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MINERAL RESOURCES OF THE SOUTHERN SANGRE DE CRISTO MOUNTAINS, SANTA FE AND SAN MIGUEL COUNTIES, NEW MEXICO

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Abstract—Precambrian massive-sulfide, Precambrian vein and replacement, pegmatites, sedimentary copper, sedimentary iron, coal and placer gold deposits are found in nine mining districts in the southern Sangre de Cristo Mountains. The largest of these deposits is the Pecos mine in the Willow Creek district, where 2.3 million tons of ore containing Pb, Zn, Cu, Ag and Au worth over $40 million were produced. The Pecos mine is a Precambrian volcanic-hosted massive-sulfide deposit. Production from other types of deposits in the southern Sangre de Cristo Mountains is insignificant. Exploration is currently underway at a massive-sulfide deposit at Jones Hill in the Santa Fe district. Reclamation is proceeding at the Pecos mine and Alamitos Canyon mill.

INTRODUCTION

Mining has occurred sporadically in the Sangre de Cristo Mountains. Precambrian massive-sulfide, Precambrian vein and replacement, pegmatite, sedimentary copper, sedimentary iron, coal and placer gold deposits are found in nine mining districts in the area (Figure 1; Table 1). The largest of these deposits is the Pecos mine in the Willow Creek district, a Precambrian volcanic-hosted massive-sulfide deposit. The Pecos mine was the largest lead and zinc producer in New Mexico from 1927 to 1939 and is one of the top ten past producers of lead and zinc in New Mexico. Production from other types of deposits in the southern Sangre de Cristo Mountains has been small and insignificant (Tables 2,3).

MINING HISTORY AND PRODUCTION

Mining began in the late 1800s, when hunters and trappers began exploring the high country of the southern Sangre de Cristo Mountains. Only minor production, primarily of placer gold, occurred before 1902 because of poor accessibility and rugged terrain.

The Pecos mine was discovered in 1881, but production did not begin until 1902 (Table 2) because of poor metal recovery using metallurgical techniques known at the time. In 1916, the Goodrich Lockhart Co. began development of the Pecos mine and in 1927 production began by the American Metal Co. (now AMAX Resource Conservation Co.). All ore was hoisted through the main shaft, crushed at the surface, and then transported by aerial tramway to the Alamitos Canyon mill site, 19 km south of the mine (Matson and Hoag, 1930; Bemis, 1932; Anderson, 1938; McLemore, 1995). New metallurgical techniques were employed, enabling excellent recovery of the lead and zinc ore (Martin, 1931). Production continued through 1939 and then ceased because bad ground conditions and excessive water increased production costs and hampered mining. The mine was 533 m deep, but little or no mining occurred below the 411 m level (Harley, 1940). Minor reprocessing of the dumps occurred in 1943–1944. Total production amounted to 2.3 million tons of ore worth over $40 million (Table 2; Harley, 1940).

Minor metal production from the Santa Fe, Glorieta and Tecolote districts occurred sporadically from 1900 to 1957 (Table 2). Minor gold plays occurred from time to time when prospectors found a few flakes, but none of these yielded any significant production. Coal was produced from the Pecos River area to supply local residents in the early 1900s. Iron ore was discovered and produced from the Kennedy mine in the Glorieta district the early 1900s. Pegmatites in the El Porvenir, Elk Mountain, Nambe, Tecolote, and Rociada districts were worked for mica, beryl, uranium, rare-earth elements and tantalum (Table 3).

DESCRIPTION OF MINERAL DEPOSITS

Precambrian massive-sulfide deposits

Massive-sulfide deposits were mined at the Pecos mine in the Willow Creek district and occur at Jones Hill in the Santa Fe district. Massive-sulfide deposits are volcanogenic, polymetallic, stratabound deposits that consist of at least 50% sulfides (Sangster and Scott, 1976). Giles (1974) was one of the first to recognize the Pecos mine as a volcanic massive-sulfide deposit. In New Mexico, massive-sulfide deposits are rare and restricted to Precambrian greenstone terrains (Robertson et al., 1986; North and McLemore, 1986, 1988). The Pecos mine is the largest productive massive-sulfide deposit in the state; the Jones Hill deposit (under exploration) may be larger if one includes the deeper zones.

The massive-sulfide deposits at the Pecos mine are hosted by quartz-sericite, quartz-chlorite and talc schists, which are interpreted to represent a metamorphosed, sheared rhyolite dome complex (Riesmeyer, 1978; Riesmeyer and Robertson, 1979). Numerous small lens-shaped ore bod-

TABLE 1. Mining districts in the southern Sangre de Cristo Mountains, Santa Fe and San Miguel Counties, New Mexico. Districts are shown in Figure 1.

