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Critical minerals in sediment-hosted stratbound copper deposits in the Nacimiento and Zuni Mountains, Northwestern New Mexico: Preliminary results

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This is one of many related papers that were included in the 2024 NMGS Fall Field Conference Guidebook.

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CRITICAL MINERALS IN SEDIMENT-HOSTED STRATABOUND COPPER DEPOSITS IN THE NACIMIENTO AND ZUNI MOUNTAINS, NORTHWESTERN NEW MEXICO: PRELIMINARY RESULTS

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Abstract—Reexamination of the mineral resources in the sediment-hosted stratabound copper deposits in the Nacimiento and Zuni Mountains is warranted in light of today's economic importance of critical minerals, which are essential in most of our electronic devices. Critical minerals are defined as nonfuel mineral commodities that are essential to the economic and national security of the United States and are from a supply chain that is vulnerable to global and national supply disruptions. Sediment-hosted stratabound copper deposits are bodies of copper minerals found as disseminations, cement, and veinlets in bleached sedimentary rocks that are restricted to a narrow range of layers within sedimentary host rocks. These deposits are found throughout New Mexico, including in the Nacimiento and Zuni Mountains. Selected samples from Nacimiento and Zuni Mountains (i.e., Nacimiento, Coyote, and Zuni mining districts) have elevated heavy rare earth elements (REE), vanadium, cobalt, and arsenic, but additional studies are required to fully characterize these areas to determine if there is any economic potential for critical minerals. Additional samples need to be collected and examined from the other sediment-hosted stratabound copper deposits in the state.

INTRODUCTION

Sediment-hosted stratabound copper deposits are bodies of copper minerals found as disseminations, cement, and veinlets in bleached sandstones, siltstones, shales, and limestones within or marginal to typical thick clastic red-bed sequences (Hayes et al., 2015; McLemore and Lueth, 2017) and are the second most important source of copper production in the world after porphyry copper deposits (Hayes et al., 2015). Three subtypes in the world are recognized by host lithologies and corresponding reductants: (1) reduced-facies type (black to gray to green shale, siltstone, mudstone, or carbonaceous siltstone containing solid amorphous organic matter and pyrite); (2) sandstone-type (gray, well-sorted, fine- to coarse-grained sandstone containing petroleum, probably sour gas in most cases); and (3) red-bed type, described below (Hayes et al., 2015). We are using the term *sediment-hosted stratabound copper deposits* as suggested by the U.S. Geological Survey (USGS; Hayes et al., 2015; Marsh et al., 2016). These deposits also have been called stratabound sedimentary-copper deposits (McLemore and Lueth, 2017), sediment-hosted Cu-Ag-Co, shale-hosted copper, red bed copper (Soulé, 1956), or sandstone copper deposits (Soulé, 1956; Phillips, 1960; Cox and Singer, 1986).

Numerous mining districts are found throughout New Mexico (Fig. 1; Table 1) that contain sediment-hosted stratabound copper and silver, and locally lead, zinc, uranium, vanadium, cobalt, and molybdenum in Pennsylvanian, Permian, or Triassic poorly to moderately sorted fluvial sandstones, conglomerates, and shales containing carbonized plant debris, including fossil logs (McLemore, 2017; McLemore and Lueth, 2017). Most deposits in New Mexico are of the red-bed type (Hayes et al., 2015; McLemore and Lueth, 2017). The majority of sediment-hosted stratabound copper deposits in New Mexico occur at or near the base of individual sedimentary layers within these sediments; some deposits are in sedimentary rocks that unconformably overlie mineralized Proterozoic granitic rocks (McLemore, 1983, 2013; McLemore and Lueth, 2017).

Critical minerals found in sediment-hosted stratabound copper deposits include copper, zinc, vanadium, cobalt, gallium, uranium, and other minor commodities (Hayes et al., 2015; Marsh et al., 2016). Globally, sediment-hosted stratabound copper deposits are the most important sources of cobalt (Hayes et al., 2015). Although the definition of critical minerals varies from country to country depending on available mineral deposits, supply, demand, and strategic conditions, critical minerals in the United States are defined as nonfuel mineral commodities that are essential to the economic and national security of the country (economic vulnerability) and are from a supply chain that is vulnerable to global and national supply disruptions. Nearly all the critical minerals identified by the USGS are mostly imported into the United States. In the mining industry, a *mineral* refers to any rock, mineral, or other naturally occurring material of economic value and sold as a commodity. There are currently 53 minerals listed as critical for the United States (National Research Council, 2008; McLemore and Gysi, 2023), including vanadium, cobalt, rare earth elements (REE), niobium, and zirconium. REE include the 15 lanthanide elements (La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu: atomic numbers 57–71), yttrium, and scandium. Although copper is not currently recognized by the USGS as a critical mineral, copper is recognized as a critical material by the U.S. Department of Energy and U.S. Department of Defense because copper is important to transitioning from fossil-fuel-based energy technologies to

