as a byproduct of lead and zinc production. SX–EW is not amenable to carbonate ores because the carbonate consumes the acid required to leach the copper. Future development of these deposits is dependent on zinc and lead production.

### Carbonate-hosted silver-manganese replacement deposits

Carbonate-hosted silver-manganese (lead) replacement deposits occur in southwest New Mexico (Fig. 1, Table 7) and were formed during the mid-Tertiary. The deposits contain predominantly silver and manganese oxides and locally contain some copper. The Lake Valley and Kingston districts each have produced more than 100,000 lbs of copper (Table 7).

The deposits are hosted by limestones and dolomitic limestones. The Percha Shale commonly acts as the uppermost, impermeable cap on mineralization. Jasperiods are common to most deposits and also act as impermeable caps. The deposits typically consist of native silver, cerussite, vanadinite, wulfenite, and smithsonite. Argentite, argentiferous galena, polybasite, pyrargyrite, stephanite, sphalerite, and chalcopyrite are rare to common in most districts. Although silver and manganese are the predominant metals, lead, followed by copper, is next in abundance in most districts (McLemore et al., 1996).

The carbonate-hosted silver-manganese replacement deposits are fair exploration targets for small mining companies because they tend to be high grade and small to medium size. The limestones are typically silicified and could, in local areas, be used as siliceous flux material. Metallurgical problems in recovering silver from the manganiferous ores has hampered production in the past, but new recovery methods may offer better recov-

eries in the future. Copper could be recovered as a byproduct.

### Laramide skarn deposits

Laramide skarn deposits in New Mexico are contact-metasomatic deposits that formed in carbonate rocks adjacent to Laramide calc-alkaline plutonic rocks (75–43 Ma; Fig. 1, Table 7; McLemore and Lueth, 1995). Three types of Laramide skarns occur in southern New Mexico: copper (typically associated with porphyry copper deposits), lead-zinc (proximal and vein-type deposits), and iron skarns. The largest copper skarns are in the Santa Rita, Fierro–Hanover, and Pinos Altos districts. Laramide iron skarns are found only in the Fierro–Hanover district.

District zoning is common in most areas, with copper adjacent to the intrusive rocks grading outwards to zinc-lead, lead-zinc, lead-silver, and locally, lead-silver-manganese (Meinert, 1987; McLemore et al., 1996). Copper skarns are typically intimately associated with plutons (e.g. Santa Rita, Pinos Altos), whereas the lead-zinc skarns are not always directly associated with igneous rocks.

The Laramide skarns in New Mexico formed from variable but higher temperature and more saline fluids compared to other carbonate-hosted deposits in the state (McLemore and Lueth, 1995). Most deposits probably formed from mixing of meteoric and magmatic fluids (Abramson, 1981; Ahmad and Rose, 1980; Lueth, 1984; Turner, 1990; Turner and Bowman, 1993).

The potential for discovering additional skarns in these districts is excellent, but development of these deposits will depend on the copper market. Cyprus Pinos Altos Corp. reports reserves at the Pinos Altos mine of more than one million tons of 4.96% Cu, 2.54% Zn, 3.5 oz/ton Ag, and 0.024 oz/ton Au (Osterberg and Muller, 1994), but the mine closed in 1995. Cobre Mining Co. reports reserves at the Continental mine in the Fierro–Hanover district of more than 10 million tons of 0.92% Cu (Hillesland et al., 1995). The Chino mine in the Santa Rita district also contains large copper skarns, but reserves are not separated from the porphyry copper deposits. Skarn deposits must be processed by conventional technologies because these carbonate ores are not amenable to SX–EW processing.

### Laramide vein deposits

Vein deposits of Laramide age (75–43 Ma) occur in a number of districts, the most important of which are Lordsburg, Bayard, and Hillsboro (Fig. 1, Table 8); the Pinos Altos district also contains Laramide vein deposits. The veins exhibit different texture and mineralogy, but are similar in form and age. Host rocks vary from Precambrian to younger sedimentary and volcanic rocks. The veins were typically worked for both base and precious metals and locally contain uranium, tungsten, and beryllium. Mineralogy and metal associations are diverse. Despite these differences, these deposits are grouped together because of similar form, association with Laramide intrusive rocks, and perceived origin at moderate to high temperatures and moderate depths.