Year	Ore (tons)	Copper (lbs)	Gold (oz)	Silver (oz)	Lead (lbs)	Zinc (lbs)
Pecos Mine						
1902	75	some	—	—	—	—
1903	1000	73026	40	799	—	—
1904	250	24000	4.8	450	—	—
1927	164874	1989000	11406.2	509446	8706000	42445000
1928	201103	2120000	14982.9	495930	10385000	46410000
1929	216809	2641000	16597.2	471619	11439000	45730000
1930	151943	1438000	13116.9	406865	10861000	33276000
1931	184502	1096000	14941	420386	15125000	41633000
1932	185515	1019000	13456.5	463000	12898000	40712000
1933	191905	1753000	19424.7	621977	14149000	37329000
1934	200839	1733000	15632.4	543639	12286000	33693000
1935	185380	1227000	14816.7	432622	10323000	26744000
1936	150932	909000	11541	300514	7491000	19334000
1937	185850	1004000	12299.5	308101	7704000	21764000
1938	203900	1184000	13847.2	322400	8554500	22581000
1939	75620	418000	5694	166619	3599000	9849000
1943	71	4000	29	1800	4000	---
1944	2185	55400	528	11593	418000	43000
Total 1902-1944	2,302,753	18,687,426	178,858	5,477,760	133,942,500	42,154,300
Santa Fe District						
1956	139	8770	—	63	—	—
1957	44	2996	—	33	—	—
Total						
1956-1957	183	11,766	—	96	—	—
Glorieta District						
Total prior	3,400	50,000	—	<300	<1,000	—
to 1905						
Tecolote District						
Total 1900-1954	596	19,112	19	128	2,816	—

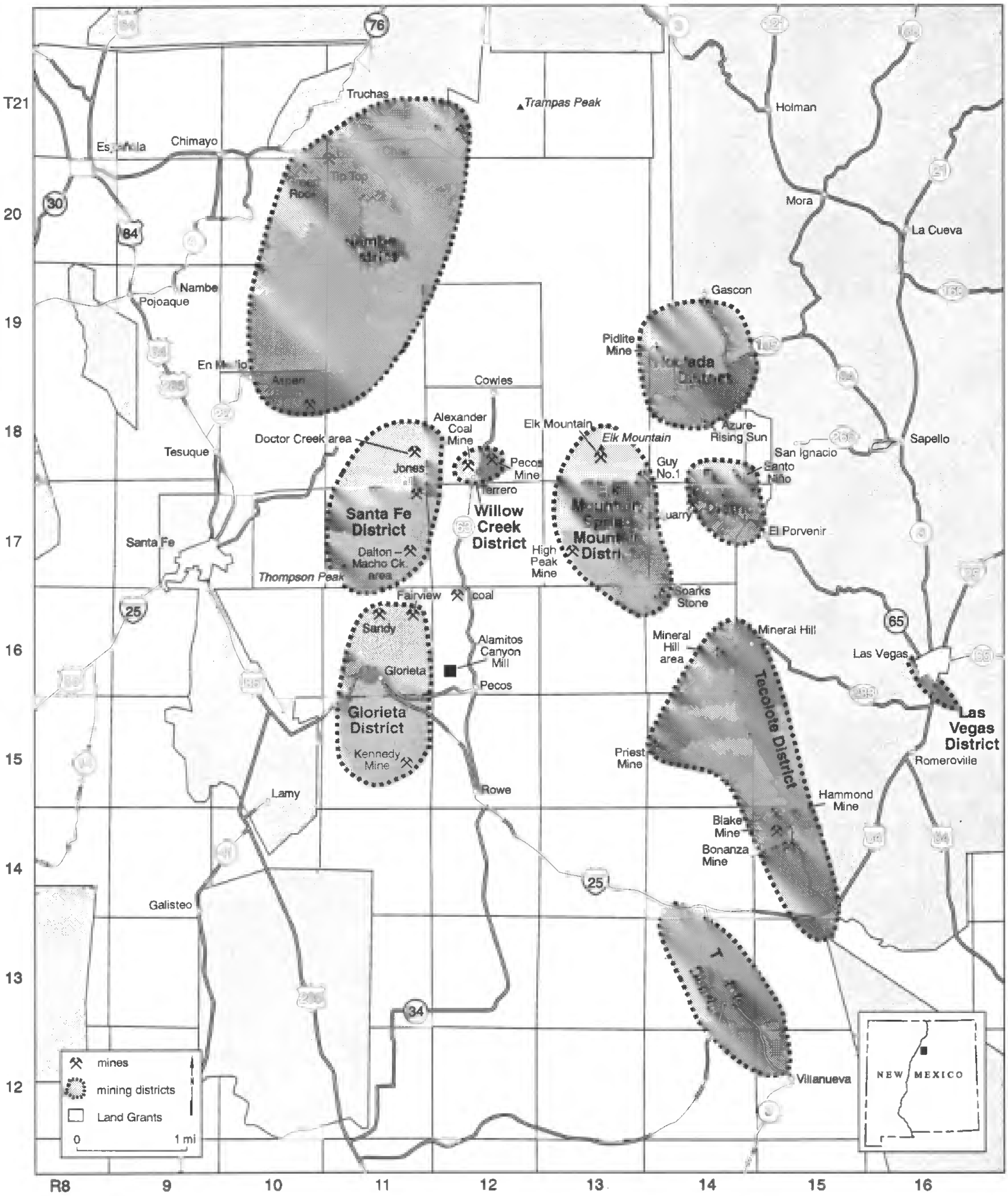

FIGURE 1. Mining districts and major mines and prospects in the southern Sangre de Cristo Mountains, Santa Fe and San Miguel Counties, New Mexico (modified from North and McLemore, 1986 and Moench and Lane, 1988).

