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MINERAL DEPOSITS IN RIO ARRIBA COUNTY, NEW MEXICO

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ABSTRACT.—More than \$40 million worth of mineral production has come from 14 types of deposits in 19 mining districts in Rio Arriba County. Three of these districts (Nacimiento, Jemez pumice, No Agua) are considered significant deposits for copper, silver, and pumice, although known large deposits are in adjacent counties (Taos, Sandoval). However, the presence of these significant deposits and the potential for discovery of additional metals resources in the Bromide No. 2 and Hopewell districts in Rio Arriba County should encourage exploration in the county. Despite the presence of remaining resources of feldspar, mica, niobium, rare-earth elements, and beryllium, it is unlikely that the pegmatites in the Petaca and Ojo Caliente districts will ever produce again because of small size and grade. Only the Menefee Formation coal at shallow depths has limited economic significance in the Moreno coal field, where preliminary estimates indicate demonstrated resources at a depth of 61 m are 8 million short tons. Currently only aggregate pits (sand and gravel, scoria, pumice) are active and production of aggregate (sand and gravel, pumice, and scoria) is likely to continue in the future.

INTRODUCTION

The purpose of this paper is to summarize the geology, geochemistry, and mineral production of 14 types of deposits in 19 mining districts as well as numerous industrial minerals deposits in Rio Arriba County (Table 1, Fig. 1) and comment briefly on the future economic potential and environmental concerns. Three of these districts contain significant deposits: Nacimiento, Jemez pumice, and No Agua although known large deposits are in adjacent counties (Taos, Sandoval). Detailed geology and stratigraphy of the districts are described elsewhere in this guidebook and in cited references. A brief description of each mineral deposit type is in Table 2; more detailed descriptions are by Cox and Singer (1986), North and McLemore (1986, 1988), McLemore et al. (1986), McLemore and Chenoweth (1989), Hoffman (1996), Du Bray (1995), and McLemore (2001). This work is part of ongoing studies of mineral deposits in New Mexico and includes updates and revisions of prior work by North and McLemore (1986, 1988), McLemore et al. (1986), and McLemore (2001).

Published and unpublished data were inventoried and compiled on existing mines and mills within Rio Arriba County. Mineralized areas were examined and sampled in 1979-1982, 1991, and 1993. Edward Smith visited many of the mines in Rio Arriba County in 1990-1993 and his unpublished field reports and notes were used. Information on the mining districts and individual mines are included in the New Mexico Mines Database (McLemore et al., 2005).

Mineral production by district since the late 1800s is listed by district in Table 3 and 4. Active mines are listed in Table 5. Mining and production records are generally poor, particularly for the earliest times, and many early records are conflicting. These production figures are the best data available and were obtained from published and unpublished sources (NMBGMR, file data). However, production figures are subject to change as new data are obtained.

MINING HISTORY AND PRODUCTION

Native Americans were the first miners in Rio Arriba County and throughout New Mexico and used local sources of hematite

and clay for pigments, and obsidian and chert for arrowheads. Mica and clay were used in making pottery. Some of these chert and clay quarries have been located and examined (Edward Smith, unpublished field notes, 1990-1993). Their houses were made of stone, adobe, and clay. Stone tools were shaped from local deposits of pebbles, jasper, chert, and obsidian.

During the Spanish/Mexican period, it is likely that the Spanish and Mexicans mined copper from some of the sandstone copper mines near Abiquiu, but little is known about this period of mining history in this county. The Plaza Colorado Grant (also known as Sierra del Cobre) was granted on June 25, 1739 (Robert Eveleth, written communication, May 5, 2005). The Spanish and Mexican miners also exploited the mica deposits in the Petaca and Ojo Caliente districts (Bingler, 1968).

The end of the Civil War brought tremendous change to mining in New Mexico. The Federal Mining Act of 1866 established rules and regulations governing prospecting and mining with

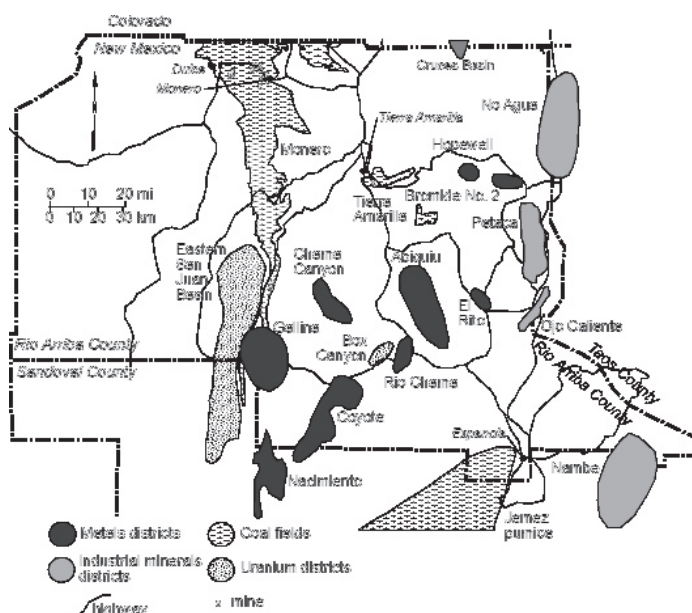


FIGURE 1. Mining districts in Rio Arriba and adjacent Counties, New Mexico.