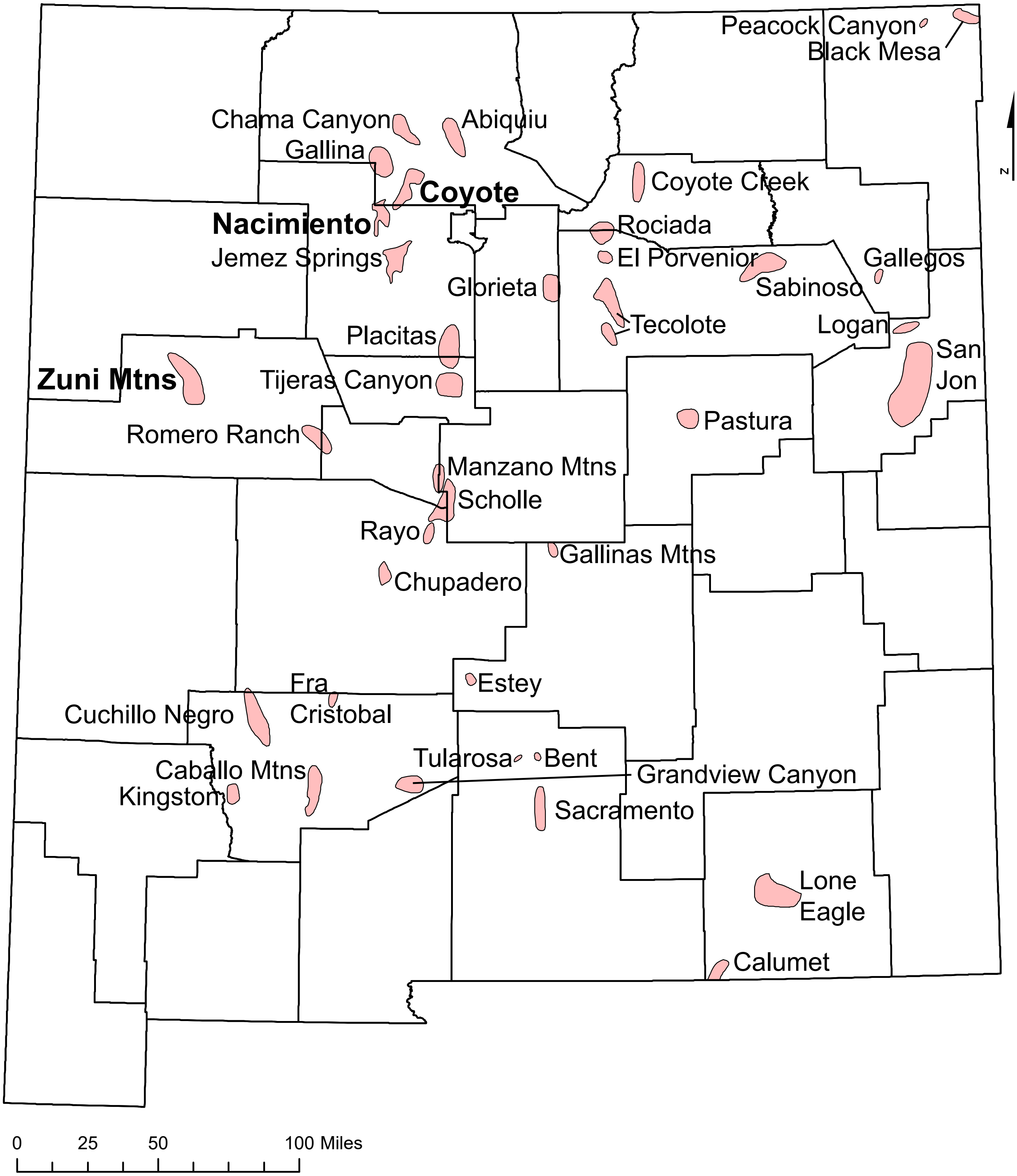

FIGURE 1. Sediment-hosted stratabound copper deposits formed during Paleozoic to Mesozoic time in New Mexico (from McLemore and Lueth, 2017). Names in bold text are discussed in this report.

TABLE 1. Sediment-hosted stratabound copper deposits in New Mexico, ranked by estimated copper production (McLemore, 2017). Bold type = discussed in this report. * = production includes that from other types of deposits. [1]TRs = Santa Rosa Formation, TRc = Chinle Formation, Pa = Abo Formation, Pb = Bursum Formation, PPs = Sangre de Cristo Formation, Py = Yeso Formation.