ies are concentrated into two subparallel, stratabound zones, named the Katydid and Evangeline deposits. The deposits strike northeast and extend for over 250 m along strike (Stott, 1931; Krieger, 1932a,b; Harley, 1940). The mineralogy of the ore bodies is predominantly sphalerite, galena and chalcopyrite with minor but appreciable amounts of gold and silver in a gangue of quartz, sericite, pyrite, pyrrhotite, chlorite, actinolite, sericite, tourmaline and calcite. The ore occurs in three textural types: massive sulfide ore with at least 50% sulfides with massive, banded, or brecciated textures; low-grade (<50% sulfides) massive or banded ore; and stringer ore containing low-grade veinlets and stringers of sulfides (Krieger, 1932a,b; Riesmeyer and Robertson, 1979). Oxidation and secondary enrichment of the ore deposits were found only in the upper levels of the mine (Krieger, 1932a,b). Silicification and chloritization of the host rocks occurs predominantly along the footwall of the ore bodies; widespread alteration is absent. The average grade of production during the first three years was 16.06% Zn, 3.73% Pb, 1.02% Cu, 116 ppm Ag, and 3.7 ppm Au (Harley, 1940).

The Jones Hill deposit, in the eastern Santa Fe district, was first developed in 1930–1940. Some high-grade ore may have been produced, but accurate production records are not available. Extensive drilling and rehabilitation of the three adits have occurred from 1979 to the present by a variety of companies, including Continental Oil Co., Inc., Santa Fe Mining Co., Inc., and Champion Resources, Inc. Two deposits have been found by drilling in sericitized Jones Hill rhyolite and Embudo granite. The deposits consist of disseminated, stringer, and rare massive zones of sphalerite, galena and chalcopyrite in a gangue of quartz, pyrite, chlorite, sericite, calcite and talc. The two zones may represent one deposit offset by faults. Proterozoic basalt and gabbro overlie the Jones Hill massive-sulfide deposit and the Embudo fault truncates the deposit to the west (U.S. Geological Survey et al., 1980; Moench and Lane, 1988). Estimates from drill data suggest that the Jones Hill deposit may contain over 5 million tons of massive and disseminated sulfide ore containing 0.89% Cu, 1.98% Zn, 0.21% Pb, 20 ppm Ag, and 2 ppm Au (Dixon and Seay, 1979). The average grade of three holes drilled in 1978, represent-

TABLE 2. Production from mining districts in the southern Sangre de Cristo Mountains, Santa Fe and San Miguel Counties, New Mexico (U.S. Geological Survey and U.S. Bureau of Mines Minerals Yearbooks; NMBMMR files; Harley, 1940; Soule', 1956).

DISTRICT (Aliases)	YEAR OF DISCOVERY	COMMODITIES PRODUCED (PRESENT)	TYPE OF DEPOSITS	REFERENCES
Willow Creek (Pecos, Hamilton, Cowles, Tererro)	1883	Pb,Zn,Ag,Au,Cu,coal	Precambrian massive-sulfide, Precambrian vein and replacement, placer gold, coal	Krieger (1932a,b), Riesmeyer and Robertson (1979), Harley (1940), Stott (1931), Giles (1974), Robertson et al. (1986), Moench and Lane (1988), U.S. Geological Survey et al. (1980), Hubbell (1926)
Santa Fe	1880s	Ag,Cu (Pb,Zn,W,Au, Mo)	Precambrian massive-sulfide, Precambrian vein and replacement, placer gold	Fulp (1982), Renshaw (1984), Fulp and Renshaw (1985), Elston (1967), Robertson et al. (1986), Harley (1940)
Glorieta	1900	Cu,Ag,Pb,Fe (Au,U,V)	Precambrian vein and replacement, sedimentary	Lindgren et al. (1910), Soule' (1956), Elston (1967), Budding (1972), Kelley (1949) copper, sedimentary iron,
Tecolote (Mineral Hill, Ribera, Villanueva)	1879	Au,Ag,Cu,Pb,Be,Nb, mica (U,V,Mo,Ni)	sedimentary copper, pegmatites, Precambrian vein and replacement, placer gold	Harley (1940), Soule' (1956), Redmon (1961), Schilling (1965), Johnson (1972), McLemore (1994)
Rociada	1900	Ta,Li (Au,Ag,Cu,Pb, Mo, U,V,Zn,Be,REE, Th)	pegmatites, Precambrian vein and replacement, sedimentary copper	Harley (1940), Soule' (1956), Robertson et al. (1986), Schilling (1965)
Elk Mountain-	1936	mica,Ta,REE,Th (Ag,	pegmatite, Precambrian	Harley (1940), Klich (1983), Redmon (1961),
Spring Mountain El Porvenir		Pb,U) Mo (Cu,Ag,Au,U,Th, F, mica,Bi,W)	vein and replacement pegmatite, Precambrian vein and replacement, sedimentary copper	U.S. Geological Survey et al. (1980) Harley (1940), Soule' (1956), Anderson (1957), McLemore and North (1985)
Las Vegas Nambe	1883	(Au)mica,Be(Ta,Au,A g,Bi)	placer gold pegmatite	Johnson (1972), McLemore (1994), Harley (1940) U.S. Geological Survey et al. (1980), Redmon (1961)

ing over 750,000 tons of massive sulfide mineralization, is reported as 1.55% Cu, 0.05% Pb, 5.47% Zn, 16 ppm Ag, and 2 ppm Au (Dixon and Seay, 1979). One drill hole contained 21 m of mineralized rock that assayed 3.05% Cu, 0.07% Pb, 6.9% Zn, 21 ppm Ag, and 2.5 ppm Au (U.S. Geological Survey et al., 1980).

