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MINERAL RESOURCES IN THE JEMEZ AND NACIMIENTO MOUNTAINS, RIO ARRIBA, SANDOVAL, SANTA FE AND LOS ALAMOS COUNTIES, NEW MEXICO

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Abstract—Mining began in the Jemez and Nacimiento Mountains during prehistoric times. Significant production of metals began in 1894 at the Cochiti district. Since then, more than $53.5 million cumulative dollars worth of pumice, gypsum, gold, silver, copper, lead, zinc, uranium and vanadium have been produced from eight districts in the Jemez and Nacimiento Mountains, including the Cochiti, Collins-Warm Springs, Coyote, Gallina, Jemez Springs, Nacimiento, Jemez pumice and White Mesa gypsum districts. In addition, significant amounts of sand and gravel and crushed stone have been produced, but production records are not available. Other commodities in the area include perlite, scoria, diatomite, sulfur, limestone and travertine, but little or no production of these has occurred. In addition, a low-grade molybdenum deposit has been found in the Sulphur Springs area; it is not economic, but it does demonstrate the ability of geothermal systems in the Jemez Mountains to form epithermal mineral deposits. Further development of mineral resources is assured in the Nacimiento and Jemez Mountains, especially pumice, gypsum, and sand and gravel. Existing mining and environmental regulations will protect the environmental integrity of the area, but increase the costs to the mining company and the consumer.

INTRODUCTION

Minerals have played and will continue to play an important role in the economy of New Mexico; the Jemez and Nacimiento Mountains in north-central New Mexico are no exception. Mining began in the Jemez and Nacimiento Mountains during prehistoric times by Native Americans who utilized stone and other materials for tools, weapons, ornaments and construction of their houses. Evidence of early use of raw materials is found at Bandelier National Monument in the Jemez Mountains. Significant production of metals began in 1894 at the Cochiti district. Since then, more than $53.5 million cumulative dollars worth of pumice, gypsum, gold, silver, copper, lead, zinc, uranium and vanadium have been produced from eight districts (Table 1; Fig. 1). An unknown amount of sand and gravel and dimension stone also has been produced, but production records are not available. Some of these are significant economic mineral deposits to New Mexico. Nearly all of the pumice and much of the gypsum production from New Mexico comes from this area; New Mexico ranks 2nd in pumice production and 10th in gypsum production in the United States (U. S. Bureau of Mines, 1994). The Nacimiento district is the 13th largest copper producing district in New Mexico (McLemore, 1996), although the district is no longer producing.

The purpose of this paper is to describe briefly the mineral deposits of the Jemez and Nacimiento Mountains and comment briefly on the future economic potential and environmental concerns. This paper is a summary and update of parts of several published and unpublished reports, including a mineral resource inventory and assessment of Sandoval, western Santa Fe, and western Rio Arriba Counties for the U. S. Bureau of Land Management (McLemore et al., 1984, 1986; McLemore and North, 1984; McLemore and Chenoweth, 1992; McLemore, 1992). Production statistics of various commodities are from published reports, NMBMMR file data, and/or from compilation by the author of yearly production reported by the U. S. Geological Survey (1902-1927), U. S. Bureau of Mines (1927-1994), U. S. Atomic Energy Commission (unpublished ore

TABLE 1. Mining districts in the Jemez and Nacimiento Mountains, Sandoval, Rio Arriba, Santa Fe and Los Alamos Counties, New Mexico. Names of districts are after File and Northrop (1966) wherever practical, but many districts have been combined and added. Estimated value of production is in original cumulative dollars and includes all commodities in the district, except aggregate (sand and gravel) and dimension stone. Type of deposit after North and McLemore (1986, 1988) and McLemore (in press). Production data modified from Lindgren et al. (1910), Anderson (1957), U.S. Geological Survey (1907-1927), U.S. Bureau of Mines (1927-1994), New Mexico State Inspector of Mines Annual Reports (1912-1982), and Energy, Minerals and Natural Resources Department (1986-1994).

DISTRICT OR COAL FIELD (ALIASES)	YEAR OF DISCOVERY	YEARS OF PRODUCTION	COMMODITIES PRODUCED (PRESENT)	ESTIMATED CUMMULATIVE VALUE OF PRODUCTION (IN ORIGINAL DOLLARS)	TYPE OF DEPOSIT	REFERENCES
Cochiti (Bland)	1880	1894-1963	Ag, Au, Cu, Pb (U)	1,400,000	volcanic-epithermal	Elston (1967), McLemore et al. (1984)
Collins-Warm Springs	1952	1957-1959	U (V)	4,000	sedimentary-uranium	McLemore and Chenoweth (1989)
Jemez pumice	1950	1950-present	pumice, perlite (scoria)	31,000,000	pumice	Austin et al. (1982), Hoffer (1994)
Jemez Springs	1849	1928-1937	Cu, Ag, Au (U)	4,000	sedimentary-copper	Elston (1967), McLemore et al. (1984)
Nacimiento	1880	1880-1974	Cu, Ag, Au, Pb, Zn (U, V)	1,500,000	sedimentary-copper, sedimentary-uranium, Precambrian veins and replacements	Anderson (1957), Elston (1967), McLemore et al. (1984)
White Mesa (San Ysidro)	1950s	1960-present	gypsum	>20,000,000	gypsum	McLemore et al. (1984)
Coyote	1911	1956-1957	Ag, Cu, U, Pb, V	4,000	sedimentary-copper, sedimentary-uranium	North and McLemore (1986)
Gallina (Youngsville, Mesa Alta, Arroyo del Aqua)	1900s	1908, 1916, 1956	(U, V, Cu, Ag, Pb)	none	sedimentary-copper, sedimentary-uranium	North and McLemore (1986)
TOTAL ESTIMATED PRODUCTION	—	1894-1995	—	>53,500,000	—	—