Laramide veins may have potential for siliceous flux. Veins in the Lordsburg district containing copper, gold, and silver have been mined for silica flux. Past production indicates that these deposits are small to medium tonnage.

### Porphyry copper (molybdenum, gold) deposits

Porphyry copper (molybdenum, gold) deposits are large, low-grade (<0.8% Cu) copper deposits of disseminated and stockwork veinlets of copper sulfides that are associated with porphyritic intrusions (Fig. 1, Table 9; Lowell and Guilbert, 1970; Lowell, 1974). Mineralization typically occurs in and around prophyritically altered dioritic to granitic plutons that are surrounded by concentric zones of hydrothermal alteration (Lowell and Guilbert, 1970). Supergene enrichment is important in many deposits where oxidizing meteoric waters dissolve primary minerals that are then redeposited under

TABLE 8—Laramide vein deposits in New Mexico with copper production. Number refers to Fig. 1.

| District, County | Year of discovery | Period of reported production | Estimated copper production (lbs) |
|---|---|---|---|
| 4. Lordsburg, Hidalgo | 1870 | 1885–1994 | 229,577,000 |
| 5. Bayard, Grant | 1858 | 1902–1969 | 110,000,000 |
| 8. Hillsboro, Sierra | 1877 | 1877–1987 | 10,000,000 |
| 60. White Signal, Grant | 1880 | 1880–1968 | 26,000 |
| 61. Gold Hill, Grant | 1884 | 1911–1941 | 6,845 |
| 62. Black Hawk, Grant | 1881 | 1881–1960 | 3,000 |
| 63. Telegraph, Grant | 1881 | 1938–1951 | 1,700 |
| 64. Fleming, Grant | 1882 | 1882–1948 | 450 |

TABLE 9—Porphyry copper deposits in New Mexico. Mineralized zones have been found in the Organ Mountains district that are indicative of a porphyry copper deposit, but no reserves have been delineated. Number refers to Fig. 1. References for age determinations are in text. *, reported reserves are recoverable copper reserves; **, skarn or carbonate-hosted replacement deposits also present.

| District, County | Year of discovery | Period of production | Age (Ma) | Estimated copper production (lbs) | Reported estimated reserves |
|---|---|---|---|---|---|
| 1. Santa Rita (Chino), Grant** | 1800 | 1804–present | 57.3–60.4 | 9,080,000,000 | 315.4 million tons 0.67 % Cu (concentrator), 720.5 million tons of 0.24% Cu (leachable)* |
| 2. Burro Mountains (Tyrone), Grant | 1871 | 1871–present | 52.8–56.6 | 5,240,000,000 | 230.2 million tons 0.35% Cu (leachable)* |
| 8. Hillsboro (Copper Flat), Sierra | 1970s | 1982 | 75.1 | 7,000,000 | 60 million tons 0.42% Cu, 0.012% Mo (minable) |
| 3. Fierro–Hanover (Hanover–Hermosa Mountain), Grant** | 1970s | none | 57.55 | none | 80 million tons 0.38% Cu (geologic reserves) |
| 48. McGhee Peak, Hidalgo** | 1970s | none | — | none | unknown—exploration underway |
| 29. Cerrillos, Santa Fe** | 1959 | none | 28.7–48.2 | none | 10 million tons of 0.30% Cu (contained) |
| 30. Old Placers (Cunningham Gulch)** | 1970s | none | 29.9 | none | none |
| 14. Orogrande, Otero** | 1970s | none | 43.7–49.5 | none | 335,000 tons of 0.7% CuO (contained) |
| 15. Organ Mountains (?), Doña Ana** | 1980s | none | 34.4 | none | unknown |

reducing conditions (Titley and Marozas, 1995). Supergene deposits typically form enriched blankets of chalcocite and other copper minerals that are overlain by a leached cap of variable thickness. One or more periods of supergene enrichment are common to the larger porphyry copper deposits (Cook, 1994; Titley and Marozas, 1995; DuHamel et al., 1995).