Early interpretations of the origin of the Pecos deposits were as hydrothermal replacement deposits formed by late-stage fluids from the Embudo Granite (Krieger, 1932a,b; Harley, 1940). However, the concordant, stratabound character of the deposits and absence of alteration in the hanging wall are consistent with formation contemporaneously with submarine volcanism by hot saline brines. The sulfides were concentrated at the contact between volcanic rocks and seawater during the late stages of silicic volcanism (Giles, 1974; Riesmeyer, 1978; Riesmeyer and Robertson, 1979). The Jones Hill deposit probably formed in a similar environment. Subsequent metamorphism and intrusion by mafic dikes altered the deposits.

Precambrian vein and replacement deposits

Several minor vein and replacement deposits occur along faults and shear zones in Proterozoic rocks in the Santa Fe, Glorieta, Rociada, Elk Mountain-Spring Mountain and El Porvenir districts (Table 1). The mineralogy and geometry of these small, low-grade deposits is variable, rang-

TABLE 3. Miscellaneous production from deposits in the southern Sangre de Cristo Mountains, New Mexico.

DISTRICT	MINE	PRODUCTION	REFERENCE
El Porvenir	Santo Nino (Romero)	several hundred tons Mo in 1914	Schilling (1965)
El Porvenir	unknown quarry	250 tons granite worth $3000 in 1932	Talmage and Wootton (1937)
Elk Mountain-Spring Mountain	Elk Mountain	450 tons sheet mica, 21 tons scrap mica in 1942-58	Redmon (1961)
Elk Mountain-Spring Mountain	Guy No. 1	500 tons Ta-U-REE in 1940-1942, several tons scrap mica	Redmon (1961), U.S Geological Survey (1965)
Elk Mountain-Spring Mountain	High Peak	518 tons containing mica, 1.5 tons 10.6% Th, 57% REE, 0.3% U3O8	Redmon (1961)
Elk Mountain-Spring Mountain	Sparks Stone	15 tons containing 32 lbs U3O8 in 1955-56	McLemore (1983)
Nambe	Fish	2,800 lbs beryl in 1957	Redmon (1961)
Nambe	Green Rock	175 lbs sheet mica in 1956	Redmon (1961)
Nambe	Rocking Chair	600 lbs beryl, 2 tons mica in 1956-57	Redmon (1961)
Nambe	Tip top	less than 50 tons mica in 1957	Redmon (1961)
Rociada	Azure-Rising Sun	small amount of Mo	Schilling (1965), Harley (1940)
Rociada	Pidlite	1.5 tons Ta, 530 tons Li in 1946-47	Jahns (1953), Sheffer and Goldsmith (1969)
Santa Fe	Kennedy	3500 tons Fe ore prior to 1910	Kelley (1949)
Tecolote	Priest	15 tons scrap mica, 24 tons beryl, 1000 lbs Nb-Ta in 1914-17, 1955-56	Redmon (1961)
Willow Creek	Alexander and an unknown adit	several 100 tons of coal	Lindgren et al. (1910)

ing from quartz veins to stratabound and disseminated pyritic (locally with base-metal sulfides) deposits. Some of these deposits were developed as early as 1879, but little, if any, production has occurred (Table 2). Development typically consists of prospect pits, adits and shallow shafts. Most are difficult to locate in the forested terrain.

Five types of vein and replacement deposits were described by Fulp (1982) in the Dalton Canyon area of the Santa Fe district: (1) semi-massive deposits of chalcopyrite, bornite and magnetite in phyllite, (2) disseminated chalcopyrite, pyrite, magnetite and pyrrhotite in phyllite, schist, granfels and gneiss, (3) disseminated pyrite, pyrrhotite and magnetite in phyllite, schist, granfels and gneiss, (4) quartz veins containing chalcopyrite, pyrite and scheelite, and (5) oxidized occurrences of malachite and azurite along shear and fracture zones. There are numerous small deposits of thin quartz veins containing malachite, chalcopyrite, pyrite, and other copper minerals and deposits of disseminations and fracture coatings of chalcopyrite, malachite and pyrite in the Macho and Dalton Canyon, Jones Hill and Doctor Creek areas. Chemical assays are typically low, except in selected samples from the Jones Hill, Macho Canyon, and Dalton Canyon areas; maximum values of hundreds of assays are 11.4% Cu, 0.46% Pb, 3.6% Zn, 68 ppm Ag, and 39 ppm Au (U.S. Geological Survey et. al, 1980; Fulp, 1982; Renshaw, 1984; New Mexico Bureau of Mines and Mineral Resources file data; report in preparation). Some of these deposits could be associated with undiscovered massive-sulfide deposits.