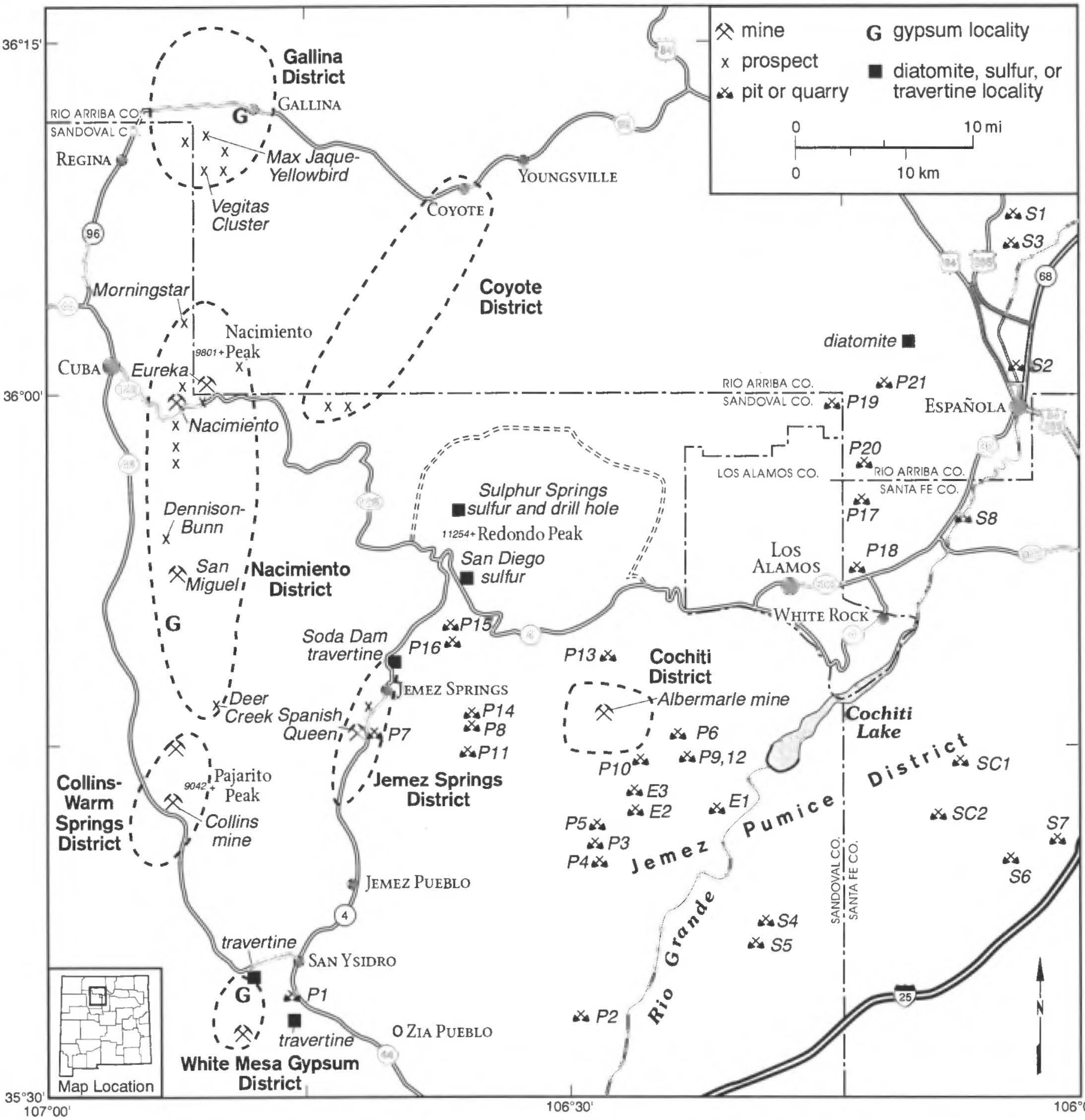

FIGURE 1. Location of mining districts and selected mines in the Jemez and Nacimiento Mountains, Rio Arriba, Sandoval, Santa Fe and Los Alamos Counties, New Mexico. Numbers refer to Tables 5 and 6; S-sand and gravel, G-gypsum, P-perlite, SC-scoria.

production records, 1947-1970), New Mexico State Mine Inspector Annual Reports (1912-1982), and Energy, Minerals and Natural Resources Department Annual Reports (1986-1994). More detailed information on mines and prospects in the area are by Chenoweth (1974), McLemore (1983), McLemore et al. (1984, 1986), Hatton et al. (1994), and Barker et al. (1995).

DESCRIPTION OF METALS DEPOSITS

Cochiti district

The Cochiti mining district is located on the southeast flank of the Jemez Mountains (Fig. 1). Although the district was discovered in 1880, only minor prospecting for base- and precious-metals occurred in the area until 1890 because of land ownership disputes. In 1897, the U.S. Supreme Court ruled that the disputed land was public domain and opened the area to mineral prospecting. By 1899, 23 patented and 116 unpatented claims were located in the area. The first report of uranium minerals in New Mexico came from the Cochiti district (Jones, 1904; Chenoweth, 1974). Total production from the district is estimated to exceed $1.4 million worth of gold, silver, copper and lead from volcanic-epithermal vein deposits (Table 2). Production was credited to Bernalillo County until 1903 when Sandoval County was formed and this has caused some confusion in the early production records.

TABLE 2. Metal production from the Cochiti district, Sandoval County, New Mexico, 1894-1963 (modified from Elston, 1967; U.S. Geological Survey, 1904-1927; U.S. Bureau of Mines, 1927-1963; Lindgren et al., 1910; McLemore et al., 1984; McLemore, 1992). *—estimated production. W—withheld, confidential data. —no reported production.

YEAR	ORE (short tons)	Au (oz)	Ag (oz)	Cu (lbs)	Pb (lbs)	VALUE ($)
1894–1904	170,000*	33,200*	1,000*	—	—	1,040,000*
1914	4,373	824	24,460	—	—	29,000
1915	18,701	4,021	93,314	—	14,657	133,006
1916	9,300	2,070	56,404	—	—	79,900
1932	659	364	13,440	—	—	11,336
1933	465	158	7,940	—	W	6,052
1934	580	110	7,060	200	—	8,440
1935	159	20	1,575	—	7,800	2,151
1938	276	164	1,700	—	—	6,846
1939	514	66	2,310	100	—	3,766
1945	19	—	28	2,000	—	290
1947	3	9	4	200	—	361
1948	9	9	451	—	—	723
1963	6	1	237	—	—	338
TOTAL	205,000*	42,000*	210,000*	2,500*	23,000*	1,400,000*

The Albemarle mine was the largest of the district, which was developed by a 220 m shaft and 1500 m of drifts, and is estimated to have yielded approximately 105,000 short tons of ore grading 7.5 ppm Au and 137 ppm Ag (McLemore, 1992). Despite ownership disputes, mining commenced about 1894 and in 1896 the R.W. Woodbury mill near Bland began operations. A 273-metric ton capacity mill at the Albermarle mine was built in 1899 and was one of the first cyanide mills in the state, but closed in 1904. The Cossak Mining Co. built another mill in 1915, but it operated only for a short time (Bundy, 1958). In 1943, another mill operated at the Iron King mine that closed in 1947. Numerous problems hampered mining and milling in the district, including rugged topography, expensive equipment, high freight cost, low recovery rates of ore (less than 40%), overselling of the district by speculators, past litigation problems, and poor understanding of the origin of the mineralization. Since 1963, only minor assessment work has been completed in the district.

The mineral deposits in the Cochiti district are volcanic-epithermal vein deposits, similar to deposits found in the Mogollon and Steeple Rock districts in southwestern New Mexico (Buchanan, 1981; McLemore, 1994). Gold and silver with minor base metals occur in quartz veins filling faults and fracture zones that were formed as a result of the Toledo and Valles calderas (Stein, 1983; Wronckiewicz et al.,1984). The host rocks are the Bland Group and Bearhead Rhyolite (Miocene). Ore bodies occurred as pods or thin shoots within the quartz veins. The veins typically strike north-south and are up to 457 m long and 15 m wide. The deepest workings in the district are 221 m, but are inaccessible (Bundy, 1958).