TABLE 1. Mining districts in Rio Arriba County, New Mexico. Names of mining districts are after File and Nothrop (1966) wherever practical, but many districts have been combined and added. Commodity symbols are defined in Appendix 1. District identification number is from the New Mexico Mines Database (McLemore et al., 2005). Estimated value of production is in original cumulative dollars and includes all commodities in the district, except aggregate (sand and gravel) and crushed and dimension stone. Production data compiled from Lindgren et al. (1910), Anderson (1957), U. S. Geological Survey and Bureau of Mines Mineral Yearbooks (1900-1993), and Energy, Minerals and Natural Resources Department (1986-2003). Types of deposits are after North and McLemore (1986) and McLemore (2001). * district contains a significant deposit. Locations of districts are in Figure 1. Under commodities, commodities in parenthesis are occurrence only, other commodities listed were produced.

District id	District	Year of Discovery	Years of Production	Estimated Cumulative Production	Commodities (occurrence only)	Types of deposits
DIS137	Abiquiu (Arroyo del Cobre, Chama Basin)	1859 (probable early Spanish mining)	1954	\$1000	U, V (Cu, Ag, Au)	sedimentary-copper, sandstone uranium, limestone uranium, placer gold
DIS138	Box Canyon	1950	1955	\$2000	U, V	Limestone uranium
DIS139	Bromide No. 2 (Bromide, Bromide No. 3)b	1881	1881-1940	\$50,000	Au, Ag, Cu, U (Fe, REE, Th, F, Ba, Mo, Ni)	Precambrian veins/ replacement
DIS140	Chama Canyon	1911		none	(Cu, Ag, U)	sedimentary-copper
DIS141	Coyote	1911	1956-1957	\$4000	U, Ag, Cu, Pb	Limestone uranium, sedimentary-copper, sandstone uranium
DIS142	Cruces Basin	1900		none	(Cu, Ag, Mn, Be)	Volcanic-epithermal vein
DIS143	El Rito (Vallecitos)	1933	1933	\$1,721,000	Au (F)	placer gold, fluorite veins
DIS144	Gallina (Youngsville, Mesa Alta, Arroyo del Agua, San Pedro Mountain)	1900	1908-1956	\$1000-2000	U, V, Cu, Ag, Pb, F (kaolinite)	sedimentary-copper, sandstone uranium
DIS145	Hopewell (Headstone)	1880	1881-1940	\$300,000	Au, Ag, Cu, Pb (Zn, Fe)	Precambrian veins/ replacement, placer gold
DIS172	*Jemez pumice (Cullum, Copar, Esquire)	1950	1950-2005	\$31,000,000	Pumice (perlite)	Pumice, perlite, scoria
DIS146	Monero coal field	1882	1882-1970	\$5,277,552	coal	coal
DIS176	*Nacimiento (Cuba, La Madera, Las Tablas, Coyote)	1880 (probable early Spanish mining)	1880-1975	\$1,500,000	Cu, Ag, Au, Pb, Zn (U, V, Mn)	sedimentary-copper, sandstone uranium, Precambrian veins/ replacements, travertine
DIS185	Nambe (Cordova-Truchas, Aspen Ranch)	1900		\$10,000	Nb, mica (Cu, Be)	pegmatite
DIS235	*No Agua (San Antonio Mountain)	1948	1950-present	>\$10,000,000	perlite, scoria	perlite, scoria
DIS147	Ojo Caliente	1900 (probable early Spanish mining)	1965	\$5000	mica (Nb, REE, Bi)	pegmatite
DIS148	Petaca (Las Tablas, Madera, Ojo Caliente)	1870 (probable early Spanish mining)	1870-1965	\$900,000	mica, Nb, Ta, Be, quartz, feldspar, kyanite, REE (Sn, U, Th, Cu, Bi, F)	pegmatite
DIS149	Rio Chama (Abiquiu, Lumberton)	1848	1800s	\$4000	Au	placer gold
DIS268	Eastern San Juan Basin			none	(U)	Sandstone uranium
DIS263	Tierra Amarilla	1935	1955		Coal	Coal

provisions to obtain 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 Rio Arriba County and elsewhere in New Mexico and the mining boom of 1870-1890 began. Many districts in Rio Arriba County began to open up and production began as the Apache Indian threat was subdued (Table 1). The telegraph and then the railroad improved conditions in

the area as mining continued to flourish. New metallurgical techniques were developed. Times were exciting for the miner in the late 1800s as metal prices soared.

The 1870s and 1880s saw growth in mining in many districts in Rio Arriba County. Silver became important in 1870-1880s in many districts. In 1890 the Sherman Silver Act was passed which increased the price and demand for silver. However, it was short lived. The Sherman Silver Act was repealed in 1893 and most

TABLE 2. Descriptions of types of mineral deposits found in Rio Arriba, New Mexico, in order of perceived age from youngest to oldest.