A possible volcanogenic-exhalative tungsten deposit of scheelite and pyrite occurs in epidote-actinolite schist in the Dalton Canyon area (Moench and Erickson, 1980; Fulp and Renshaw, 1985). This deposit, the Blacklite prospect, is a stratabound horizon of scheelite and quartz with assays that range from 0.0058% to 1.25% tungsten (Fulp and Renshaw, 1985). Numerous discordant quartz veins and pods in the Dalton Canyon area also contain scheelite (Fulp, 1982; Renshaw, 1984). The relationship, if any, of the tungsten deposits to the massive-sulfide and vein and replacement deposits in the Santa Fe and Pecos districts is speculative.

Other minor vein and replacement deposits, in the Glorieta, Tecolote, Rociada, Elk Mountain-Spring Mountain, and El Porvenir districts (Table 1; Lindgren et al., 1910; Harley, 1940; Budding, 1972), typically consist of disseminations, fracture coatings, and small veinlets of malachite, azurite, chalcopyrite, bornite, pyrite and locally quartz, with possible chalcocite and covellite in 1–2 m wide zones. Assays at the Sandy mine in the Glorieta district range from 0.5 to 1.85% Cu, trace to 58 ppm Ag, and trace to no detectable gold (Eveleth and Wakefield, 1982). A minor gold rush occurred in the Mineral Hill area of the Tecolote district in 1879–1880, but little if any gold was produced (Harley, 1940). Most mineral deposits in the Mineral Hill area are in Pennsylvanian-Permian sandstones, but some veins in Precambrian rocks were developed. Veins in the Rociada district contain pyrite, chalcopyrite, sphalerite, galena, and locally gold and molybdenite (Harley, 1940). Veins in the El Porvenir district contain chalcopyrite, scheelite, bismuthinite, molybdenite, malachite and azurite (Hurley, 1940). Several hundred tons of molybdenite ore have been produced from some veins (Schilling, 1965). Quartz veins cutting metamorphic rocks in the Elk Mountain-Spring Mountain area contain galena and chalcopyrite and assayed 0.7 ppm Ag (U.S. Geological Survey et al., 1980; Klich, 1983). Similar veins are found throughout the southern Sangre de Cristo Mountains, but their economic potential is low because of low grade and small tonnage.

The origin and exact age of many of these Precambrian vein and replacement deposits is unknown. A Proterozoic age is assigned because schistosity appears to control mineralization in most areas, mineral deposits are absent in immediately overlying Paleozoic sedimentary rocks in many areas, and there is no evidence of Tertiary intrusive activity. Many of these occurrences may be related to undiscovered massive-sulfide deposits and may have formed by similar saline brines. Fulp and Renshaw (1985) proposed a volcanogenic-exhalative model for stratabound quartz-scheelite (tungsten) deposits in Dalton Canyon whereby the deposits were exhaled as a chemical sediment on the seafloor and subsequently metamorphosed. Similar models can be evoked to explain the origin of other vein and replacement deposits in the area. Subsequent metamorphism has altered the deposits in some areas.

Pegmatites

Pegmatites are coarse-grained, granitic intrusive igneous rocks that typically occur as dikes, lenses or veins, and are simple or complex. Simple pegmatites consist of feldspar, quartz and mica, whereas complex pegmatites are mineralically and texturally zoned and consist of varied additional minerals. Complex pegmatites can contain rare elements such as beryllium, lithium, uranium, thorium, rare-earth elements, boron, niobium, tantalum, and fluorine and are favorite mineral collecting sites. Typically, such minerals are scattered discontinuously throughout the pegmatite, thereby hampering recovery. Past production of pegmatites in New Mexico typically has been by hand-sorting or other selective mining techniques. Both simple and complex pegmatites also have been a source of feldspar and mica (Table 3). Proterozoic pegmatites occur in the Tecolote, Rociada, Elk Mountain-Spring Mountain, El Porvenir and Nambe districts in the southern Sangre de Cristo Mountains (Table 1).

Most pegmatites in New Mexico are poor mining targets under current economic conditions because they are small and low grade. The Pidlite pegmatite in the Rociada district consists of several lenses that are up to 6 m wide and 46 m long. Minor lithium, found in lepidolite, and tantalum, found in microlite, were produced in 1946–1947 (Table 3; Sheffer and Goldsmith, 1969), but future economic production from the pegmatite is unlikely (Moench and Lane, 1988). The Elk Mountain pegmatites in the Elk Mountain-Spring Mountain district are up to 61 m long and 6 m wide. Minor amounts of mica were produced in 1942–1958 (Table 3; Redmon, 1961). Other pegmatites in the district have been exploited for tantalum, uranium, rare-earth elements and mica (Table 3). Numerous pegmatites occur in the Nambe district, but most are simple and were exploited only for mica. A few pegmatites in the Nambe district were mined for beryl (Table 3). Most of these pegmatites are small, less than a few meters wide and a few tens of meters long.