Multiple episodes of vein filling, stockwork zones and brecciation occurred. The veins consist predominantly of quartz with minor amounts of pyrite, calcite, argentite, sphalerite, chalcopyrite, galena, covellite and proustite-pyrargyrite (Bundy, 1958; Wronkiewicz et al., 1984). Gold is typically associated with pyrite and argentite and tellurium minerals are also reported (Northrop, 1959). A sample by Barbour (1908) of typical ore assayed 6.2 ppm Au, 420 ppm Ag, 0.19% Sb, 0.242% Te, 0.61% S, 98.1% SiO_2, and a trace of copper. Additional assays are reported as high as 153 ppm Au and 2.2% Ag (NMBMMR file data). Alteration of the host rock is zoned from regional propylitic alteration consisting of chlorite and montmorillonite farthest from the vein to advanced argillic alteration consisting of illite-kaolinite and dickite next to the vein (Bundy, 1958; Parkison et al., 1985). Oxygen isotope data also support this decrease in hydrothermal alteration away from the vein (WoldeGabriel, 1989).

Fluid inclusion data indicate mineral deposition occurred at or near boiling at temperatures between 240° and 315° C (Parkison et al., 1985; Wronkiewicz et al., 1984). Salinities ranged from 0 to 5 eq. wt.% NaCl. Oxygen isotope data indicate mineralizing fluids were predominantly meteoric water (WoldeGabriel, 1989). Structural and stratigraphic relationships and known ages of the host rocks suggest that the mineralization occurred between 6.5 and 1.4 Ma (Wronkiewicz et al., 1984; Parkison et al., 1985). Two hydrothermal alteration events have been dated at Cochiti at 8.07 Ma and 6.5-5.6 Ma (WoldeGabriel, 1989), suggesting that the mineralization was preceded by early alteration. Thus, this district is one of the youngest volcanic-epithermal districts in New Mexico (McLemore, 1994; in press).

The potential for additional deposits in the district is good. The ore is high in silica and could be used as silica flux, especially if it contains significant precious metals and copper. However, the distance to operating smelters is excessive (653 km to the Hidalgo smelter at Playas, New Mexico and 540 km to the ASARCO smelter at El Paso, Texas). Interpretation of geophysical data suggests that the Cochiti district is part of a northeast-trending zone of felsic intrusives beneath Tertiary volcanics, which suggests additional deposits could occur near these intrusives along this zone at depths exceeding 30 m (McLemore et al., 1984).

Collins-Warm Springs

The Collins-Warm Springs area is one of several districts discovered in the 1950s that contains uranium in the Morrison Formation (Jurassic) outside of the Grants uranium district. The Collins-Warm Springs area is on the southwestern flank of the Nacimiento Mountains (Fig. 1). Chenoweth (1974) and McLemore and Chenoweth (1992) mapped the uranium deposits and associated alteration. Uranium occurs in at least four stratigraphic horizons in the upper Westwater Canyon Member, lower and middle Brushy Basin Member, and lower Jackpile Sandstone Member of the Morrison Formation. One mine, the Collins, produced 839 lbs U_3O_8 that averaged 0.14% U_3O_8 (McLemore, 1983; McLemore and Chenoweth, 1989). Uranium occurs at the contact between sandstone and green claystone, along bedding planes and fractures in sandstone and underlying siltstone, and as disseminations within homogeneous sandstone (Kittleman and Chenoweth, 1957). The mineralized zones range in thickness from a few centimeters to 1 meter. The deposits are small and uneconomic.

Nacimiento district

Various types of deposits are found in the Nacimiento district, first discovered in 1880, on the western flank of the Nacimiento Mountains (Fig. 1). The largest deposits are stratabound, sedimentary-copper deposits that occur in the Agua Zarca Sandstone, Chinle Group (Triassic); smaller deposits also occur in the Madera (Pennsylvanian), Abo, and Cutler Formations (Permian). Sedimentary-uranium deposits are found in the Morrison Formation throughout the range. Veins and replacement deposits in Precambrian rocks are found in the Proterozoic rocks. Total production amounts to 7,700,000 lbs Cu, 76,000 oz Ag, and minor lead, zinc, and gold (Tables 3, 4).

Although the copper deposits were worked by Native American and Spanish miners before 1800, extensive mining in the Nacimiento district did not occur until the 1880s. Interest in the district faded after 1917, only to increase in the late 1960s. In 1971, Earth Resources Company began production at the Nacimiento mine (formerly the Copper Glance-Cuprite patented claims) after an extensive exploration program. A 2722 metric ton/day mill was built to handle estimated reserves of 807 million metric tons of 0.71% Cu (Talbott, 1974; Woodward et al., 1974). The deposit was mined by open-pit methods. In 1973, a break in the tailings dam occurred and in 1974 the company ceased production. The deposit was sold to various companies through the 1970s and 1980s; Leaching Technology Inc. now owns the deposit. New reserves are reported for the Nacimiento mine amounting to 5.4 million metric tons of ore at a grade of 0.56% Cu and an additional 11.8 million metric tons of ore at a grade of 0.48% Cu as of May 2, 1980 (NMBMMR file data). An in-situ leaching project is proposed for the deposit, but poor recovery, low permeability and environmental concerns have hampered the project.

The largest copper deposit in the Nacimiento district is at the Nacimiento mine, where the host rock is white, poorly cemented arkosic conglomeratic sandstone in the Agua Zarca Sandstone, 23 to 30 m thick.

TABLE 3. Metal production from the Nacimiento district, Sandoval and Rio Arriba Counties, New Mexico, 1880-1975 (modified from Elston, 1967; McLemore et al., 1986; U.S. Geological Survey, 1904-1927; U.S. Bureau of Mines, 1927-1975). W—withheld, confidential data.

YEAR	ORE (short tons)	Ag (oz)	Cu (lbs)	VALUE ($)
1880-1900	W	63,000	6,300,000	700,000
1904	467	52	846	190
1911	10	46	5,731	741
1916	130	274	26,276	6,684
1917	20	153	12,901	3,648
1918	6	118	10,935	2,819
1919	166	1,317	100,000	20,075
1920	89	700	53,821	10,666
1929	W	W	W	W
1943	13	45	4,000	552
1945	19	28	2,000	290
1950	465	10	6,000	1,257
1951	132	11	4,000	978
1955	1,729	410	600,00	22,751
1956	12,903	7,564	548,200	239,831
1957	10,094	1,392	421,700	128,912
1959	75	55	6,000	1,658
1960	277	99	12,000	3,505
1961	99	23	2,000	1,362
1964	1,010		6,000	1,923
1967	W	W	W	W
1971	W	W	W	W
1972	W	W	W	W
1973	W	W	W	W
1974	W	W	W	W
TOTAL REPORTED 1880-1964	27,704	75,297	7,582,410	1,147,842
ESTIMATED TOTAL 1880-1974	—	76,000	7,700,000	1,500,000

Kaolinization is present. Copper is associated with carbonaceous material, which is difficult to completely leach by H_2SO_4. Much of the deposit occurs at the surface; the deepest mineralized zones are at 274 m and deeper. Both disseminated deposits and high-grade, mineralized fossil logs are present. In the disseminated deposits, the sulfide to oxide ratio is 1:3 above the water table and 10:1 below the water table, where most of the copper is as chalcocite (NMBMMR file data). Chalcocite occurs as discrete anhedral grains and replacement of the organic material (Talbott, 1974). Pyrite and native silver are present locally throughout the deposit and the oxidized portion contains malachite, chrysocolla, azurite, cuprite, antlerite, spangolite and native copper (Talbott, 1974; Woodward et al., 1974; LaPoint, 1979). Large, high-grade, mineralized fossil logs up to several meters long have been replaced by chalcocite, locally preserving the woody cell structure. The adjacent carbonaceous shales are not mineralized. Copper content varies, with some deposits containing as much as 40-50% copper. Silver averages 17 ppm and typically increases with increasing copper concentrations. Gold is rare. Similar, but smaller, sedimentary-copper deposits occur in the Agua Zarca Sandstone at the San Miguel mine, where sphalerite is found in addition to the copper minerals.