Type of deposit	Description	Mineralogy	Perceived age (Ma)	References
Travertine	Sedimentary spring deposit	travertine	Recent	
Placer gold	Low grade, disseminated deposits consisting of small flakes of gold in Late Tertiary to Holocene alluvial fan deposits, bench or terrace gravel deposits, river-bars, and stream deposits or as residual placers formed directly on top of lode deposits	Gold, native silver, magnetite, zircon	Pliocene–Recent	McLemore (2001)
Fluorite veins	Fluorite veins along fractures and faults	fluorite		
Volcanic epithermal veins	Veins in various host rocks	Quartz, pyrite, gold, silver, chalcopyrite	35-16 Ma or younger	McLemore (2001)
Pumice, scoria	Volcanic pumice and scoria, cinder deposits (scoria)	Pumice, scoria	Late Miocene to Pliocene	
perlite	Weathered natural glass that is formed by the rapid cooling of viscous, high-silica rhyolite lave and lava domes	perlite	3.3-7.8 Ma	
Limestone uranium deposits	organic-rich, uraniumiferous limestones (Todilto) were deposited in a subkha environment on top of the permeable Entrada Sandstone	U, V	Jurassic	McLemore and Chenoweth (1989)
Sandstone uranium deposits	Uranium deposits in sandstones	U, V, Se, Mo	Penn–Permian, Triassic, Jurassic, Cretaceous, Eocene, Miocene	McLemore and Chenoweth (1989)
Cretaceous black sandstone deposits	concentrations of heavy minerals that formed on beaches or in longshore bars in a marginal-marine environment	thorium, rare earth elements, zirconium, titanium, uranium, niobium, tantalum, and iron	Cretaceous	Houston and Murphy (1970, 1977)
Coal	coal	coal	Cretaceous	Hoffman (1996)
Sedimentary-copper deposits	Copper with other metals 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, without any igneous association	predominantly chalcopyrite, chalcocite, malachite, and azurite with local uranium minerals, galena, sphalerite, and barite	Paleozoic?	North and McLemore (1986), McLemore (2001)
Vein and replacement deposits in Precambrian rocks	Vein and replacement deposits are found along faults, fractures, shear zones, and contact zones within Precambrian granitic and metamorphic rocks. Age is uncertain.	malachite, chalcopyrite, chalcocite, azurite, gold, silver minerals, iron oxides, quartz common to most deposits	Proterozoic or younger	North and McLemore (1986), McLemore (2001)
mica	Scrap and flake mica hosted by Precambrian mica schist, some large sheets in pegmatites	Muscovite, quartz	Proterozoic	
Pegmatite (1.6-1.2 Ga)	Coarse-grained granitic dikes, lenses, or veins and represent the last and most hydrous phase of crystallizing magmas	Quartz, mica, feldspar, various accessory minerals containing Be, Li, U, TH, REE, Nb, Ta, W, Sn	Probably 1450–1400 Ma, 1100–1200? Ma	

silver mines in the Southwest closed, never to reopen. A depression resulted.

New mining and milling technologies were developed throughout the 20th century that encouraged exploration and development of many deposits in New Mexico that were ignored in the 1800s. But booms and busts were the norm for most mining towns in New Mexico as world wars and financial slumps controlled the metals markets. Demands for new commodities such as manganese and uranium were seen and encouraged exploration and production for these commodities in Rio Arriba County and elsewhere in New Mexico.

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. World War II began in 1940 and once again a war increased demand for metals and strategic minerals found in the pegmatites of the Petaca district. On October 6, 1942, the U. S. War Department closed all gold mines in the U.S.,

including those in the Bromide No. 2 and Hopewell districts. Only base metals and other strategic minerals such as manganese, beryllium, niobium, and rare earth elements were mined. The war ended in 1945 as did the Federal ban on gold mining.

Very little mining in Rio Arriba County continued after the war (Table 1), except for aggregates; booms and busts in exploration and production continued to be the trend. The Federal government initiated incentive buying programs for domestic production of manganese, tungsten, and uranium in 1951. Termination of these programs in 1956 (tungsten), 1959 (manganese) and 1965 (uranium) effectively closed many of these mines for good. Many districts in Rio Arriba County have seen some exploration since the 1960s as company after company examined the area, looking for the missed deposit. But most districts in Rio Arriba County have seen insignificant production since the 1950s (Table 3, 4, 6). Currently only aggregate pits (sand and gravel, scoria, pumice) are active in the county (Table 5).

TABLE 3. Reported and estimated base and precious metals production by district in New Mexico. — no reported production. W withheld or not available. * includes placer gold production. () estimated data. From North and McLemore (1986), Johnson (1972), Bingler (1968), Elston (1967). Majority of production from Nacimiento district is from mines in Sandoval County.

District	Years	Ore (short tons)	Copper (lbs)	Gold (oz)	Silver (oz)	Lead (lbs)	Zinc (lbs)	Estimated value (\$)
Bromide No. 2	1881-1940	—	—	(300)	(4500)	—	—	50,000
El Rito	?	—	—	(<100)*	—	—	—	<1000
Coyote	1956-1957	—	462,000	—	841	W	—	4000
Hopewell	1933-1940	1,445	400	94	734	7100	—	300,000
	1881-1940	—	—	(24,000)	(10,000)	—	—	—
Nacimiento (production 1969-1975 withheld)	1880-1975	—	(7,700,000)	(1)	(76,000)	1783	463	1,500,000

DESCRIPTION OF MINERAL RESOURCES

Vein and Replacement deposits in Precambrian rocks

Vein and replacement deposits containing base and precious metals occur sporadically throughout most of the Precambrian terranes in New Mexico (McLemore, 2001). The age of mineralization is uncertain in most districts. Many of these deposits, like some of the deposits in the Bromide No. 2 and Hopewell districts, are structurally controlled by schistosity or shear zones of Precambrian age and are syn- or post-metamorphic. It is probable that multiple periods of mineralization occurred and detailed geologic and geochronologic studies are needed to constrain the timing of mineralization.