Porphyry copper deposits are the most important type of copper deposit in the world. The Tyrone (Burro Mountains district) and Chino (Santa Rita district) mines (Table 9) were the 3rd and 5th largest copper mines in the United States in 1990 (Jolly and Edelstein, 1992). In 1994, the Chino mine was the 4th and the Tyrone mine was the 10th largest copper mines in the United States (Daniel Edelstein, U. S. Bureau of Mines, oral comm. October 17, 1995).

Only the known deposits in New Mexico that have produced, are under permitting, and/or have reported reserves are included as porphyry copper deposits in this report. The copper skarn deposits associated with Laramide porphyry deposits are classified as Laramide skarns. There are eight known porphyry copper deposits in New Mexico: Chino in the Santa Rita district; Tyrone in the Burro Mountains district; Copper Flat in the Hillsboro district; Hanover–Hermosa Mountain in the Fierro–Hanover district; McGhee Peak district in the Pelloncillo Mountains; Cerrillos district; Cunningham Gulch in the Old Placers district; and the Orogrande district (Table 9). Most are Laramide in age (Late Cretaceous–Eocene) and calc-alkaline in composition. The Cerrillos, Cunningham Gulch, and Orogrande deposits are alkaline-related, Oligocene–Miocene Great Plains margin deposits. In addition, suspected Oligocene–Miocene porphyry copper deposits are indicated by geologic data in the Organ Mountains (Newcomer and Giordano, 1986; McLemore et al., 1996). Williams and Forrester (1995) call the porphyry at the Organ Mountains a pyrite porphyry, which is uneconomic. Many other areas in the state have potential for porphyry copper deposits, but there are no reported reserves or production. Exploration and re-evaluation of porphyry copper targets in New Mexico for SX–EW processing will probably increase in the near future.

The largest porphyry copper deposit in New Mexico is the Chino mine at Santa Rita where copper sulfides occur in the upper, fractured granodiorite and adjacent sedimentary rocks. Three periods of supergene enrichment have further concentrated the ore during the Eocene, early Miocene (approximately 25 Ma), and late Miocene–Pliocene (Cook, 1994). Adjacent copper skarns are becoming increasingly more important economically. Reported age dates of the granodiorite stock range from 66.3 to 60.4 Ma (K-Ar, McDowell, 1971; recalculated using new decay constants), but Phelps Dodge Corp. data suggests the age of the stock is 56.5–58.2 Ma (Wunder and Trujillo, 1987). Total production from 1911 to 1993 is estimated as 4.54 million tons of copper from 500 million tons of ore (Long, 1995). Reserves (recoverable copper) are reported as 315.4 million tons of ore grading 0.67% Cu (Phelps Dodge Co., 1995).

The Tyrone porphyry copper deposit occurs within a quartz-monzonite laccolith and adjacent Proterozoic rocks (Kolessar, 1982). The age of the Tyrone stock is 52.8±1.2 to 56.6±1.6 Ma (K-Ar, R. J. Stegen, Phelps Dodge Mining Co., written comm. October 3, 1994; DuHamel et al., 1995). At least three cycles of supergene enrichment have concentrated the ore during the Eocene (approximately 39–45 Ma), early Miocene (approximately 16–19 Ma), and late Miocene (approximately 8–10 Ma; Cook, 1994; DuHamel et al., 1995). Several ore bodies, sometimes considered separate porphyry copper deposits, have been found. Approximately 300 million tons of ore grading 0.81% Cu were processed by the concentrator from 1969 to 1992. Approximately 425 million tons of ore grading 0.35% Cu have been leached (R. J. Stegen, Phelps Dodge Mining Co., written comm. October 3, 1994). Reserves (recoverable copper) are estimated as 230 million tons of ore grading 0.35% Cu (Phelps Dodge Co., 1995).