DISTRICT	COUNTY	ESTIMATED COPPER PRODUCTION (LBS)*	ESTIMATED SILVER PRODUCTION (OZ)	HOST ROCK[1]
Pastura	Guadalupe	13,578,214	42,500	TRs
Nacimiento	Sandoval	7,561,567	>75,000	TRc, Pa
Scholle	Socorro, Valencia	1,122,468	8,200	Pa, Pb
Coyote	Sandoval	462,000	841	Pc
Estey	Lincoln	444,000	124	Pa
Sacramento	Otero	260,570	891	Pa
Glorieta	Santa Fe	50,000	—	PPs
Lone Eagle	Eddy	35,236	21	Py
***Zuni Mountains**	Cibola	30,484	260	Pa
Jemez Springs	Sandoval	19,200	159	Pa
Tecolote	San Miguel	19,112	128	PPs
Coyote Creek	Mora	10,100	48	PPs
Romero Ranch	Valencia	9,300	24	Pa
*Placitas	Sandoval	2,441	48	Pa
Black Mesa	Union	800	10	TRs

Other deposits: Tijeras Canyon (Bernalillo), Gallegos (Harding), Gallinas (Lincoln), Tularosa (Otero), Logan (Quay), Red Peak (Quay), Abiquiu (Rio Arriba), Chama Canyon (Rio Arriba), Gallinas (Sandoval, Rio Arriba), El Porvenir (San Miguel), Rociada (San Miguel), Caballo Mountains (Sierra), Cuchillo (Sierra), Chupadera (Socorro), Rayo (Socorro), Peacock Canyon (Union), Sabinoso (San Miguel)

non-carbon-based energy technologies. Furthermore, copper is important to the security and economy of the United States and is subjected to future supply disruptions; therefore, copper is considered a critical mineral in this paper.

Reexamination of the mineral resources, including critical minerals, in the sediment-hosted stratabound copper deposits in New Mexico is warranted in light of today's economic importance of critical minerals, which are essential in most of our electronic devices. This study reexamines sediment-hosted stratabound copper deposits in the Nacimiento and Zuni Mountains as part of statewide studies of critical minerals. The Nacimiento and Zuni Mountains are found along the edge of the San Juan Basin in northwestern New Mexico, and both mountain ranges have a core of Proterozoic granitic, metamorphic, and metavolcanic rocks with onlapping Triassic or Permian sedimentary units. Additional deposits will be examined in the future.

METHODS

Published and unpublished data on existing mines and mills within the Nacimiento and Zuni Mountains districts were identified, plotted on base maps, and compiled in the New Mexico Mines Database (McLemore, 2017). Locations of mines were obtained from published and unpublished reports and patented mining claims files. Mineralized areas were previously sampled and analyzed for limited elements in 1980, 1985–1986, and 2011–2012 by the senior author. These previous studies concluded that the deposits were not economic at that time (McLemore, 1983, 1989, 2013; McLemore et al., 1984, 1986 and references therein).

Both composite and select samples were collected for this new study in 2023 (Figs. 2, 3, 4). Composite samples include sampling along the width and thickness of the sedimentary layer, vein, igneous intrusion, bed, or mine waste feature (i.e., tailings, mine rock piles) in order to obtain a representative sample of the unit. Multiple subsamples were collected and homogenized for a composite sample. Select samples were collected that included separately collected hand specimens of mineralized rocks, samples from individual sites from outcrops, or the mine waste features; these were collected to identify minerals and for separate chemical analyses.

Geochemical data are an important part of locating and evaluating critical mineral resources. Whole-rock major and trace element geochemical analyses of samples collected for this study were determined by the ALS Laboratory (description of their methods can be found at https://www.alsglobal.com/en/geochemistry/geochemistry-fee-schedules and in future reports) or USGS contract laboratories. Samples were submitted to the laboratories, where sample preparation occurred. Duplicate samples and standards were analyzed, and the uncertainty of the results was generally <5%. Specific analytical methods