Additional stratabound, sedimentary-copper deposits containing uranium and vanadium are found in the Madera, Abo and Cutler Formations throughout the Nacimiento Mountains (Soulè, 1956; McLemore, 1983; Woodward, 1987), but are small and uneconomic. A sample from the Deer Creek prospect assayed 5.92% Cu, 0.144% U_3O_8, and 30 ppm Ag, but the deposit is less than 10 m long and 5 m thick (McLemore et al., 1984).

The majority of sedimentary-copper deposits in New Mexico, including the Nacimiento deposit, would not be conventionally mined for copper. Most 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. If in-situ leaching of these deposits becomes feasible and economic, copper might be recovered from the Nacimiento deposit.

Uranium occurs in the Westwater Canyon Member of the Morrison Formation at the Dennison-Bunn claim on the western flank of the Nacimiento Mountains (Fig. 1). The Westwater Canyon Member is approximately 61 m thick and uranium is found at the irregular boundary between oxidized and reduced sandstones throughout the member. Uranium is associated with iron-oxides and carbonaceous material and may be representative of a roll-type uranium deposit (Ridgley, 1980) or a remnant uranium deposit (McLemore and Chenoweth, 1992). The U. S. Department of Energy estimated a potential resource of 344 metric tons of uranium at a price of $30/lb at a grade of 0.27% U_3O_8 (U.S. Department of Energy, 1980), which is uneconomic at present. Additional, small insignificant uranium occurrences are found in the Morrison Formation throughout the Nacimiento Mountains, but are not important economically (McLemore, 1983).

Several small vein and replacement deposits of copper and silver in Precambrian rocks occur throughout the Nacimiento Mountains, but no production is reported (McLemore et al., 1984; McLemore and North, 1984). Chalcocite and malachite occur in a schist xenolith in Proterozoic granite near a Proterozoic diabase dike at the Chalcocite claim in sec. 36, T21N, R1W (Lindgren et al., 1910; McLemore and North, 1984). A sample contained 7000 ppm Pb, 5 ppm Ag, and 150 ppm Ni (Santos et al., 1975). An 18-m adit has developed the deposit. Oxidized copper minerals and free gold occur in a 1-m-wide vein along a shear zone in Proterozoic granite at the Morningstar prospect south of the Nacimiento mine (R. H. Weber, field notes, 1961; Woodward et. al, 1972). At Jemez Springs (sec. 13, T18N, R2E), thin barite veins occur in the Proterozoic granite, but have not been developed (McLemore et al., 1984). A small pit exposes a copper vein in Proterozoic quartz monzonite in sec. 24, T20N, R1W (Woodward et al., 1973; McLemore et al., 1984). Minor radioactive anomalies occur in Proterozoic granite in the southern Nacimiento Mountains (McLemore et al., 1984). The age of these deposits is uncertain, but presumed Precambrian. These deposits are uneconomic, but could have served as sources for younger sedimentary-copper deposits.

Coyote district

Stratabound, sedimentary-copper deposits containing uranium and vanadium are found in the Abo Formation in the Coyote district, in the northern Nacimiento Mountains (Fig. 1; Soulè, 1956; McLemore, 1983; Woodward, 1987). These were discovered in 1911. In 1956-1957, 462,000

TABLE 4. Reported and estimated base- and precious-metals production by district in Jemez and Nacimiento Mountains, New Mexico. —no reported production. W—withheld or not available. *—production 1969-1975 withheld. (), estimated data.

DISTRICT	YEARS	ORE (short tons)	COPPER (lbs)	GOLD (oz)	SILVER (oz)	LEAD (lbs)	ZINC (lbs)	ESTIMATED VALUE ($)	REFERENCES
Coyote	1956-1957	—	462,000	—	841	W	—	4,000	Bingler, 1968
Cochiti		205,045	2,500	41,072	208,923	22,457	—	1,322,210	Elston, 1967; McLemore et al.,
	1894-1963	—		(42,000)	(210,000)			1,400,000	1984
Jemez Springs	1928-1937	233	19,200	1	159	—	—	4,000	Elston, 1967
Nacimiento*	1880-1964	27,704	7,582,410	2.4	75,297	—	—	1,147,842	Elston, 1967; McLemore et al.,
	1880-1975	—	(7,700,000)	(3)	(76,000)	1,783	463	1,500,000	1984

lbs Cu, 841 oz Ag, and some lead were produced from the Coyote district (Table 4; Bingler, 1968) and in 1954-1955, 177 lbs of U_3O_8 and 142 lbs of V_2O_5 were produced. The deposits are similar to those found in the Nacimiento district, although smaller and uneconomic.

Gallina district

Additional stratabound, sedimentary-copper deposits containing uranium and vanadium were discovered in the early 1900s in the Abo, Cutler and Madera Formations throughout the Gallina district in the northwestern Nacimiento Mountains (Fig. 1; Soulè, 1956; McLemore, 1983; Woodward, 1987). Copper production, if any, is unknown from most mines, but two mines in the Vegitas Cluster area yielded 19 lbs of no-pay U_3O_8 (McLemore, 1983). The U. S. government only paid for high-grade shipments. A sample from the Max Jacque-Yellow Bird prospect assayed 0.26% Cu, 0.05% U_3O_8, and 1 ppm Ag (McLemore et al., 1986). The deposits are similar to those found in the Nacimiento district, although smaller and uneconomic.

Jemez Springs district

Stratabound, sedimentary-copper deposits containing uranium and vanadium were discovered in 1849 in the Abo Formation in the Jemez Springs district on the southeastern flank of the Nacimiento Mountains (Fig. 1). In 1928-1937, 233 short tons of ore containing 19,200 lbs Cu, 159 oz Ag, and 1 oz Au was produced from the Jemez Springs district, predominantly from the Spanish Queen mine (Table 4). Two samples from the Spanish Queen mine assayed 3.49-4.9% Cu, 0.006-0.018% U_3O_8, and 21-36 ppm Ag (McLemore et al., 1984). The deposits are similar to those found in the Nacimiento district, although smaller and uneconomic.