The Copper Flat deposit in the Hillsboro district, discovered in 1975, consists of copper, gold, molybdenum, and silver disseminated in a quartz-monzonite stock and in quartz veins (Dunn, 1982, 1984). Unlike the Santa Rita and Tyrone deposits, there is no supergene enrichment zone at Copper Flat; Copper Flat is a high-grade hypogene deposit with low pyrite. The Copper Flat porphyry is 75.1±2.5 Ma (NMBMMR unpublished age dates; Hedlund, 1974). Approximately 7 million pounds of copper was produced in March through June 1982 by Quintana Minerals Corp., prior to closure of the mine (Ohl and Eveleth, 1984). Alta Gold Co. is currently applying for mining permits to reopen the Copper Flat mine. Minable reserves were estimated in 1984 as 60 million tons of 0.42% Cu (504 million lbs Cu) and 0.012% Mo (14.4 million lbs Mo; Dunn, 1984). Current reserves of the deposit are estimated as 487 million lbs Cu, 243,000 oz Au, 3.2 million oz Ag, and 15.7 million lbs Mo (Dillard, 1995).

Supergene-enriched copper ore occurs near the Continental skarn deposits, at Hanover and Hermosa Mountains in the Fierro–Hanover district (Hillesland et al., 1995). The tabular zones contain fine-grained chalcocite along fractures in the Colorado Formation (Cretaceous) and are 50–500 ft thick. Age dates of intrusive rocks in the Fierro–Hanover district range from 72.2±2.1 to 58.6±2.0 Ma (K-Ar, McDowell, 1971; recalculated using new decay constants); a granodiorite porphyry sample collected from the Continental pit was dated as 57.55±0.07 Ma ($^{40}Ar/^{39}Ar$, McLemore et al., 1995). Drilling in the 1970s and 1990s has delineated 80 million tons of geologic reserves of 0.38% Cu at Hanover Mountain, northeast of the Continental mine (Hillesland et al., 1995). The deposit at Hermosa Mountain, southwest of the Continental mine, has not been defined.

During drilling in the early 1970s and 1990s a porphyry copper deposit was found at 100 ft deep in the northwest part of the McGhee Peak district (McLemore et al., 1996). Carbonate-hosted lead-zinc replacement and Laramide skarn deposits occur in the district and yielded 12 million lbs Pb, 10 million lbs Zn, and 85,000 pounds Cu (McLemore et al., 1996). Cyprus Minerals Corp. has filed claims in secs. 30 and 31 T24S R21W and plans to continue exploration drilling. Quartz-pyrite and argillic alteration occurs in most drill holes. No other information describing the porphyry copper deposit is available.

A porphyry copper deposit was discovered in the Cerrillos district at Bear Creek in 1959–1960 (Wargo, 1964; Akright, 1979; Giles, 1995). Thin veins and disseminations of copper sulfides occur in a monzonite porphyry stock; there is no supergene chalcocite blanket (Giles, 1995). The leach cap is 100–400 ft thick (Giles, 1995). Latites and monzonites range from 28.9±1.0 to 48.2±3.2 Ma (Bachman and Mehnert, 1978; Aronson and Lee, 1986). In 1976 Occidental Corp. estimated that the deposit contained 10 million tons of ore grading 0.30% Cu (Engineering and Mining Journal, 1976; Giles, 1995).

The Cunningham Gulch deposit in the Old Placers district is a gold-bearing, porphyry copper deposit (Maynard, 1995). Crackle breccia and stockwork veinlets of tenorite, magnetite, fluorite, gold, and molybdenite occur in oxidized augite monzonite surrounding the barren latite porphyry. Chalcopyrite occurs in unoxidized deposits below the oxidized zone. The latite has an age date of 29.9±1.2 Ma (Kay, 1986; Maynard, 1995). No reserves are known.

Geologic mapping, zoning, and geochemical data from the base-metal skarn deposits and intrusive rocks in the Orogrande district led Beane et al. (1975) to suggest an underground porphyry copper deposit possibly exists in the Orogrande district. A granodiorite was dated as 48.3±1.8 Ma and a latite as 43.7±2.2 Ma by K-Ar (Beane et al., 1975; Bloom, 1975). Drilling in the 1980s delineated a resource of 335,000 tons of 0.05 oz/ton Au and 0.7% CuO (Strachen, 1991). No other information on the porphyry deposit is available.