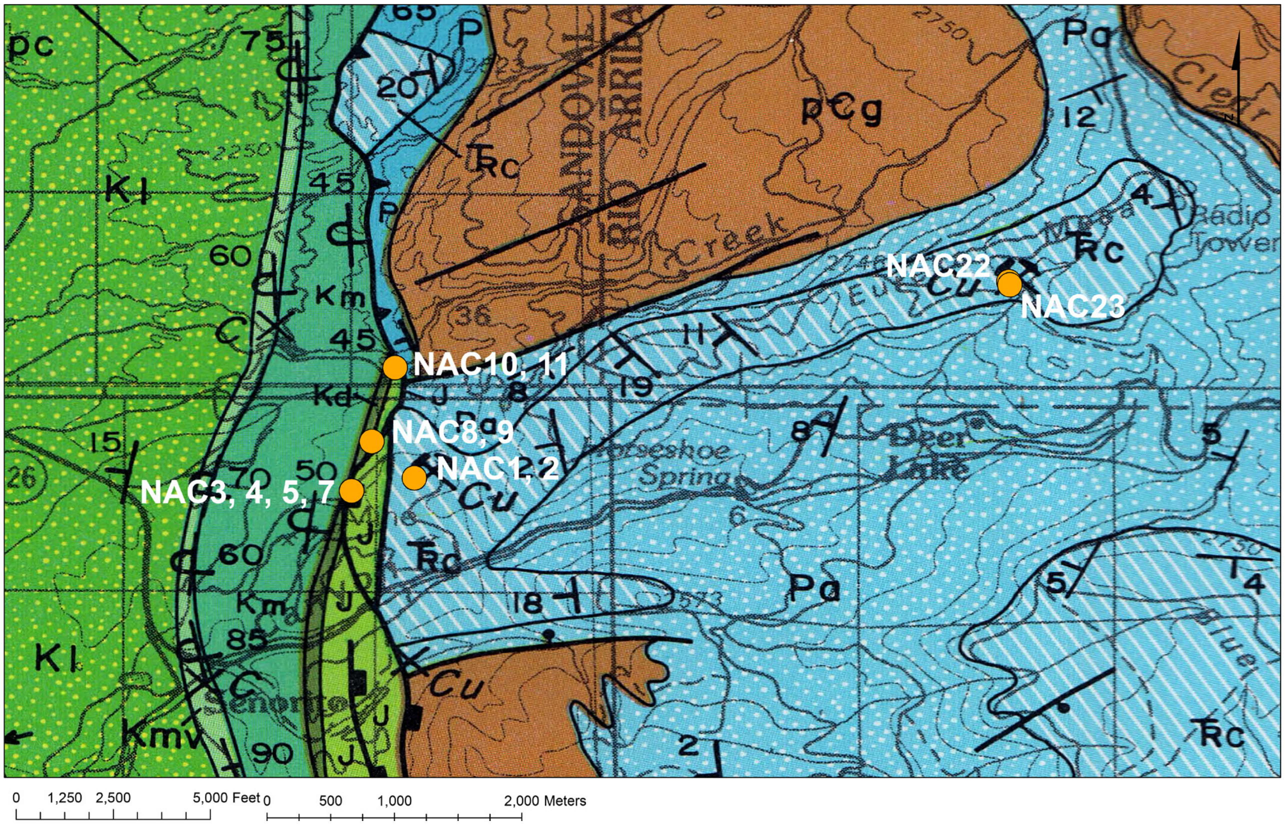

FIGURE 2. Locations of samples from the Nacimiento mining district, Nacimiento Mountains. Geologic map from Woodward (1987). Yellow circles are sample locations. Coordinates and chemical analyses for each sample are in Appendix 1.