Bromide No. 2 district

Quartz-sulfide veins with copper, gold and silver in Precambrian rocks form the bulk of the metals deposits in the Bromide district (Fig. 1, Table 1) discovered in 1881, and are similar to those found in the Hopewell district. In addition to quartz, the veins contain chalcopyrite, gold, tetrahedrite, calcite, malachite, and pyrite. The age of mineralization is unknown, but presumed Precambrian because mineralized bodies are found along Precambrian structures within Precambrian rocks.

Precambrian magnetite and hematite contact-metasomatic deposits, also known as banded iron formation, are found in the Cleaveland Gulch, Cana Plaza, and Burned Gulches where more than 100 million tons of iron resources are estimated to occur (Harrer and Kelly, 1963). The multilayered deposits are 1.8-2.1 m thick, 30.5-45.7 m wide, 915 m long, contain 32% iron, and are interbedded with quartzite and schist (McLeroy, 1970, 1972; Harrer and Kelly, 1963).

Hopewell district

The Hopewell district lies in the Tusas Mountains and placer deposits were discovered about 1880 and quickly mined out (Fig. 1, Table 1). Lode deposits in Proterozoic rocks were later discovered. Proterozoic rocks in the district consist of the Moppin Metavolcanic Series, the Burned Mountain Rhyolite, and a succession of metavolcanic and metasedimentary rocks (Boadi, 1986). The granite of Hopewell Lake intruded the Moppin Metavolcanic Series and Burned Mountain Rhyolite and has a Rb-Sr isochron age date of 1467±43 Ma (Boadi, 1986). The low initial ⁸⁷Sr/⁸⁶Sr

ratio of 0.70256 suggests that the granite was formed by partial melting of a pre-existing rock derived from a depleted mantle source (Boadi, 1986). Most of the gold deposits are in the Moppin Metavolcanic Series. Altered rocks of the Moppin Metavolcanic Series typically contains 1-10 ppm Au; one sample from near the Croesus mine contained 1160 ppm Au (Boadi, 1986).

Lode gold occurs in quartz (± carbonate) veins and massive, sulfide-bearing veins and replacement bodies (Bingler, 1968; Boadi, 1986). Veins and replacement bodies typically are less than 30 cm wide and several meters long. The quartz (± carbonate) veins typically occur in the felsic units of the series, whereas the massive, sulfide-bearing veins and replacement bodies typically are restricted to the altered mafic rocks. Pyrite halos commonly surround the deposits. The deposits consist of pyrite, chalcopyrite, sphalerite, galena, and hematite with trace amounts of gold, stibnite, and arsenopyrite in a gangue of calcite, dolomite, quartz, tourmaline, iron oxides, chlorite, and sericite (Boadi, 1986). Gold is associated with pyrite and chalcopyrite. Rock and vein samples from the district assayed <0.15-1160 ppm Au, <0.002-2.37% Cu, 0.003-3.8% Pb, 0.002-6.26% Zn, 1-240 ppm As, and 0.5-29 ppm Sb (Boadi, 1986). Fluid inclusion studies indicate that deposition occurred at 250-330°C at pressures of approximately 1.5 kb during unmixing of a CO₂-rich fluid (Boadi, 1986). The deposits appear to be coeval with the granite of Hopewell Lake (Boadi, 1986).

Precambrian magnetite and hematite contact-metasomatic deposits similar to those found in the Bromide No. 2 district, also known as banded iron formation, are found in the Iron Mountain area in phyllitic schist. Two layers, ranging in thickness from 3 to 6 m and several hundred meters long, are present (Bingler, 1968).

Alluvial placer gold was predominantly produced from Placer Creek; small flakes and nuggets can still be obtained by persistent gold panning (Johnson, 1972; Boadi, 1986). These deposits were most likely derived from weathering of the nearby lode gold deposits.

Pegmatite deposits

Pegmatites are coarse-grained granitic dikes, lenses, or veins and represent the last and most hydrous phase of crystallizing magmas. Most of these pegmatites are associated with the Late Proterozoic granite plutonism of 1450-1400 Ma, although some could be possibly as young as 1100-1200 Ma. The pegmatites in New Mexico vary in size, but are typically several hundred

TABLE 4. Production of selected commodities in Rio Arriba County, New Mexico.

District (mine)	Years of production	Commodity	Short tons of production	Est. value
Monero	1882-1970	coal	1,697,012	\$5,277,552
Gallina		fluorite	19	<\$1000
Petaca	1950	mica	25,000	
Nambe (Fish)	1957	Be	0.75	
Petaca (Fridlund)		columbite, samarskite and monazite	2.5	
Petaca (Kiawa)		samarskite	0.05	
Petaca (Lonesone)		samarskite-monazite	0.006	

meters long and several meters wide. Simple pegmatites consist of feldspar, quartz, and mica, whereas complex pegmatites are mineralogically and texturally zoned and consist of a variety of rare minerals. Several commodities have been produced from complex pegmatites in New Mexico in the past; including mica, beryl, lithium, uranium, thorium, rare earth elements, feldspar, niobium, tantalum, tungsten, and gem stones. Additional commodities occur in pegmatites that could be recovered, including quartz, antimony, rubidium, and molybdenum. Typically minerals containing these rare commodities are scattered discontinuously throughout the pegmatite, thereby hampering economic recovery.