Sedimentary-copper deposits

Stratabound, sedimentary copper deposits occur in the Glorieta, Tecolote, Rociada and El Porvenir districts (Table 1). These deposits contain copper, silver, and locally lead, zinc, uranium, vanadium, molybdenum, and gold and they occur in bleached gray, pink, green or tan sandstones, siltstones, shales and limestones within thick red-bed sequences of fluvial, deltaic or marginal-marine sedimentary rocks of Pennsylvanian to Permian age (North and McLemore, 1986). These deposits have been also called "red-bed" or "sandstone-copper" deposits by previous workers (Soule', 1956; Phillips, 1960). Development consists of shallow shafts, prospect pits and adits, but most of the workings are difficult to locate because of natural backfilling and vegetation overgrowths.

The largest and most productive deposits were in the Tecolote district, where nearly 20,000 lbs of copper were produced (Table 2). A leaching plant was built at the Blake mine by the Blake Mining and Milling Investment Co. with a daily capacity of 50 tons. Smaller leaching plants were built at the Bonanza (Lindgren et al., 1910) and Hammond (Soule', 1956) mines.

Copper minerals typically occur in arkosic sandstones as discrete grains, disseminations, cement and thin veinlets. Malachite, tennorite, azurite, bornite and chalcocite are the predominant minerals and are typically associated with organic material (Lindgren et al., 1910; Harley, 1940; Soule', 1956). The ore at the Blake mine in the Tecolote district was up to 2.4 m thick and ranged from 1.5 to 5% Cu. The Fairview deposit in the Glorieta district was 1.5 m thick and 15 m wide: a sample assayed 3.26% Cu and 21 ppm Ag (Soule', 1956). The Paytiamo deposit, also in the Glorieta district, was 1.2 m long and 3 cm thick. Most of the other deposits are smaller and lower in grade. Locally, high concentrations of uranium, vanadium, lead, zinc, molybdenum and gold occur, but rarely in economic concentrations. Locally, folds and other structures control mineralization, such as anticlines in the Tecolote district (Soule', 1956).

Copper and other metals were probably transported in low-temperature solutions which migrated through permeable sedimentary rocks, along bedding planes, fractures and faults. Replacement textures and diagenetic features of the organic material indicate mineralization occurred during or after diagenesis. Oxidizing waters could leach copper and other metals from Proterozoic rocks, Proterozoic base-metal deposits, or clay minerals and detrital grains within the red-bed sequences (LaPoint, 1976). The close proximity of the sedimentary-copper deposits in the southern Sangre de Cristo Mountains to Precambrian massive-sulfide and vein and replacement deposits strongly suggests that the Precambrian base-metal deposits could be a source. Precipitation occurred at favorable oxidation-reduction interfaces in the presence of organic material or H_2S-rich waters.

Sedimentary iron deposits

A small iron deposit was developed at the Kennedy mine in the Glorieta district (NW¼ sec. 23, T15N, R11E). The deposit contains impure, ochery limonite and hematite approximately 1 m thick in the San Andres Formation (Permian). Approximately 3500 tons of ore were shipped from open pits and adits to Socorro and El Paso for use as flux in the mills and as pigments in paints (Lindgren et al., 1910; Kelley, 1949; Elston, 1967). The deposit was approximately 84 m long and 46 m wide. Some reserves remain (Elston, 1967); but the deposit is low grade, small, and uneconomic.

Coal

Several hundred tons of coal were mined for domestic use prior to 1910 from several thin coal seams along the Pecos River (Lindgren et al., 1910), but have no current economic significance (Hoffman, in press). These coal seams are in the Sandia Formation (Pennsylvanian) as determined from fossil assemblages (Gardner, 1910a,b; Kosanke and Meyers, 1986). Adits were driven in the coal seams in NE¼ sec. 28, T18N, R12E by O.W. Alexander in 1905 and in SE¼ sec. 5, T16N, R12E by Gould and Thomas. The coals are poor in quality, high in ash, thin and discontinuous.

Additional occurrences of coal in Pennsylvanian rocks in the southern Sangre de Cristo Mountains are economically insignificant (Sutherland and Montgomery, 1975; Kosanke and Myers, 1986). Discontinuous, thin lenses of Pennsylvanian coal were mined from a quarry in the Hyde Estates of northeast Santa Fe city for use in a small lime kiln, but production is unknown (F.E. Kottlowski, written commun., March, 1993).

Placer gold deposits

A placer deposit is any natural accumulation or concentration of a material in unconsolidated sediments of a stream, beach or residual deposit (Bolye, 1979). Small discontinuous, stream placer gold deposits are reported from the Willow Creek, Santa Fe, Villanueva area of the Tecolote, and Las Vegas districts (Johnson, 1972; McLemore, 1994). Total estimated placer production from the southern Sangre de Cristo Mountains is 100 oz or less, primarily from the Willow Creek district (Johnson, 1972). Some placer gold production may have come from other districts, but production records are not available.

Placer gold was produced from the Pecos River, south of the Pecos mine in the Willow Creek district. Stream-sediment samples collected from along the Pecos River and analyzed for gold using neutron-activation methods all contained less than 0.2 ppm gold. Panning of the stream sediments and examination of the panned concentrates failed to locate any free, visible gold.