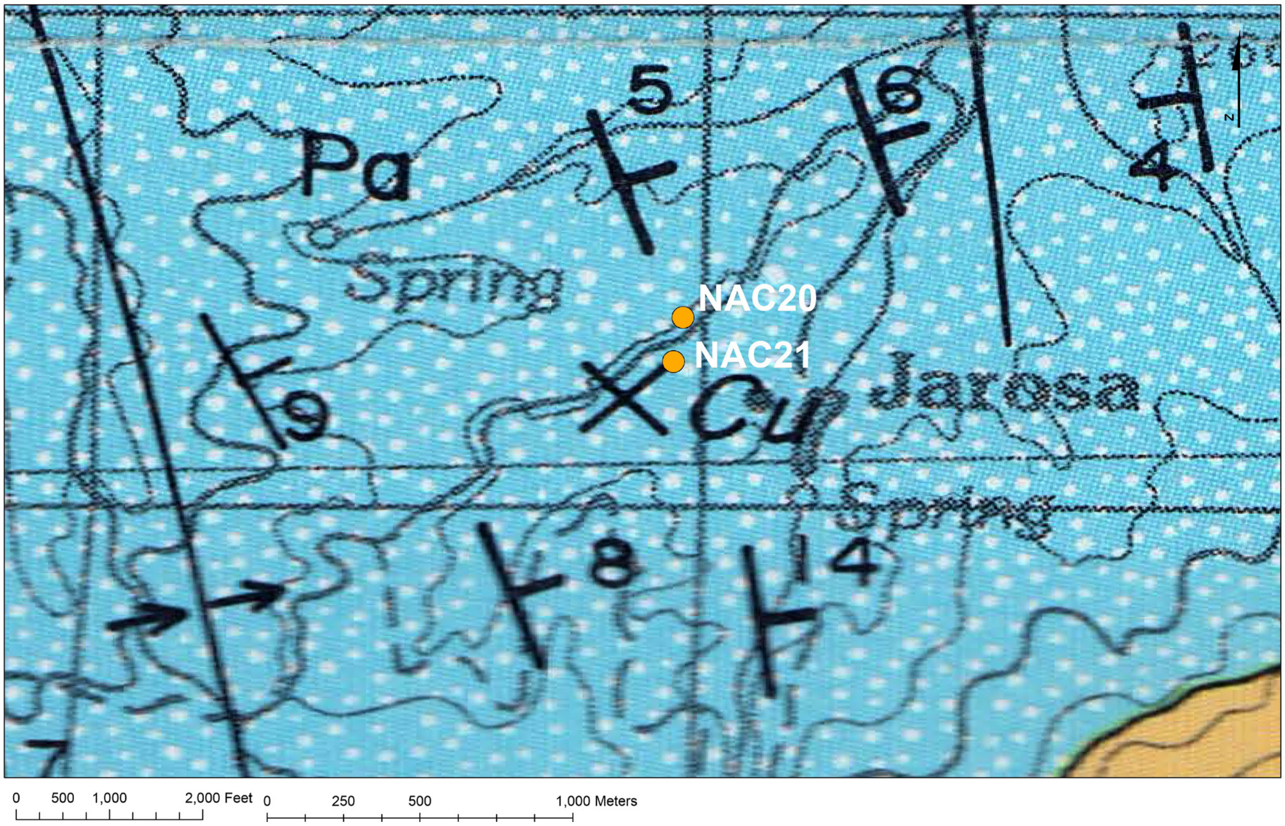

FIGURE 3. Locations of samples from the Coyote mining district, Nacimiento Mountains. Geologic map from Woodward (1987). Pa (blue) = Permian Abo Formation. Yellow circles are sample locations. Coordinates and chemical analyses for each sample are in Appendix 1.