Ojo Caliente and Petaca districts

The predominant deposits found in the Ojo Caliente and Petaca districts are pegmatites (Fig. 1, Table 1). All of the pegmatites in the Ojo Caliente and Petaca districts are Precambrian in age and intruded metamorphic and granitic rocks. Mica, feldspar, beryl, uranium, and other commodities have been produced from these pegmatites (Table 1; Bingler, 1968; Chenoweth, 1974). Most pegmatites in New Mexico will not constitute an economic resource because of low grade, small size, and the expensive hand-sorting techniques required in order to recover any of the commodities.

Mica production was in excess of 250 short tons and was mostly scrap from the pegmatites and Precambrian micaceous schist. At least two mills were built in the district. Mica is used as a functional filler in building materials because of its unique physical characteristics, including color, flexibility, durability, thermal properties, and weight. Mica is used in the manufacture of numerous industrial and consumer products such as joint compound, paints, automotive sound deadening materials, thermoplastics, coatings, and cosmetics. Red-brown to golden micaceous clay and flake mica are developed on the Precambrian pegmatite and associated Precambrian Vadito Group schist throughout the district.

One of the few occurrences of kyanite in New Mexico is found in the Petaca district. The Big Rock kyanite deposits lie within a northeast-trending zone in Precambrian quartz-kyanite and kyanite schist. Approximately 1500 short tons of kyanite was obtained from boulders and shipped to St. Louis in 1928 by P.

S. Hoyt (Bingler, 1968). The U. S. Bureau of Mines estimated reserves as 1750 short tons of 85% kyanite, indicated reserves as 10,000 short tons of 85% kyanite, and inferred reserves as 100,000 short tons of 85% kyanite (Bingler, 1968).

Nambe district

Additional pegmatites and micaceous schist deposits are found in the Nambe district. Only the northern portion of the district is in Rio Arriba County (Fig. 1). Not much production is reported from the district (Table 1).

Stratabound sedimentary copper and sedimentary uranium deposits

Stratabound, sedimentary-copper deposits containing copper, silver, and locally gold, lead, zinc, uranium, vanadium, and molybdenum are found in Pennsylvanian, Permian, and Triassic rocks throughout New Mexico. These deposits also have been called red-bed sandstone, or sediment-hosted stratiform copper deposits by previous workers (Soulé, 1956; Phillips, 1960; Cox and Singer, 1986, #30b; LaPoint, 1976, 1989). 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. Volcanic and magmatic activity is absent.

Sandstone uranium deposits account for the majority of the uranium production from New Mexico (McLemore and Chenoweth, 1989). The most significant deposits are those in the Morrison Formation, specifically the Westwater Canyon Member, where more than 169,500 short tons of U_3O_8 were produced from 1948 to 1999. In contrast, production from other sandstone uranium deposits in New Mexico amounts to 234 short tons U_3O_8 (1952-1970, McLemore and Chenoweth, 1989). Sandstone uranium deposits occur in other formations in New Mexico, but were insignificant compared to those in the Morrison deposits (McLemore and Chenoweth, 1989).

TABLE 5. Active mines in Rio Arriba County (from Pfeil et al., 2001). Mine identification number is the Mine ID from the New Mexico Mines Database.

Mine ID No.	Name	Latitude, longitude*	Commodity	Operating Company
NMRA0224	Abiquiu Sand and Gravel Pit		Sand and gravel	Abiquiu Sand & Gravel
NMRA0152	El Guique Pit	36.1111, 106.0625	Sand and gravel	Espanola Transit Mix Company
NMRA0225	Lowdermilk		Sand and gravel	Espanola Transit Mix Co.
NMRA0150	Red Hill Mine	36.7758, 106.0158	scoria	Colorado Aggregate of NM
NMRA0153	Velarde Pit	35.1694, 105.9722	Sand and gravel	Espanola Transit Mix Company
NMRA0226	Rocky Mountain Mine		pumice	CR Minerals Company, Llc

*Longitude and Latitude as decimal degrees

Abiquiu district

The Abiquiu district also is known as the Chama Basin and Arroyo del Cobre districts (Fig. 1, Table 1) and has produced some minor uranium and vanadium from stratabound sedimentary-copper and sandstone uranium deposits in conglomerate and conglomeratic sandstone of the basal part of Triassic Chinle Group (Soulè, 1956; Bingler, 1968). Placer gold deposits are reported from arroyos in the district.

Chama Canyon district

Stratabound sedimentary-copper deposits with silver are found in Permian Cutler Formation (Light, 1982, 1983; Ridgley and Light, 1983; Schreiner, 1986; Ridgley et al., 1988; McLemore, 1992).

Coyote district

The Coyote district is located in the northern Nacimiento Mountains in southern Rio Arriba and northern Sandoval Counties (Fig. 1, Table 1). Stratabound, sedimentary-copper deposits containing uranium and vanadium are found in the Abo Formation in the Coyote district, which were discovered in 1911 (Soulè, 1956; McLemore, 1983, 1996; Woodward, 1987). In 1956-1957, 462,000 lbs Cu, 841 oz Ag, and some lead were produced from the Coyote district (Bingler, 1968) and in 1954-1955, 177 lbs of U_3O_8 and 142 lbs of V_2O_5 were produced.

Gallina district

The Gallina district is in the northwestern Nacimiento Mountains (Fig. 1, Table 1). 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 (Soulè, 1956; McLemore, 1983, 1996; 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).