Miscellaneous metal deposits

An uneconomic molybdenite deposit was discovered in brecciated tuffs and sedimentary rocks in core hole VC-2A at Sulphur Springs (Fig. 1; Hulen et al., 1987). The deposit is at a depth of 25-125 m and was formed about 0.66 Ma (WoldeGabriel and Goff, 1989) from fluids at temperatures of 200° C (Sasada and Goff, 1995). Although this deposit is too deep and low grade to be mined, it is significant because it demonstrates the ability of geothermal systems in the Jemez Mountains to form epithermal mineral deposits. These studies also are important in understanding the origin of mineral deposits in epithermal systems. For instance, similarities in textures, mineralogy, and temperatures of alteration and mineralization between altered Carboniferous carbonate rocks from the Valles caldera (1.14 Ma) 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, such as those found in the Magdalena district (Armstrong et al., 1995; Renault et al., 1995).

ORIGIN OF METALS AND URANIUM DEPOSITS

The volcanic-epithermal vein deposits in the Cochiti district were formed by a convective geothermal system related to the various Miocene to Pliocene rhyolitic intrusives in the area. Metals were leached from underlying sedimentary and volcanic rocks as the heated waters circulated through fractures and other open spaces. Episodic deposition occurred at or near boiling when CO_2 and H_2S were lost as a vapor phase resulting in an increase in pH, oxygen fugacity, and cooling of the solution (Buchanan, 1981; McLemore, in press). A similar convective geothermal system formed the molybdenite deposit at Sulphur Springs.

Stratabound, sedimentary-copper deposits were formed by low-temperature meteoric groundwater. Copper and other metals were probably transported in solutions through permeable zones during or soon after diagenesis (LaPoint, 1979). Oxidizing waters could leach copper and other metals from Proterozoic rocks enriched in these metals, Proterozoic base-metal deposits, and clay minerals and detrital grains within 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 from deeper within the San Juan Basin.

The sandstone-uranium deposits were also formed by low-temperature groundwater moving through permeable zones during or soon after diagenesis. Precipitation occurred at favorable oxidation-reduction interfaces in the presence of organic material, such as humates, or H_2S-rich waters from deeper within the San Juan Basin. Another proposed model indicates that uranium precipitated at the interface between fresh water and groundwater brines (Granger and Santos, 1986).

DESCRIPTIONS OF INDUSTRIAL MINERAL DEPOSITS

Sand and gravel (aggregate)

Sand and gravel and crushed rock, also known as aggregate, are used for base course in highways, as aggregate in cement, concrete and blacktop for roads. Sand and gravel and crushed rock pits are typically found near highways or urban areas to minimize transportation costs; active pits and quarries in the Jemez and Nacimiento Mountains are listed in Table 5 and located in Figure 1. Other pits and quarries are shown in McLemore et al. (1984, 1986) and Barker et al. (1995). Sand and gravel deposits are typically formed by alluvial processes. Sand dunes along the Jemez River (sec. 21, 22, T14N, R3E) were mined in the 1960s for roofing sand (Elston, 1967). Abundant sand and gravel resources exist in Recent and Quaternary river, pediment and terrace deposits in the Jemez and Nacimiento Mountains for future needs.

Crushed rock quarries have been utilized in the past and consist of a variety of lithologies such as basalt, limestone, sandstone and shale (McLemore et al., 1984, 1986; Barker et al., 1995). Most stone is used in construction, as aggregate, and in railroad abutments. Abundant lithologies occur in the Jemez and Nacimiento Mountains for future needs (McLemore et al., 1984).

Limestone

Limestone is abundant in the Jemez and Nacimiento Mountains in the Madera Formation (Pennsylvanian) and Todilto Formation (Jurassic). Limestone is typically crushed and used as an aggregate or in cement, but the distance to the cement plant at Tijeras is too far to be economic. In many places the Todilto Limestone, which is as much as 12 m thick, is suitable for high-calcium uses such as flue-gas sulfurization (Kottlowski, 1962).

Pumice

New Mexico is the second leading producer of pumice in the United States and the majority of New Mexico production comes from deposits in the Jemez Mountains (Table 6, Fig. 1). Total cumulative production from the Jemez Mountains area amounts to nearly 6 million tons of pumice worth nearly $31 million from 1950 to the present (cumulative value). Pumice is a light-colored, lightweight rhyolitic volcanic rock with a vesicular structure that is used in concrete, building blocks, dental pol-

TABLE 5. Active sand and gravel pits and quarries in the Jemez and Nacimiento Mountains, Rio Arriba, Sandoval and Santa Fe Counties (from Hatton et al., 1994).

NO. FIG. 1	NAME	LOCATION	COMPANY
S1	El Guique	26 T22N R8E	Espanola Transit Mix Co. (aggregate)
S2	Lowdermilk	26 T21N R8E	Southwest Custom Crushing
S3	MFM Pit	16 T22N R8E	FNF Mining Co. (aggregate)
S4	Peña Blanca	T15N R6E	Alternative Resource Corp.
S5	Santa Fe River pit	32 T16N R6E	Central Concrete Products Inc.
S6	Blotter Constructio n pit	9 T16N R8E	Blotter Construction Co. (fill dirt, gravel, base course)
S7	Leeder pit	1 T16N R8E	R. L. Stacey Construction
S8	Totavi Gravel pit	7 T19N R8E	Paul Barker Construction (base coarse, crushed rock, rip rap, sand)

TABLE 6. Pumice, perlite and scoria mines and prospects in the Nacimiento and Jemez Mountains, Sandoval, Santa Fe and Rio Arriba Counties (from McLemore et al., 1984; Hoffer, 1994; Hatton et al., 1994; Barker et al., 1995). *—active pits.

NO. FIG. 1	NAME	LOCATION	COMMENTS
	PUMICE		
P1	Jonas	13 T15N R1E	—
P2	Volcalite	27 T15N R4E	—
P3	Pumice Group	2 T16N R4E	—
P4	Pumice mine	11 T16N R4E	several quarries
P5	unknown	35 T17N R4E	—
P6	unknown	18 T17N R5E	—
P7	Pyramid	3 T17N R2E	quarry
P8	U.S Forrest Service mine*	3 T17N R3E	mined by Utility Block Co., Inc., 31 mt/day
P9	Santa Barbara	15, 16 T17N R5E	—
P10	unknown	17, 18, 34 T17N R5E	—
P11	Strip mine	9, 10, 11, 15 T17N R3E	quarries
P12	unknown	10, 11, 14 T17N R5E	quarries
P13	Valle Grande	13, 14 T18N R4E	mined by Mission Mining, Inc.
P14	Esquire claims	34 T18N R3E	mined by Utility Block Co.
P15	Las Conchas mine*	5 T18N R4E	mined by Copar Pumice Co., 600 mt/day
P16	unknown	7 T18N R4E	Mission Mining, Inc.
P17	White Eagle	4, 5, 6, 8 T19N R7E	—
P18	Guaje Canyon mine*	31, 32 T19N R7E	mined by Copar Pumice Co., 100 mt/day
P19	unknown	1, 2, 12, 15 T20N R6E	—
P20	unknown	32, 33, 34, 35 T20N R7E	—
P21	Rocky Mountain mine*	34 T21N R7E	mined by General Pumice Corp., 124 mt/day
	PERLITE		
E1	Bland Canyon	25 T17N R5E	prospect only, expansion tests promising
E2	unknown	29, 32 T17N R4E	—
E3	Peralta Canyon	19, 28, 29, 30 T17N R5E	extensive deposit
	SCORIA		
SC1	La Cienega (Crego)*	18 T16N R8E	mined by Crego Block Co.
SC2	Cerrito Pelado*	35 T17N R7E	mined by Big Chief Stone, Inc.

ishes, and soap for stone-washed denim (Hoffer, 1994; Austin, 1994). Coarse pumice, greater than 1.9 cm, is desirable for soaps (Hoffer, 1994).