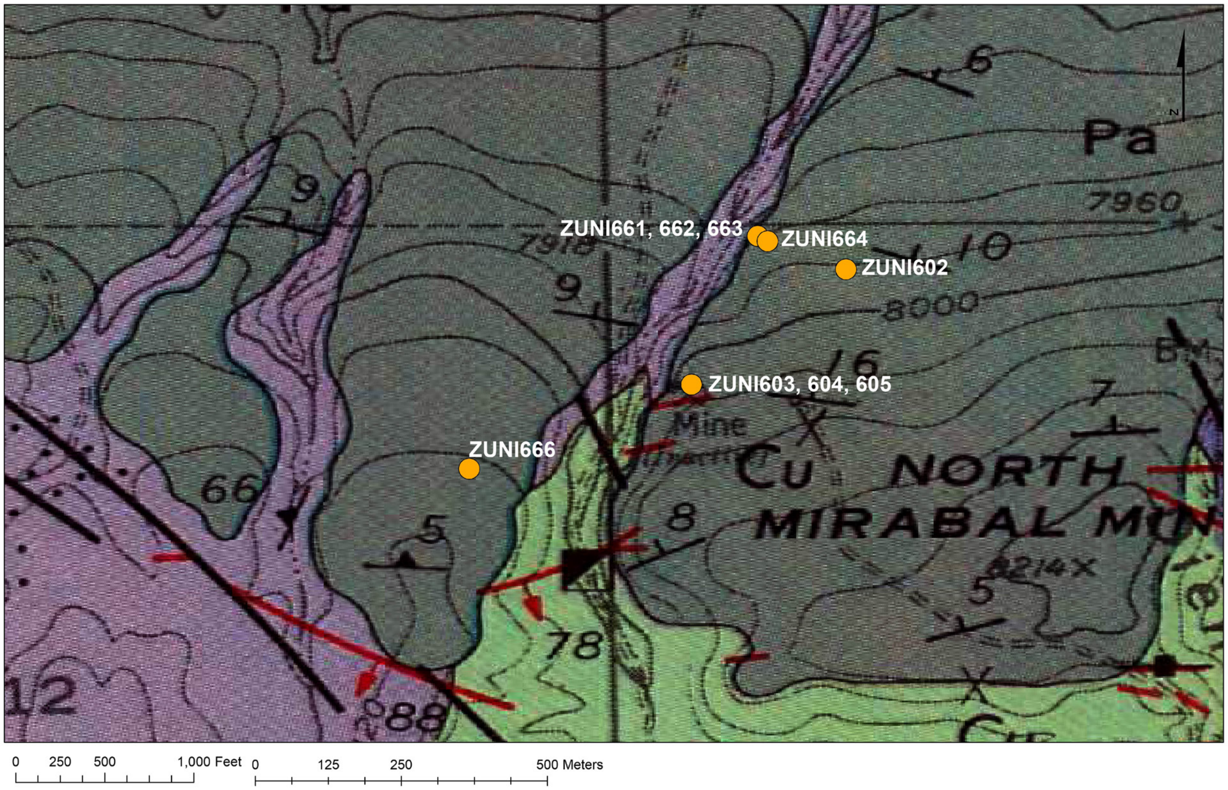

FIGURE 4. Location of samples collected from the Copper Mountain area, Zuni Mountains. Geologic map from Goddard (1966). Lithologic units (oldest to youngest): gg (green) = gneissic granite, ap (purple) = porphyritic aplite, Pa (dark gray) = Permian Abo Formation, red lines = fluorite veins. Yellow circles are sample locations. Coordinates and chemical analyses for each sample are in Appendix 1.

for each element and associated quality assurance and quality control methods are available on request. Chemical plots were created using ioGAS-64 (https://reflexnow.com/product/iogas/). Coordinates of sample locations and chemical analyses are presented in Appendix 1. Locations of samples are in Figures 2, 3, and 4.

The mineralogy of selected samples was determined by visual, petrographic, X-ray diffraction (XRD), and electron microprobe methods. Powder XRD analysis was conducted on either whole rock or mineral separates with a Panalytical X'Pert Pro® diffractometer at the New Mexico Bureau of Geology and Mineral Resources (NMBGMR) XRD Laboratory using Cu Kα radiation and a tube power of 45 kV x 40 mA. Phase identification from XRD data was done using the HighScore Plus® software and the ICDD Powder Diffraction File database. Because the information reported here is preliminary, X-ray diffraction data will be available in future reports.

A Cameca SX-100 electron microprobe analyzer (EMPA) at the NMBGMR Electron Microprobe Laboratory was used to collect backscattered electron (BSE) images and quantitative elemental analyses of various mineral phases. Rock chips were mounted in 1-inch epoxy rounds, polished, and carbon coated. Imaging was conducted at an accelerating voltage of 15 kV and 20 nA beam current. Quantitative elemental analysis was performed using the instrument's four wavelength dispersive (WD) spectrometers. Electron beam parameters for quantitative analysis were similar to those used for BSE imaging. Electron microbe data also will be available with future reporting.

MINING HISTORY AND PRODUCTION

Nacimiento Mountains

The copper deposits of the Nacimiento Mountains were mined by Native Americans and Spanish miners perhaps as early as the 1500s. Larger-scale mining in the Nacimiento district did not occur until the 1880s. Two mining districts are associated with the copper deposits in the Nacimiento Mountains: Nacimiento and Coyote mining districts (Fig. 1). The Nacimiento mine is known for mineral collecting of copper minerals replacing fossil logs and wood and azurite spheres (Ottea and Uhl, 2020).

The Nacimiento Mining Co. was formed about 1868 to examine deposits in the Nacimiento Mountains. Later, the Juratrias Mining Co. and Senorito Mining Co. explored and mined parts of the Nacimiento deposit by both surface and underground mining techniques in the early 1900s; at least two small smelters were constructed in the area to process the ores. Interest in the district faded after 1917 (Ottea and Uhl, 2020), only to increase again in the late 1960s. In 1971, Earth Resources Company constructed a mill and concentrator and began an open pit mine excavation and 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 the estimated reserves of 807 million metric tons of 0.71% Cu (Talbott, 1974; Woodward et al., 1974). There was also a flotation circuit to concentrate the copper sulfides during Earth Resources Company operations. The deposit was mined by open-pit methods (Fig. 5).

In 1973, there was release from the tailings dam into Señorito Creek, followed by issues with high-wall instability in the open pit and falling copper prices; in 1975, the company ceased production. The property was operated by various companies through the 1970s. In the early 1980s, Leaching Technology Inc. attempted to mine the deposit by in situ recovery methods using sulfuric acid, but poor results, low recovery from wells, and environmental concerns have hampered the project. Contaminated groundwater in the open pit area was pumped and effectively treated onsite by the U.S. Forest Service beginning in about 2007, and the treated water was discharged to Señorito Creek. A plume of sulfuric acid remains in the subsurface.

Production from the district is shown in Table 2. Historic reserves are reported for the Nacimiento mine and amount 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 (NMBMGR file data).