Several small, but high-grade kaolinite deposits are found in cross bedded yellow-brown sandstone and conglomerate along the contact between the Dakota Sandstone and underlying Morrison Formation in section 2 and 11, T23N, R2E near Mesa Alta (Binger, 1968). The 0.6-m thick kaolinite is relatively pure and white, but is interlayered with less pure gray kaolinite and kaolinitic sandstone. There has been no reported production.

Nacimiento district

The northern portion of the Nacimiento district is in Rio Arriba County (Fig. 1, Table 1). Although the copper deposits were worked by Native Americans 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 in Sandoval County (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 (Talbot, 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. 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 (NMBGMR file data). An *in-situ* leaching project was proposed for the deposit, but poor recovery, low permeability, and environmental concerns have hampered the project and the area is currently being reclaimed.

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 Aqua Zarca Sandstone Member, 23 to 30 m thick. Kaolinization is present. Copper is associated with carbonaceous material, which is difficult to completely leach by H_2SO_4 . Geologic contacts are an important structural control of the red-bed copper occurrences. Much of the deposit occurs at the surface; the deepest mineralized zones are at least 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 (Talbot, 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 (Talbot, 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, while gold is rare. Similar, but smaller, sedimentary-copper deposits are found in the Agua Zarca Member 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. Sedimentary-uranium deposits are found in the Morrison Formation throughout the range. Small, uneconomic veins and replacement deposits in Precambrian rocks

TABLE 6. Metal production from the Nacimiento district, Sandoval and Rio Arriba Counties, New Mexico, 1880-1975 (modified from Elston, 1967; McLemore et al., 1986; McLemore, 1996; U. S. Geological Survey, 1900-1927; 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

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 (Table 6).

The majority of sedimentary-copper deposits in New Mexico, including the Nacimiento deposit, would not be conventionally mined for copper economically. 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, then copper might be recovered from the Nacimiento deposit.

Eastern San Juan Basin district

The sandstone uranium deposits of the northern portion of the Eastern San Juan Basin district are in Rio Arriba County (Fig. 1). There hasn't been any production from these deposits, but ground water anomalies, surface radiometric anomalies, and uranium occurrences in sandstones of the San Jose Formation indicate a potential for roll-front deposits at shallow depths (<150 m deep) (Chenoweth, 1957; McLemore and Chenoweth, 1989).

Limestone uranium deposit

Box Canyon district

Uranium is found only in a few limestones in the world, but the deposits in the Jurassic Todilto Limestone are the largest and most productive (Chenoweth, 1985; Gabelman and Boyer, 1988). Limestone is typically an unfavorable host rock for uranium because of low permeability and porosity and lack of precipitation agents, such as organic material. However, a set of unusual geological circumstances allowed the formation of uranium deposits in the Todilto Limestone. The organic-rich limestones were deposited in a subkha environment on top of the permeable Entrada Sandstone. The overlying sand dunes of the Summerville or Wanakah Formation locally deformed the Todilto muds, producing the intraformational folds in the limestone. Uraniferous waters derived from a highland to the southwest migrated through the Entrada Sandstone. Ground water migrated into the Todilto Limestone by evapotranspiration or evaporative pumping. Uranium precipitated in the presence of organic material within the intraformational folds and associated fractures in the limestone (Rawson, 1981; Finch and McLemore, 1989). Uranium occurs in the Todilto Limestone only where the gypsum-anhydrite member is absent (Hilpert, 1969). The Box Canyon deposit is a small, limestone uranium deposit in the Chama Basin that has produced a small amount of uranium.

Other deposit types

Cruces Basin district

Silver (0.5-0.9 oz/ton) is associated with small deposits of manganese (0.14-6% Mn) along fractures and faults in the Tertiary Conejos quartz latite and underlying Proterozoic gneiss and pegmatites (Muehlberger, 1968; Light, 1982, 1983; Hannigan, 1984; McLemore, 1992, 1996).

El Rito district

Placer gold deposits were produced from sand and gravel deposits in El Rito Creek and Arroyo Seco of the El Rito or Vallecitos district (Lasky and Wootton, 1933; McLemore, 1994). Fluorite veins are found in veinlets in a fault zone in volcanic rocks of the Santa Fe Group near the Chama River (Bingler, 1968). Approximately 1000 short tons of 65% fluorite were shipped to the Los Lunas mill.

Jemez Pumice district

New Mexico is the second leading producing state of pumice in the United States and the majority of New Mexico production comes from deposits in the Jemez Mountains. Total cumulative production from the Jemez Mountains area amounts to nearly 6 million short 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 polishes, 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 metric tons 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 metric tons (Hoffer, 1994).

Perlite, also found in the Jemez pumice district, is a glassy rhyolite with onionskin, granular, or pumiceous texture, and 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. 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. It is unlikely that these deposits will be exploited in the near future because better perlite deposits occur elsewhere in the state.

Scoria, also found in the Jemez pumice district, 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. The scoria is predominantly red with some gray to black. It is pumiceous to coarsely cellular with particles from sand-size to over 3 cm in diameter. Active mines are listed in Table 5. Total production is unknown.

Rio Chama district

Placer gold deposits are found in sand and gravel deposits of the Rio Chama district, also known as the Abiquiu district (Johnson, 1972; McLemore, 1994).

No Agua district

Only the western portion of the No Agua district is in Rio Arriba County; the eastern portion is in Taos County and was described by McLemore and Mullen (2004). The No Agua district in Taos County contains a world-class perlite deposit; one mine is currently operating. In the Rio Arriba County portion of the district, scoria deposits are found and at least one scoria mine is in operation.