TABLE 10—Sedimentary-copper and Precambrian deposits in New Mexico with reported copper production. Number refers to Fig. 1. *, districts with minor production from veins and replacements in both sedimentary-copper deposits and Precambrian rocks.

| District, County | Year of discovery | Period of reported production | Estimated copper production (lbs) | Host rock |
|---|---|---|---|---|
| 7. Willow Creek, San Miguel | 1883 | 1927–1944 | 18,687,426 | Volcanic massive-sulfide deposits in Precambrian rocks |
| 10. Pastura, Guadalupe | 1900 | 1916–1969 | 13,578,214 | Triassic Santa Rosa Formation |
| 12. Gallinas, Lincoln | 1885 | 1909–1954 | 8,000,000 | Permian Yeso Formation |
| 13. Nacimiento, Sandoval, Rio Arriba* | 1880 | 1880–1964 | 7,700,000 | Triassic Chinle Group, Permian Abo Formation, Pennsylvanian Madera Formation, veins in Precambrian rocks |
| 65. Scholle, Socorro, Torrance, Valencia | 1900s | 1915–1961 | 1,122,468 | Permian Bursum, Abo, and Yeso Formations |
| 75. Bent, Otero* | 1900 | 1906–1957 | 560,000 | Cambrian Bliss Formation, Permian Abo Formation, near Tertiary dikes, veins in Precambrian rocks |
| 66. Coyote, Sandoval, Rio Arriba | ? | 1956–1957 | 462,000 | Permian Cutler Formation |
| 67. Estey, Lincoln | 1900 | 1900–1910 | 444,000 | Permian Abo Formation |
| 68. Sacramento, Otero* | 1900 | 1900–1962 | 260,570 | Permian Abo Formation, veins in Precambrian rocks |
| 69. Glorieta, Santa Fe* | 1900 | prior to 1905 | 50,000 | Pennsylvanian–Permian Sangre de Cristo Formation, veins in Precambrian rocks |
| 70. Lone Eagle, Eddy | 1905 | 1905–1956 | 35,236 | Permian Yates Formation |
| 71. Zuni Mountains, Cibola* | 1800s | 1905–1965 | 30,484 | Permian Abo Formation, veins in Precambrian rocks |
| 72. Jemez Springs, Sandoval | 1849 | 1928–1937 | 19,200 | Permian Abo Formation |
| 73. Tecolote, San Miguel | 1879 | 1900–1954 | 19,112 | Pennsylvanian–Permian Sangre de Cristo Formation |
| 76. Santa Fe, Santa Fe | 1880s | 1956–1957 | 11,766 | Veins and replacements, volcanic massive-sulfide deposits in Precambrian rocks |
| 74. Coyote Creek, Mora | 1847 | 1917–1956 | 10,100 | Pennsylvanian–Permian Sangre de Cristo Formation |
| 38. Black Mountain, Doña Ana* | ? | 1883–1900s | <10,000 | Veins in Precambrian rocks, Rio Grande rift barite-fluorite-galena deposits |
| 77. Romero Ranch, Valencia | 1929 | 1929–1956 | 9,300 | Triassic Chinle Group |
| 78. Hell Canyon, Valencia | ? | 1880–1976 | 7,900 | Veins and replacements in Precambrian rocks |
| 79. Picuris, Taos | ? | 1902–1955 | 3,400 | Veins and replacements in Precambrian rocks |
| 36. Caballo Mountains, Sierra* | ? | 1937–1957 | 2,800 | Veins in Precambrian rocks, sedimentary-copper deposits |
| 80. Placitas, Bernalillo, Sandoval* | 1860s | 1904–1961 | 2,441 | Triassic Chinle Group, veins in Precambrian rocks |
| 81. Black Mesa, Union | 1903 | 1956 | 800 | Triassic Sheep Pen Sandstone |
| 82. Hopewell, Rio Arriba | | 1881–1940 | 400 | Veins in Precambrian rocks |
| 83. Tijeras Canyon, Bernalillo* | 1880 | 1880–1952 | 223 | Permian Abo Formation, veins in Precambrian rocks |
| 84. Grandview Canyon, Sierra | ? | ? | unknown | Veins and replacements in Precambrian rocks |
| 85. Ladron Mountains, Socorro | ? | ? | unknown | Veins in Precambrian rocks, supergene copper-uranium deposits |
| 86. Lemitar Mountains, Socorro | ? | ? | unknown | Veins in Precambrian rocks, Rio Grande rift barite-fluorite-galena deposits |
| 87. Twinning, Taos | ? | ? | unknown | Veins in Precambrian rocks |