Ancient placer gold deposits were reportedly found in sandstone cliffs between Villanueva and Sena in the Villanueva area of the Tecolote district. The exact location of these deposits are unknown. Two to four adits were driven in placer gold accumulations in Permian sandstones or conglomerates along the Pecos River (Harley, 1940; Johnson, 1972). Assays ranged as high as 22 ppm gold (Harley, 1940). The host rock is probably the Glorieta Sandstone Member.

MINERAL RESOURCE POTENTIAL

On the basis of favorable geology, structures, and geochemical anomalies, Moench and Lane (1988) determined that a moderate potential for copper, lead, silver, zinc and gold in massive-sulfide deposits exists in the Pecos mine, Jones Hill, Dalton Canyon areas, and east of Elk Mountain and north of Elk Mountain. The Dalton Canyon area has a high potential for massive-sulfide, stratabound tungsten, and local molybdenum deposits. Moench and Lane (1988) also suggested that Precambrian granitic batholiths in the Glorieta district may have potential for tin-bearing greisen deposits. Elsewhere in the southern Sangre de Cristo Mountains, the mineral resource potential is probably low because of small size and low grade. Exploration is underway at Jones Hill to further delineate the massive-sulfide deposits. Any mining in the southern Sangre de Cristo Mountains in the near future will be difficult because of political sensitivities and environmental concerns. Reclamation is underway at the Pecos mine and Alamitos Canyon mill site.

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REFERENCES

Anderson, E. C., 1938, The aerial tramway as used at the Pecos mine [M.S. thesis]: Socorro, New Mexico School of Mines, 15 p.

Anderson, E. C., 1957, The metal resources of New Mexico and their economic features through 1954: New Mexico Bureau of Mines and Mineral Resources, Bulletin 39, 183 p.

Bemis, H. D., 1932, Milling methods and costs at the Pecos concentrator of the American Metal Co., Tererro, New Mexico: U.S. Bureau of Mines, Information Circular 6605, 23 p.

Boyle, R. W., 1979, The geochemistry of gold and its deposits: Geological Survey of Canada, Bulletin 280, 584 p.

Budding, A. J., 1972, Geologic map of the Glorieta quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Geologic Map 24, scale 1:24,000.

Dixon, R. L. and Seay, M. W., 1979, Report on Pecos massive sulfide project: Continental Oil Co., Anaconda Geological Document Collection, American Heritage Center, University of Wyoming, unpublished report, 123 p.

Elston, W. E., 1967, Summary of the mineral resources of Bernalillo, Sandoval, and Santa Fe Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 81, 81 p.

Eveleth, R. W and Wakefield, J., 1982, Preliminary report on the Sandy No. 1 copper prospect, Glorieta mining district, Santa Fe County, New Mexico: New Mexico Bureau of Mines and Mineral Reources, unpublished report (mine archives), 6 p.

Fulp, M. S., 1982, Precambrian geology and mineralization of the Dalton Canyon volcanic center, Santa Fe County, New Mexico [M.S. thesis]: Albuquerque, University of New Mexico, 199 p.

Fulp, M. S. and Renshaw, J. L, 1985, Volcanogenic-exhalative tungsten mineralization of Proterozoic age near Santa Fe, New Mexico and implications for exploration: Geology, v. 13, p. 66–69.

Gardner, J. H., 1910a, Carboniferous coal in New Mexico: Mines and Minerals, April, p. 570–571.

Gardner, J. H., 1910b, Isolated coal fields in Santa Fe and San Miguel Counties, New Mexico: U.S. Geological Survey, Bulletin 381C, p. 447–451.

Giles, D. L., 1974, Massive sulfide deposits in Precambrian rocks, northern New Mexico: New Mexico Geological Society, Guidebook 25, p. 378.

Harley, G. T., 1940, The geology and ore deposits of northeastern New Mexico (exclusive of Colfax County): New Mexico Bureau of Mines and Mineral Resources, Bulletin 15, 104 p.

Hoffman, G. K., in press, Coal resources of New Mexico: New Mexico Bureau of Mines and Mineral Resources, Resource Map.

Hubbell, A. H., 1926, Pecos mine: a new lead-zinc project: Engineering and Mining Journal, v. 122, p. 1004–1012.

Jahns, R. H., 1953, The genesis of pegmatites: American Mineralogist, v. 38, p. 1078–1112.

Johnson, M. G., 1972, Placer gold deposits of New Mexico: U.S. Geological Survey, Bulletin 1348, 46 p.

Kelley, V. C., 1949, Geology and economics of New Mexico iron ore deposits: University of New Mexico, Publications in Geology, no. 2, 246 p.

Klich, I., 1983, Precambrian geology of the Elk Mountain-Spring Mountain area, San Miguel County, New Mexico [M.S. thesis]: Socorro, New Mexico Institute of Mining and Technology, 170 p.

Kosanke, R. M. and Myers, D. A., 1986, Palynological analyses of several Pennsylvanian coal beds from Santa Fe County, New Mexico: New Mexico Geology, v. 8, p. 54–56.

Krieger, P., 1932a, Geology of the lead-zinc deposits at Pecos, New Mexico-Part I: Economic Geology, v. 27, p. 344–404.

Krieger, P., 1932b, Geology of the lead-zinc deposits at Pecos, New Mexico-Part II: Economic Geology, v. 27, p. 450–470.