McLEMORE AND HOFFMAN

Coal fields

Monero field

Outcrops of the Mesaverde Group that extend southward from the New Mexico–Colorado state line for about 43 km define the Monero field on the northeast side of the San Juan Basin (Fig. 1). The coal-bearing rocks strike N–S in the Menefee and Fruitland Formations under influence of the Gallina–Archuleta arch separating the central San Juan Basin from the smaller Chama Embayment to the east. Small domes and southwest–trending synclines, which are part of the Archuleta arch (Dane, 1948), influence most of the northern Monero field. The southern part of the field parallels the N30°W trend of the arch. Several faults in the Monero field parallel the eastern edge of the basin and are associated and contemporaneous with the folding that took place along the eastern San Juan Basin (Dane, 1948) during Laramide tectonic activity. High angle or normal faults are widespread with displacement of less than 30 m (Dane, 1948), generally to the west. The dips of the beds are variable because of the complex structure. Outcrops of the Menefee and Fruitland Formations are limited to the steep canyon walls of the fault–block mesas. Only the Menefee Formation coal at shallow depths has limited economic significance in this field. The Menefee Formation thins to the northeast, near the New Mexico–Colorado border, and is replaced by marine sandstones of the Point Lookout Sandstone or Cliff House Sandstone; the coal beds, therefore, are mainly in the central and southern parts of the field.

Considerable shallow coal is present in the central Monero field on the backslopes of cuesta blocks. Although very little drill data are available, preliminary estimates of demonstrated resources to a depth of 60 m are 8 million short tons. Beds up to 2.2 m thick have been mined but the average coal thickness is 1 m. Deeper coal resources are estimated at 32 million short tons but dips greater than 5° and faulting make underground mining difficult. These moderate sulfur, moderate ash coal beds are of high-volatile bituminous B to A apparent rank. Some of the seams have coking qualities (Averitt, 1966), but these resources have not been determined. Weighted–averages of 14 as–received analyses are given below:

	Average	Std Dev.	No. of Samples
Moisture (%)	3.90	1.88	14
Ash (%)	10.16	3.10	14
Volatile matter (%)	36.91	1.58	12
Fixed carbon (%)	48.74	3.13	12
Sulfur (%)	1.85	1.01	14
Calorific value (Btu/lb)	12373	963	13
Lbs of Sulfur/MBtu	1.50	0.84	13

Small underground coal mines operated in the Monero field from 1881 to 1971 (Fig. 1). Development of the coal began when the Denver and Rio Grande Western Railroad came through this area. The first coal camp in the area was northeast of Monero, at a settlement called Amargo. A post office existed at Amargo from 1881 to 1884 however, more mines developed near the Monero camp, named by Italian miners meaning money, and Amargo soon became a ghost town. The Monero and San Luis mines

are listed in the Territorial Mine Inspectors report of 1893-94. Coal production peaked from 1899-1907 at 35,000-51,000 short tons/year. Total production for this period was 391,752 short tons which essentially depleted the known reserves in the Monero area. After a recession in 1908, production for the field dropped to 9,799 short tons in 1909. Coal production did not improve until 1922 when 16,000 short tons were extracted for the year. From 1922 to 1953, yearly production remained above 16,000 short tons and totaled 849,270 short tons for these years. Production dropped considerably from 1953 to 1963 when the railroad was abandoned. In 1970, the last mine in the Monero field closed because the owner was financially unable to comply with the new mine-safety laws.

Most of the early mines in the Monero field were located near the town of Monero. After 1921, mines opened near the town of Lumberton supplying coal to the BIA in Dulce and providing coal for the railroad transporting lumber from Lumberton south to the Burns-Biggs Mill at El Vado (Myrick, 1970). From 1881 to 1971 up to 40 mines were open at various times in the Monero-Lumberton area. Total coal production for the Monero field from 1882-1963 is 1.6 million short tons.

Tierra Amarilla field

This small field is an outlier of the coal-bearing Menefee Formation, about 20 km east of the edge of the San Juan Basin, southeast of Tierra Amarilla (Fig. 1). The field is on the eastern flank of the Chama embayment and the lowest part of this basin is marked by the Chama syncline that cuts through the western part of the coal area. Exposures of the Mesaverde Group, including the Cliff House Sandstone, Menefee Formation, and Point Lookout Sandstone dip to the west, forming a hogback along the boundary between the Chama and San Juan basins. Most of the coal seams in these Menefee Formation exposures are thin and lenticular, and are overlain by excessive overburden, including massive sandstones of the Cliff House preventing surface mining. Three to four upper Menefee coal beds exposed in the western part of the Tierra Amarilla field reach a maximum thickness of 50 cm (Landis and Dane, 1969). The lower coal zone contains 3 coal beds. The upper bed is the most persistent and reaches a maximum thickness of 122 cm in places. Samples from the Dandee mine indicate the coal is of subbituminous A apparent rank, contains 1.0%–1.1% sulfur, about 8% ash yield, and averages about 10,000 Btu/lb. (Landis and Dane, 1969). The primary coal resources are in the western part of this field; Landis and Dane (1969) estimated resources of 1.8 million short tons for this area and 4.5 million short tons for the entire Tierra Amarilla field.

Very little mining took place in the Tierra Amarilla field except for local use; Landis and Dane (1969) located four prospects or small mines in this area. The Dandee mine operated from 1944 until 1954, and the White mine, opened in 1935 and operated for several years (Fig. 1; Landis and Dane, 1969; Nickelson, 1988). Production from these mines was limited and used for domestic purposes.