In the Organ Mountains, disseminated copper and molybdenum minerals have been found in drill holes northwest of Organ and may represent a faulted portion of a porphyry copper-molybdenum deposit (Newcomer and Giordano, 1986). The Sugarloaf Peak quartz monzonite is the host and has been dated as 34.4±0.3 Ma ($^{40}Ar/^{39}Ar$, hornblende, McLemore et al., 1995). Alteration, metal zonations, and drilling indicate that at least three porphyry systems probably occur in the Organ Mountains, but the potential for an economic deposit is low (Luddington et al., 1988; McLemore et al., 1996).

### Mississippi Valley-type deposits

Mississippi Valley-type (MVT) deposits are low-temperature, lead-zinc deposits generally found in carbonate rocks near the margins of marine sedimentary basins without any associated volcanic or intrusive activity. Small deposits occur adjacent to the marine Permian Basin in southeast New Mexico and may be oxidized MVT deposits (North and McLemore, 1986, 1988; Hill, 1993). This type of deposit differs from Rio Grande rift barite-fluorite-galena deposits by association with a marine basin in contrast to the association of Rio Grande rift deposits in New Mexico with continental basins along the Rio Grande rift. The MVT deposits in New Mexico consist of open-space fillings in breccia zones with little or no replacement. The deposits are small, highly oxidized, and contain only minor amounts of lead, silver, copper, and zinc. Geochemical

and stable-isotope data suggest these deposits were formed by basin brines, possibly related to migration of oil and gas deeper within the basin during the Oligocene–Miocene uplift of the Delaware Basin (Hill, 1993). Production has been insignificant and economic potential is low (North and McLemore, 1986, 1988).

### Sedimentary copper deposits

Stratabound, sedimentary copper deposits containing copper, silver, and locally gold, lead, zinc, uranium, vanadium, and molybdenum occur throughout New Mexico (Table 10). These deposits also have been called "red-bed" or "sandstone" copper deposits by previous workers (Soulé, 1956; LaPoint, 1979; Cox and Singer, 1986). They typically occur in bleached gray, pink, green, or tan sandstones, siltstones, shales, and limestones within or marginal to typical thick red-bed sequences of red, brown, purple, or yellow sedimentary rocks deposited in fluvial, deltaic, or marginal-marine environments of Pennsylvanian, Permian, or Triassic age. Some deposits (Table 10) are in sedimentary rocks that unconformably overlie Proterozoic granitic rocks.

The mineralized bodies typically occur as lenses or blankets of disseminated and/or fracture coatings of predominantly chalcocite, malachite, azurite, and chalcopyrite. The deposits in New Mexico range in size from 1 to 20 m thick and as much as several thousand meters long. Copper mineralization is dominant, with some deposits containing as much as 40–50% copper. The sedimentary copper deposits are typically associated with organic debris and other carbonaceous material.

Orebodies range in size from small, containing less than a ton of ore (Black Mesa), to moderate-sized deposits containing several hundred thousand tons of ore (Stauber). Most deposits were mined as open pits although underground methods were employed locally in many districts.

Copper and other metals were probably transported in low-temperature solutions through permeable zones during or soon after diagenesis (LaPoint, 1979; McLemore, in press a). Oxidizing waters could leach copper and other metals from (1) Proterozoic rocks enriched in these metals, (2) Proterozoic base-metal deposits, and (3) clay minerals and detrital grains in the red-bed sequences (LaPoint, 1979). Sources for chloride and carbonate to form soluble cuprous chloride or cuprous carbonate and other metal complexes occur in older Paleozoic evaporite and carbonate sequences. Precipitation occurred at favorable oxidation-reduction interfaces in the presence of organic material or $H_2S$-rich waters.