Most of the commercial pumice is in the lower Otowi Member of the Bandelier Tuff (1.45 Ma) and the El Cajete Pumice. The lower Bandelier Tuff is, in part, a basal pumice-fall unit known as the Guaje Pumice Bed, which is approximately 0-9 m thick. Coarse pumice greater than 19 mm comprises 5-6 wt% of the pumice bed (Hoffer, 1994; Austin, 1994). Reserves are estimated as 50,000,000 mt near the surface (Hoffer, 1994; Austin, 1994) and mining is expected to continue.

The El Cajete Pumice of the Valles Rhyolite (0.17 Ma) is a surge deposit (Self et al., 1988). It is 0-75 m thick along the southern rim of the Valles caldera and locally contains 30% very-coarse pumice. Reserves are estimated as 310,000 mt (Hoffer, 1994) and mining is expected to continue in the future.

Perlite

Perlite, a glassy rhyolite with onionskin, granular, or pumiceous texture, is used in plaster aggregate, filtrate, concrete aggregate, oil well cement, insulation and as a soil conditioner. It is relatively light weight and expands when heated. Perlite is widespread in the Jemez volcanic field, but tonnages are small and impurities are present. Total production is unknown, but it is presumed to be small. Three areas have been prospected (Table 6, Fig. 1). The Peralta Canyon deposit yielded minor quantities (Elston, 1967) and consists of pale-gray perlite to pumiceous perlite of commercial grade. The deposit also contains interbedded rhyolite, which is undesirable. The Bear Springs deposit consists of highly vitreous, green to gray perlite with brecciated zones of glass and rhyolite (Jaster, 1956); it is uneconomic because of these impurities and remoteness. The Bland Canyon deposit, in the Cochiti district, consists of gray to black vitreous to pitchy glass and rhyolitic breccia that expands upon heating (Jaster, 1956), but has not been developed. It is unlikely that these deposits will be exploited in the near future because better perlite deposits occur elsewhere in the state.

Scoria

Scoria (Table 6, Fig. 1) is a porous, red to black, light-weight basaltic volcanic rock that is also known as volcanic cinder. Scoria is used as an aggregate in cinder blocks, landscaping, and as a heat sink in gas grills. Total production is unknown. Scoria is mined from a series of small volcanoes or cinder cones west of the Rio Grande.

White Mesa gypsum

Gypsum has been mined from White Mesa in the Nacimiento Mountains (sec. 14, 16, 28, T15N, R1E; Fig. 1) since the 1950s. Production since 1960 has amounted to more than $20 million in cumulative value. The first production was for use in agriculture and was shipped as far as the San Luis Valley in southern Colorado (Logsdon, 1982). The largest mine is the White Mesa mine; a smaller operation, the G and W mine, yielded gypsum in the 1980s for soil conditioner (McLemore et al., 1984). Gypsum occurs in the upper gypsum member of the Todilto Formation (Jurassic) where it is up to 46 m thick and 93-97% pure (Logsdon, 1982; Woodward, 1987). In the lower 15 m of this member, the gypsum is diluted by anhydrite and is not mined. It is exposed in a nearly continuous band around the southern, western and northern margins of the Nacimiento Mountains (Woodward, 1987). It is mined from a dipslope (10-20°) at White Mesa. At many places along the Nacimiento uplift, the Todilto is steeply dipping and smaller outcrop areas are exposed, making open-pit mining difficult. The gypsum is used to manufacture wallboard at the Centex Bernalillo plant. Reserves are abundant and mining will probably continue far into the future.

Gypsum in the Todilto Formation also occurs along the western flanks of the Nacimiento Mountains, east of La Ventana (sec. 1, T18N, R1W; sec. 14, 23, T19N, R1W). The deposits were evaluated during World War II, but never produced much gypsum. Gypsum was mined from the Todilto near Gallina in the 1930s for local use (Talmage and Wootton, 1937). These deposits are too far from the wallboard plants in Bernalillo and Albuquerque and probably will not be mined in the near future.

Diatomite

Diatomite, a light-weight, light-colored siliceous sedimentary rock, occurs in sec. 22, T21N, R7E in the Jemez Mountains in Rio Arriba County (Fig. 1). In 1953-1954, a small amount of diatomite was mined and shipped to the J. H. Rhodes Pumice Co., Inc. plant near Santa Fe for use as an oil absorbent and floor sweep (Patterson, 1965). Diatomite is also used in filtration, insulation, mild abrasives, and as a filler and extender. It occurs in the Tesuque Formation of the Santa Fe Group (Tertiary-Quaternary) and the diatoms are similar to diatoms typically found in saline lake deposits of Miocene to Late Pliocene age. The diatomite is calcareous with fine-grained mineral impurities, is approximately 3 m thick, and is largely covered by thin overburden, including a basalt cap. The deposit is small and not expected to be developed in the near future.

Sulfur

One of the few occurrences of natural sulfur at the surface in New Mexico is found at Jemez Springs, where sulfur is deposited by Recent hot springs (Fig. 1). Two deposits are known; San Diego (sec. 28, T19N, R3E) and Sulphur Springs (sec. 4, T19N, R3E) developed by open pits, cuts and one adit. A 150-ton mill was built by New Mexico Acid Co. at Sulphur Springs to attempt to recover sulfur in the early 1900s, but was unsuccessful (Mansfield, 1918). Approximately 100 tons of 60% sulfur was mined from Sulphur Springs in 1902-1904 by M. S. Otero (Mansfield, 1918; Wideman, 1957). The San Diego deposit is 213 m long, 46 m wide, less than 10 cm thick, and contains as much as 15-39% S and 6-8.5% SO_4 in Pennsylvanian Madera limestone (Mansfield, 1918; Wideman, 1957). The Sulphur Springs deposit covers approximately 3.6 hectares and contains as much as 60% S in fractured rhyolite (Mansfield, 1918). It is unlikely that any sulfur will be produced in the near future from this deposit, because of extremely small tonnage and low grade.