Other Commodities

Cretaceous black sandstone deposits

Several small Cretaceous black sandstone deposits are found in the Mesaverde Formation on the Jicarilla Apache Reservation. The Stinking Lake is the largest of these deposits in Rio Arriba County. Heavy mineral, beach-placer sandstone deposits are concentrations of heavy minerals that formed on beaches or in longshore bars in a marginal-marine environment (Houston and Murphy, 1970, 1977). Many beach-placer sandstone deposits contain high concentrations of thorium, rare earth elements, zirconium, titanium, uranium, niobium, tantalum, chromium and iron. Detrital heavy minerals comprise approximately 50-60% of the sandstones and typically consist of titanite, zircon, magnetite, ilmenite, rutile, monazite, apatite, and allanite interlayered with quartz sandstone that is as much as 80 ft thick. One sample contained 5.73% TiO₂ (Bingler, 1968). Although mapping is required to calculate the reserves, there could be as much as 5 million short tons of material.

Aggregates

Sand and gravel and crushed rock, also known as aggregate, is 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 Rio Arriba County are listed in Table 5. 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 Rio Arriba County 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., 1986). Most stone is used in construction, as aggregate, and in railroad abutments. Abundant lithologies occur in Rio Arriba County. Gray to brown travertine is found on top of the Los Piños Formation on north side of NM-96 in secs. 26 and 35 T25N R8E (Bingler, 1968).

Limestone is abundant in Rio Arriba County in the Madera Formation 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 for it 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). Travertine, a limestone deposited by warm or cold bicarbonate-waters (mainly springs), is found in several areas of the Jemez Mountains and could be used for crushed and dimension stone.

Adobe bricks are made from sandy loam and sandy clay deposits from the Santa Fe Group near Alcade.

Gypsum

Gypsum from the Todilto Formation is exposed throughout south-central Rio Arriba County and constitutes a large reserve. Large outcrops of white, alabaster gypsum are present south of NM-96 via USFS-76 on west side of dirt road in secs. 18 and 19 T23N R1W, in the Ghost Ranch area and at Gurule Mesa. Gypsum is quarried at White Mesa south of Cuba in Sandoval County and used in the manufacture of wall board in Bernalillo and Albuquerque. Deposits in Rio Arriba County are too far from the market to be economic.

Clay

Bentonite is found as altered volcanic ash deposits in the Santa Fe Group and Los Pinos Formation in section 5, T22N, R9E west of Velarde and section 24, T28N, R6E southwest of Burned Mountain (Ross and Shannon, 1926; Bingler, 1968). Clay in the Chinle Formation is found on the west side of Arroyo Cobre sec. 6 T23N R5E.

Diatomite

Diatomite, a light-weight, light-colored siliceous sedimentary rock composed largely of siliceous diatoms, as much as 45 m thick, occurs in section 22, T21N, R7E in the Jemez Mountains (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; Bingler, 1968). 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.

RECLAMATION

All currently active mines in Rio Arriba County are undergoing some reclamation, but very few of these mines fall under the New Mexico Mining Act of 1993. Most active mines in Rio Arriba County are aggregate operations and have different reclamation requirements than most mines covered under the New Mexico Mining Act of 1993 and the numerous regulations covering coal mines. Various agencies, including the New Mexico Abandoned Mine Lands Bureau and the U. S. Forest Service have reclaimed some of the older, inactive mines in the county, based on their priority ratings. 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 or pose an environmental hazard.

OUTLOOK

Minerals production in New Mexico has continued to decline since maximum annual minerals production was achieved in 1989 (McLemore et al., 2002). This decline was a result of numerous complex and interrelated factors. Some of the more important factors include declining commodity prices and quantity of ore. Other factors have hampered new mines from opening in the state, including water rights issues, adverse public perceptions, and the complexity and length of time for the entire regulatory process to occur in the United States at the local, state, and federal levels. All of these factors add to the cost of mining, not only in New Mexico, but also throughout the world. However, the increased demand for raw materials in the last few years has led to an increase in production worldwide. A healthy mineral industry is vital to the economy of New Mexico and to maintenance of public education and services. The occurrence of significant deposits in adjacent counties (Jemez pumice, Nacimiento, No Aqua) and the potential for discovery of additional metals resources (Bromide No. 2, Hopewell) in Rio Arriba County should encourage exploration. Despite the presence of remaining resources of feldspar, mica, niobium, rare-earth elements, and beryllium, it is unlikely that the pegmatites in the Petaca and Ojo Caliente districts would ever produce again because of small size and grade. Only the Menefee Formation coal at shallow depths has limited economic significance in the Moreno coal field, where preliminary estimates indicate demonstrated resources at a depth of 61 m are 8 million short tons. Production of aggregate (sand and gravel, pumice, and scoria) is likely to continue in the future.

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APPENDIX 1

As—arsenic	Fe—iron	Sb—antimony
Au—gold	Ga—gallium	Sn—tin
Ba—barium	Ge—germanium	Te—tellurium
Be—beryllium	Mn—manganese	Th—thorium
Bi—bismuth	Mo—molybdenum	U—uranium
Co—cobalt	Ni—nickel	V—vanadium
Cu—copper	Pb—lead	W—tungsten
F—fluorine	REE—rare-earth elements	Zn—zinc