LaPoint, D. J., 1976, A comparison of selected sandstone copper deposits in New Mexico: Oklahoma Geological Survey, Circular 77, p. 80–96.

Lindgren, W., Graton, L. C. and Gordon, C. H., 1910, The ore deposits of New Mexico: U.S. Geological Survey, Professional Paper 68, 361 p.

Martin, G. V., 1931, Flotation of a western complex ore [M.S. thesis]: Rolla, School of Mines and Metallurgy of the University of Missouri, 37 p.

Matson, J. T. and Hoag, C., 1930, Mining practice at the Pecos mine of the American Metal Co. of New Mexico: U.S. Bureau of Mines, Information Circular 6368, 21 p.

McLemore, V. T., 1983, Uranium and thorium occurrences in New Mexico: New Mexico Bureau of Mines and Mineral Resources, Open-file report 183, 180 p.

McLemore, V. T., 1994, Placer gold deposits in New Mexico: New Mexico Geology, v. 16, p. 21–25.

McLemore, V. T., 1995, Pecos mine and Alamitos Canyon mill: New Mexico Geological Society, Guidebook 46.

McLemore, V. T. and North, R. M., 1985, Copper and uranium mineralization in east-central New Mexico: New Mexico Geological Society, Guidebook 36, p. 323–329.

Moench, R. H. and Erickson, M. S., 1980, Occurrence of tungsten in the Sangre de Cristo Range near Santa Fe, New Mexico–possible stratabound scheelite peripheral to favorable settings for volcanogenic massive-sulfide deposits: U.S. Geological Survey, Open-file report 80–1162.

Moench, R. H. and Lane, M. E., 1988, Mineral resource potential map of the Pecos Wilderness, Santa Fe, San Miguel, Mora, Rio Arriba, and Taos Counties, New Mexico: U.S. Geological Survey, Miscellaneous Field Studies Map MF-1921A, 15 p.

North, R.M. and McLemore, V.T., 1986, Silver and gold occurrences in New Mexico: New Mexico Bureau of Mines and Mineral Resources, Resource Map 15, 32 p.

North, R. M. and McLemore, V. T., 1988, A classification of the precious metal deposits of New Mexico; *in* Bulk mineable precious metal deposits of the western United States Symposium Volume: Geological Society of Nevada, Reno, Symposium proceedings, p. 625–659.

Phillips, J. S., 1960, Sandstone-type copper deposits of the United States [Ph.D. dissertation]: Cambridge, Harvard University, 320 p.

Redmon, D.E., 1961, Reconnaissance of selected pegmatite districts in north-central New Mexico: U.S. Bureau of Mines, Information Circular 8013, 79 p.

Renshaw, J. L., 1984, Precambrian geology of the Thompson Peak area, Santa Fe County, New Mexico [M.S. thesis]: Albuquerque, University of New Mexico, 215 p.

Riesmeyer, W. D., 1978, Precambrian geology and ore deposits of the Pecos mining district, San Miguel and Santa Fe Counties, New Mexico [M.S. thesis]: Albuquerque, University of New Mexico, 215 p.

Riesmeyer, W. D. and Robertson, J. M., 1979, Precambrian geology and ore deposits of the Pecos mine, San Miguel County, New Mexico: New Mexico Geological Society, Guidebook 30, p. 175–179.

Robertson, J. M., Fulp, M. S. and Daggett, M. D. III, 1986, Metallogenic map of volcanogenic massive-sulfide occurrences in New Mexico: U.S. Geological Survey, Miscellaneous Field Studies Map MF-I1853-A.

Sangster, D. F. and Scott, S. D., 1976, Precambrian, strata-bound, massive Cu-Zn-Pb sulfide ores of North America; *in* Wolf, K. H. ed., Handbook of strata-bound and stratiform ore deposits: Elsevier Scientific Publishing Co., Amsterdam, v. 6, p. 129–222.

Schilling, J. H., 1965, Molybdenum resources of New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 76, 76 p.

Sheffer, H. W. and Goldsmith, L. A., 1969, Tantalum project, Rociada, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Mineral Resources Report 2, 15 p.

Soule', J. M., 1956, Reconnaissance of the "redbed" copper deposits in southeastern Colorado and New Mexico: U.S. Bureau of Mines, Information Circular 7740, 74 p.

Stott, C. E., 1931, Geology of the Pecos mine: Engineering and Mining Journal, v. 131, p. 270–275.

Sutherland, P. K. and Montgomery, A. 1975, Trail guide to geology of the Upper Pecos: New Mexico Bureau of Mines and Mineral Resources, Scenic Trip 6, 116 p.

Talmage, S. B. and Wootton, T. P., 1937, The non-metallic resources of New Mexico and their economic features: New Mexico Bureau of Mines and Mineral Resources, Bulletin 12, 159 p.

U.S. Geological Survey, 1965, Mineral and water resources of New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 87, 437 p.

U.S. Geological Survey, U.S. Bureau of Mines, and New Mexico Bureau of Mineral Resources, 1980, Mineral resources of the Pecos Wilderness and adjacent areas, Santa Fe, San Miguel, Mora, Rio Arriba, and Taos Counties, New Mexico: U.S. Geological Survey, Open-file Report 80–382, 103 p.