Travertine

Travertine is limestone deposited by warm or cold bicarbonate-waters, mainly from springs. Varieties of travertine are also known as tufa, calcareous sinter, marble, Mexican onyx, or onyx marble (Austin and Barker, 1990). Several small deposits of travertine are found in the San Ysidro and Holy Ghost Spring areas, mostly on Zia Indian Pueblo land in sec. 16, 21, T15N, R1E and sec. 18, 24, 25, 36, T16N, R1E (Fig. 1; Woodward and Ruetschilling, 1976; Woodward, 1987) and at Soda Dam (Goff and Shevenall, 1987). The travertine is white to light tan, up to 15 m thick, and suitable for decorative dimension stone. Some of the deposits are slightly radioactive; a sample from Soda Dam assayed 0.001% U_3O_8 and 35.9% Ca (McLemore, 1983; McLemore et al., 1984). Travertine has not been produced in the Jemez and Nacimiento Mountains, because the deposits are too small to be mined economically.

ENVIRONMENTAL CONSIDERATIONS

Most precious- and base-metals and uranium mines and prospects in the Jemez and Nacimiento Mountains were operated before present mining and reclamation regulations were enacted. Many of these mines and prospects are considered abandoned and eventually will be reclaimed by the New Mexico Abandoned Mine Lands Bureau or other federal or state agencies. Current existing (operated since 1970, i.e., Nacimiento mine) and active mining operations must comply with rigid state and federal regulations and must be reclaimed after mining for suitable post-mining uses. The environmental issues range from visual impacts, hazardous mine openings (shafts, adits), possible surface subsidence because of collapse of underground workings, dust, and possible contamination to adjacent soils and arroyos of acid drainage and environmentally sensitive elements (such as lead and uranium). These mining districts in the Jemez and Nacimiento Mountains are currently under study by various federal and state agencies for these potential environmental impacts and any additional statements assessing environmental impacts are premature before these investigations are completed.

Most of the industrial minerals are of low-value, chemically benign commodities that are mined by simple open-pit methods. The major environmental issues are typically the dust and noise during mining, truck transport, and the visual impact left by mining operations. In the past, mines were not reclaimed and some highwalls and barren areas remain. However, most abandoned industrial minerals mines quickly revegetate and are no longer visible (Austin, 1994). Current mining operations must comply with state and federal regulations and must be reclaimed after mining for suitable post-mining use. Pollution concerns from industrial minerals mines are negligible, although simple prevention methods must be employed to reduce dust into the air as well as erosion and deposition into adjacent arroyos and streams. Proper prevention measures during mining and reclamation after mining will reduce pollution and minimize visual impacts of concern to some citizens, but will increase the cost of production to the mining companies and the consumer.

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REFERENCES

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.

Armstrong, A. K., Renault, J. R. and Oscarson, R. L., 1995, Comparison of hydrothermal alteration of Carboniferous carbonate and siliclastic rocks in the Valles caldera with outcrops from the Socorro caldera, New Mexico: Journal of Volcanology and Geothermal Research, v. 67, p. 207–220.

Austin, G. S., 1994, Pumice mining and environmental concerns in New Mexico: New Mexico Geology, v. 16, p. 1-6.

Austin, G. S. and Barker, J. M., 1990, Commercial travertine in New Mexico: New Mexico Geology, v. 12, p. 49-58.

Austin, G.S., Kottlowski, F.E. and Siemers, W.T., 1982, Industrial minerals of New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circular 182, p. 9-16.

Barbour, P. E., 1908, The Cochiti mining district, New Mexico: Engineering and Mining Journal, v. 86, p. 173-175.

Barker, J. M., Austin, G. S., Smith, E. W. and Sivils, D. J., 1995, Industrial minerals and rocks in Santa Fe County, New Mexico: New Mexico Geological Society, Guidebook 46, p. 179-183.

Bingler, E. C., 1968, Geology and mineral resources of Rio Arriba County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 91, 158 p.

Buchanan, L. J., 1981, Precious metal deposits associated with volcanic environments in the southwest: Arizona Geological Society, Digest, v. 14, p. 237-262.

Bundy, W. M., 1958, Wall-rock alteration in the Cochiti mining district, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 59, 71 p.

Chenoweth, W. L., 1974, Uranium occurrences of the Nacimiento-Jemez region, Sandoval and Rio Arriba Counties, New Mexico: New Mexico Geological Society, Guidebook 25, p. 309-313.

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.

Energy, Minerals and Natural Resources Department, 1986-1994, Annual resources report: New Mexico Energy, Minerals and Natural Resources, Santa Fe, Annual Report, variously paginated.

File, L. and Northrop, S. A, 1966, County, township, and range locations of New Mexico's mining districts: New Mexico Bureau of Mines and Mineral Resources, Circular 84, 66 p.

Goff, F. and Shevenell, L., 1987, Travertine deposits of Soda Dam, New Mexico and their implications for the age and evolution of the Valles caldera hydrothermal system: Geological Society of America Bulletin, v. 99, p. 292-302.

Granger, H. C. and Santos, E. S., 1986, Geology and ore deposits of the Section 23 mine, Ambrosia Lake district, New Mexico; *in* Turner-Peterson, C. E., Santos, E. S. and Fishman, N. S., (eds.), A basin analysis case study: the Morrison Formation, Grants uranium region, New Mexico: American Association of Petroleum Geologists, Studies in Geology 22, p 185-210.

Hatton, K.S., Barker, J.M., Golmer, N.A., Campbell, K., Hemenway, L. and Mansell, M., compilers, 1994, Mines, mills, and quarries in New Mexico: New Mexico Bureau of Mines and Mineral Resources, 66 p.

Hoffer, J. M., 1994, Pumice and pumicite in New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 140, 23 p.

Hulen, J. B., Nielson, D. L., Goff, F., Gardner, J. N. and Charles, R. W., 1987, Molybdenum mineralization in an active geothermal system, Valles caldera, New Mexico: Geology, v. 15, p. 748-752.

Jaster, M. C., 1956, Perlite resources of the United States: U. S. Geological Survey, Bulletin 1027-I, p. 375-403.

Jones, F. A., 1904, New Mexico mines and minerals: Santa Fe, New Mexican Printing Company, 349 p.

Kittleman, L. R., Jr. and Chenoweth, W. L., 1957, Uranium occurrences on the Goodner lease, Sandoval County, New Mexico: U. S. Atomic Energy Commission, TM-184, 13 p.

Kottlowski, F. E., 1962, Reconnaissance of commercial high-calcium limestones in New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circular 60, 77 p.

LaPoint, D. J., 1979, Geology, geochemistry, and petrology of sandstone copper deposits in New Mexico: [Ph.D. dissertation]: Boulder, University of Colorado, 333 p.

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.

Logsdon, M. J., 1982, Gypsum resources of New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circular 182, p. 43-48.

Mansfield, G. R., 1918, Sulphur in Jemez Canyon, New Mexico: Engineering and Mining Journal, v. 106, p. 449.

McIntosh, W. C., Kedzie, L. L. and Sutter, J. F., 1990, Paleomagnetic and $^{40}Ar/^{39}Ar$ dating database for Mogollon-Datil ignimbrites, southwestern New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 135, 79 p.

McLemore, V. T., 1983, Uranium and thorium occurrences in New Mexico: distribution, geology, production, and resources, with bibliography: New Mexico Bureau of Mines and Mineral Resources, Open-file Report 183, 960 p.