Little is known about the mining history of the Coyote district. The known deposits are small. Some production was recorded in 1956–1957 (Table 2).

Zuni Mountains

Base and precious metals were found in the Zuni Mountains circa 1900, and at least two metals mills and one leaching operation were built in the district. Total reported metals production from the district amounts to more than 30,000 pounds Cu, 260 oz Ag, and 2 oz Au from 1923 to 1965 (Table 3); additional copper, gold, and silver production probably occurred during the late 1800s from sediment-hosted deposits and veins in Precambrian rocks (McLemore, 1989, 2013).

DESCRIPTION OF MINERAL DEPOSITS

Nacimiento Mountains

Various types of deposits are found in the Nacimiento and Coyote mining districts in the Nacimiento Mountains. The largest deposits are sediment-hosted stratabound copper deposits that occur in the Agua Zarca Sandstone Member of the Chinle Formation (Triassic); smaller deposits occur in the Madera (Pennsylvanian), Abo, and Cutler Formations (Permian) in the Coyote district. The copper deposits in the Triassic sandstones in the Nacimiento district are found in large, braided stream complexes in the Agua Zarca Sandstone Member of the Chinle Formation (LaPoint, 1979, 1983) and are less arkosic than Pennsylvanian-Permian deposits in the Coyote district.

The largest copper deposit in the Nacimiento district is at the Nacimiento mine, where the host rock is white, poorly cemented arkosic conglomeratic sandstone, 23 to 30 m thick. Kaolinization is present. The sandstones consist primarily of quartz, feldspar with local chert, magnetite, muscovite, zircon, chlorite, and biotite. Copper is associated with carbonaceous material. Much of the deposit occurs at the surface; the deepest mineralized zones are at least 274 m and deeper. The deposit is bounded by the El Cajete fault to the north and the Bluebird fault to the south (Woodward et al., 1974). 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 (NMBGMR 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, native silver, silver sulfides, and native copper (Table 4; Talbott, 1974; Woodward et al., 1974; LaPoint, 1979). Uranium and barite are present locally but only in trace amounts (Appendix 1; McLemore, 1983). Large, mineralized fossil logs up to several meters long have been replaced by chalcocite, locally preserving the woody cell structure (Fig. 6). In some places, the logs were replaced by pyrite followed by bornite and chalcocite, then finally replaced by covellite (Woodward et al., 1974). The adjacent carbonaceous shales typically are not mineralized. Copper content varies, with some deposits containing as much as 40–50% Cu. Gold is rare (typically less than 1 ppb). Similar but smaller sedimentary-copper deposits are found in the Agua Zarca Member at the San Miguel and Eureka mines, where sphalerite is found in addition to the copper minerals. Note that zinc is a critical mineral.

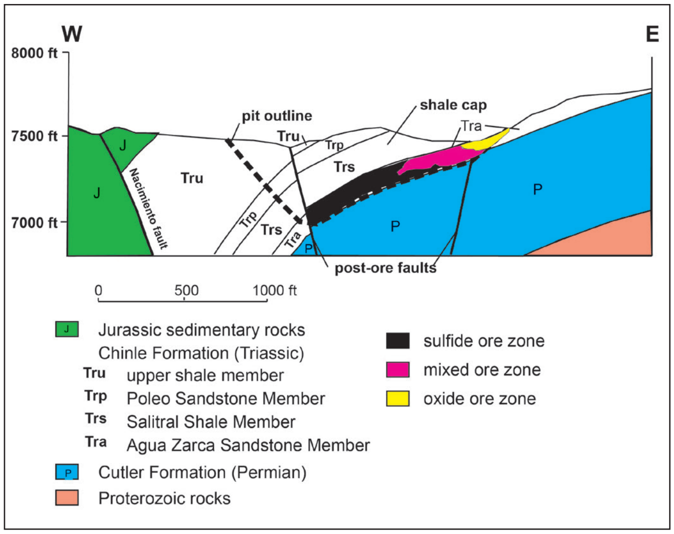

FIGURE 5. Cross section through the Nacimiento open pit mine in the Nacimiento district exposing the sediment-hosted stratabound copper deposit (modified from Talbot, 1974).

Additional sediment-hosted stratabound copper deposits containing uranium and vanadium are found in the Pennsylvanian and Permian Madera, Abo, and Cutler Formations throughout the Nacimiento Mountains (Soulé, 1956; McLemore, 1983; Woodward, 1987), but they are small and uneconomic. The copper deposits in the Pennsylvanian-Permian beds are typically more arkosic than Triassic deposits and are found in small, meandering stream channels. Silver is rarely as abundant in Permian deposits as in Triassic deposits (Appendix 1). Uranium concentrations are higher in Permian deposits than Triassic deposits (Chenoweth, 1974).