Most sedimentary copper deposits in New Mexico would not be conventionally mined for copper. The deposits are low grade, low tonnage, and inaccessible to existing mills. They are generally too low in silica to be suitable as silica flux material. Resources are reported for only the Nacimiento mine, which contains 6 million tons of ore at a grade of 0.56% Cu and 13 million tons of ore at a grade of 0.48% Cu as of 5/2/80 (NMBMMR files). An in situ leaching project is proposed for the deposit, but poor recovery, low permeability, and environmental concerns have hampered the project for years. If in situ leaching of these deposits becomes feasible and economic, then copper might be recovered from some of the larger deposits.

### Vein and replacement deposits in Precambrian rocks

Vein and replacement deposits containing predominantly precious metals with local base metals occur sporadically throughout most of the Precambrian terranes in New Mexico (Fig. 1). Production of copper has been insignificant from most districts unless sedimentary copper deposits also occur (Tables 10). Many districts containing veins and replacements in Precambrian rocks also contain other types of deposits, leading a number of geologists to believe that Precambrian deposits are a significant source for younger deposits. Copper minerals with gold and silver occur in quartz veins, shear zones, and as disseminations in granitic and mafic rocks. The age of mineralization is uncertain in most of these districts (Robertson et al., 1986; McLemore, in press a).

### Precambrian volcanogenic massive-sulfide deposits

Volcanogenic massive-sulfide deposits (VMS) contain varying amounts of copper, along with lead, zinc, and silver, and are associated with Precambrian greenstone terranes. Only three districts in New Mexico contain known VMS deposits (i.e. Willow Creek, Santa Fe, and La Virgen), and only the Willow Creek district has yielded any significant copper production (Table 10). However, several additional districts have characteristics that suggest VMS deposits may occur (Robertson et al., 1986) and offer excellent exploration targets. Many of these deposits are classified as vein and replacement deposits in Precambrian rocks.

VMS deposits are polymetallic, stratabound deposits formed contemporaneously with submarine volcanism by hot saline brines. Subsequent metamorphism or hydrothermal activity may have redistributed and reconcentrated new deposits. VMS deposits in New Mexico are hosted by volcanic rocks, clastic sediments, and carbonate rocks, all of Precambrian age (Robertson et al., 1986).

Ore deposits typically occur as several stratabound lensoid bodies that are conformable with layering and metamorphic fabric (Robertson et al., 1986). Pyrite and pyrrhotite in varying amounts occur with chalcopyrite, sphalerite, magnetite, hematite, and galena. Chloritization, silicification, and argillization occur adjacent to most deposits.

Many of the VMS deposits and suspected deposits occur in or near wilderness areas and cannot be developed in the foreseeable future. The Pecos mine (Willow Creek district) is currently being reclaimed. Exploration drilling continues at Jones Hill (Santa Fe district) to delineate reserves in that area. Estimates from drill data suggest that the Jones Hill deposit may contain a resource of over 5 million tons of ore containing 0.89% Cu, 1.98% Zn, 0.21% Pb, and some gold and silver (Dixon and Sealy, 1979; McLemore, 1995). Additional deposits may be discovered in other Precambrian terranes.

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# New Mexico Geological Society 1996 Fall Field Conference

The 1996 NMGS Fall Field Conference will examine the geology of the Los Alamos/Jemez Mountains and Nacimiento Mountains area on September 25–28. This scenic and geologically diverse region includes spectacular Tertiary–Quaternary volcanism, including the 14-mi-wide Valles caldera, an excellent record of Rio Grande rift faulting and sedimentation, a complex Tertiary–Quaternary record deposition and erosion by the Rio Grande, a thick and richly fossiliferous late Paleozoic section, and much more. The guidebook for the conference will be an approximately 400-page, hard-bound book containing three major road logs and 35–40 contributed papers.

Cochairmen are Margaret Anne Rogers and Barry S. Kues. For more information on the field conference, refer to

World Wide Web: http://XRFMAC.lanl.gov/nmgs1996.html

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