McLemore, V. T., 1992, Precious and base metal districts in Rio Arriba and Sandoval Counties, New Mexico: New Mexico Geological Society, Guidebook 43, p. 385-390.

McLemore, V. T., 1994, Volcanic-epithermal deposits in the Mogollon-Datil volcanic field, New Mexico: New Mexico Geological Society, Guidebook 45, p. 299-309.

McLemore, V. T., 1996, Copper in New Mexico: New Mexico Geology, v. 18, in press.

McLemore, V. T., in press, Silver and gold occurrences in New Mexico: New Mexico Bureau Mines and Mineral Resources, Resource Map 21.

McLemore, V. T., Broadhead, R. F., Roybal, G. K., Chenoweth, W. L., Barker, J. M., Copeland, P., Bowie, M. W., Cook, K., Hingtgen, J. S., Klein, K. and Brown, K. B., 1986, A preliminary mineral-resource potential of western Rio Arriba County, New Mexico: New Mexico Bureau of Mines and mineral Resources, Open-file Report 233, 157 p.

McLemore, V. T. and Chenoweth, W. C., 1989, Uranium resources in New Mexico: New Mexico Bureau of Mines and Mineral Resources, Resource Map 18, 37 p.

McLemore, V. T. and Chenoweth, W. C., 1992, Uranium deposits in the eastern San Juan Basin, Cibola, Sandoval, and Rio Arriba Counties, New Mexico: New Mexico Geological Society, Guidebook 43, p. 341-349.

McLemore, V. T. and North, R. M., 1984, Occurrences of precious metals and uranium in the northern Rio Grande rift, New Mexico: New Mexico Geological Society, Guidebook 35, p. 205-212.

McLemore, V. T., Roybal, G. H., Broadhead, R. F., Chamberlin, R. M., North, R. M., Osburn, J. C., Arkell, B. W., Colpitts, R. M., Bowie, M. R., Anderson, K., Barker, J. M. and Campbell, F. W., 1984, Preliminary report on the geology and mineral-resource potential of the northern Rio Puerco Resource Area in Sandoval and Bernalillo Counties and adjacent part of McKinley, Cibola, and Santa Fe, Counties, New Mexico, New Mexico Bureau of Mines and Mineral Resources, Open-file Report 211, 817 p.

New Mexico State Mine Inspector, 1912-1982, Annual Reports: New Mexico Energy and Minerals Department, Albuquerque, variously paginated.

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., scale 1:1,000,000.

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 held April 6-8, 1987, p. 625-660.

Northrop, S. A., 1959, Minerals of New Mexico: University of New Mexico Press, Albuquerque, New Mexico, 665 p.

Parkison, G.A., Emanuel, K.M., Wronkiewicz, D.J. and Norman, D.I., 1985, Geology of the Cochiti district, Sandoval County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circular 199, p. 54.

Patterson, S. H., 1965, Diatomite: New Mexico Bureau of Mines and Mineral Resources, Bulletin 87, p. 322-324.

Renault, J., Armstrong, A. K., Repetski, J. E. and Oscarson, R. L., 1995, Geology, mineralogy, geochemistry, and geothermometry of Kelly Limestone jasperiods, Magdalena mining district, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 152, 50 p.

Ridgley, J. L., 1980, Geology and characteristics of uranium mineralization in the Morrison Formation at the Dennison-Bunn claim, Sandoval County, New Mexico: New Mexico Bureau of Mines and Minerals Resources, Memoir 38, p. 299-303.

Santos, E. S., Hall, R. B. and Weisner, R. C., 1975, Mineral resources of the San Pedro Parks Wilderness and vicinity, Rio Arriba and Sandoval Counties, New Mexico: U. S. Geological Survey, Bulletin 1385-C, 29 p.

Sasada, M. and Goff., F., 1995, Fluid inclusion evidence for rapid formation of the vapor-dominated zone at Sulphur Springs, Valles caldera, New Mexico, USA: Journal of Volcanology and Geothermal Research, v. 67, p. 161-169.

Self, S., Kircher, D. E. and Wolf, J. A., 1988, The El Cajete Series, Valles caldera, New Mexico: Journal of Geophysical Research, v. 93, no. B6, p. 6113-6127.

Soulé, J. H., 1956, Reconnaissance of the "red bed" copper deposits in southeastern Colorado and New Mexico: U. S. Bureau of Mines, Information Circular 7740, 74 p.

Stein, H. L., 1983, Geology of the Cochiti mining district, Jemez Mountains, New Mexico: [M.S. thesis]: Albuquerque, University of New Mexico, 122 p.

Talbott, L. W., 1974, Nacimiento pit, a Triassic strata-bound copper deposit: New Mexico Geological Society, Guidebook 25, p. 301-303.

Talmage, S.B. and Wootton, T.P., 1937, The nonmetallic mineral resources of New Mexico and their economic features (exclusive of fuels): New Mexico Bureau of Mines and Mineral Resources, Bulletin 12, 178 p.

U. S. Bureau of Mines, 1927-1994, Minerals Yearbook: Washington, D.C., U.S. Government Printing Office, variously paginated.

U. S. Department of Energy, 1980, An assessment report on uranium in the United States of America: U. S. Department of Energy, Report GJO-111(80), 150 p.

U. S. Geological Survey, 1902-1927, Mineral resources of the United States (1901-23): Washington, D.C., U.S. Government Printing Office, variously paginated.

Wideman, F. L., 1957, A reconnaissance of sulfur resources in Wyoming, Colorado, Utah, New Mexico, and Arizona: U. S. Bureau of Mines, Information Circular 7770, 61 p.

WoldeGabriel, G., 1989, Hydrothermal systems in two areas of the Jemez volcanic field: Sulphur Springs and the Cochiti mining district: Los Alamos Report, LA-11509-OBES, 67 p.

WoldeGabriel, G. and Goff, F., 1989, Temporal relations of volcanism and hydrothermal systems in two areas of the Jemez volcanic field, New Mexico: Geology, v. 17, p. 986-989.

Woodward, L. A., 1987, Geology and mineral resources of Sierra Nacimiento and vicinity, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Memoir 42, 84 p.

Woodward, L. A., Anderson, J. B., Kaufman, W. H. and Reed, R. K., 1973, Geologic map and sections of San Pablo quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Geologic Map GM-26, scale 1:24,000.

Woodward, L. A., Kaufman, W. H., Schumacher, O. L. and Talbott, L. W., 1974, Stratabound copper deposits in Triassic sandstone of Sierra Nacimiento: Economic Geology, v. 69, p. 108-120.

Woodward, L. A., McLellan, D., Anderson, J. B. and Kaufman, W. H., 1972, Geologic map of Cuba quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Geologic Map GM-25, scale 1:24,000.

Woodward, L. A. and Ruetschilling, R. L., 1976, Geology of San Ysidro quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Geologic Map GM-37, scale 1:24,000.

Wronkiewicz, D. J., Norman, D. I., Parkison, G. A. and Emanuel, K. M., 1984, Geology of the Cochiti mining district, Sandoval County, New Mexico: New Mexico Geological Society, Guidebook 35, p. 219-222.