TABLE 2. Reported metals production from the Nacimiento and Coyote mining districts, Nacimiento Mountains, Sandoval and Rio Arriba Counties (from USGS, 1902–1927; U.S. Bureau of Mines Mineral Yearbooks, 1927–1990; McLemore, 1989, 2017; NMBGMR file data). Production data can change as better data are obtained. Blank = no reported production. W = withheld or not available.

Year	Ore (short tons)	Copper (lbs)	Gold (oz)	Silver (oz)	Lead (lbs)	Zinc (lbs)	Total value ($)	Comments
Nacimiento mining district								
1880-1900		6,300,000		63,000			$700,000	
1904	467	846		52			$190	
1911	10	5,731		46			$741	
1916	130	26,276		274			$6,684	
1917	20	12,901		153			$3,648	Nacimiento mine
1918	6	10,935		118			$2,819	
1919	166	100,000		1,317			$20,075	
1920	89	53,821		700			$10,666	
1929								withheld
1943		4,000		45			$552	
1945		2,000		28			$290	
1950		6,000		10			$1,257	
1951		4,000		11			$978	
1955		600,00		410			$22,751	
1956		548,200		7,564			$239,831	Eureka mine
1957		421,700		1,392			$128,912	
1959	75	6,000		55			$1,658	
1960	277	12,000		99			$3,505	
1961	99	2,000		23			$1,362	
1964	1,010	6,000					$1,923	Nacimiento mine
1967, 1971–1975								withheld, Nacimiento mine
TOTAL REPORTED 1880–1964	27,704	7,582,410		75,297			$1,147,842	Nacimiento mining district
ESTIMATED TOTAL 1880–1975		7,700,000	1	76,000	1,783	463	$1,500,000	Nacimiento mining district
Coyote mining district								
1956–1957		462,000		841	W		$4,000	Coyote mining district

Zuni Mountains

Types of deposits in the Zuni Mountains include (1) veins and replacements in Proterozoic rocks, (2) sediment-hosted stratabound copper deposits, (3) fluorite veins, (4) REE-Th-U metasomatic bodies (episyenites), (5) high-calcium limestone, (6) volcanic cinders (scoria), and (7) iron deposits (McLemore, 2013, 2017). In the Zuni Mountains, copper deposits are found in both Proterozoic granite and gneiss and Permian Abo Formation sandstones and shale (Schrader, 1906; Lindgren et al., 1910; McLemore et al., 1986). The copper deposits typically are found in bleached pink or light-gray sandstones, siltstones, and conglomerates of the Pennsylvanian (?)-Permian units deposited unconformably on the Proterozoic rocks in the Copper Hill area. At one locality, the Proterozoic granite beneath the mineralized conglomerate consists of thin veinlets and disseminations of malachite and chalcocite. Fluorite-barite veins locally cut the copper deposits (Fig. 4). The deposits are predominantly in the Abo Formation (Permian), but some replacements of the Pennsylvanian rocks also are found. The mineralized bodies typically occur as lenses or blankets of disseminated and/or fracture coatings of copper minerals, predominantly chalcocite, malachite, and azurite with local uranium minerals, galena, sphalerite, chalcopyrite, and barite.

TABLE 3. Reported metals production from the Zuni Mountains mining district, Cibola County (from USGS, 1902–1927; U.S. Bureau of Mines Mineral Yearbooks, 1927–1990; McLemore, 1989, 2017; NMBGMR file data). Production data can change as better data are obtained. — = no reported production. W = withheld or not available.

Year	Ore mined (short tons)	Gold (oz)	Silver (oz)	Copper (lbs)	Total value ($)
1905	W	—	—	W	W
1923	16	—	36	4,884	748
1925	30	—	27	3,300	487
1930	57	—	57	6,600	880
1937	59	—	88	11,000	1,399
1940	12	—	28	2,700	325
1959	—	2	12	W	81
1963	W	—	W	W	W
1965	15	—	12	2,000	901
Total (excluding withheld values)	189	2	260	30,484	4,821

TABLE 4. Mineralogy of the sediment-hosted stratabound copper deposits in the Zuni and Nacimiento Mountains. X = XRD (this study), E = EMPA (this study), O = optical petrography (this study), M = Mindat.org

Mineral Name	Mineral Formula	Nacimiento Mountains	Zuni Mountains
Azurite	$Cu_3(CO_3)_2(OH)_2$	O, M	E, M
Barite	$BaSO_4$	E	E, M
Bornite	Cu_5FeS_4	O, M	
Chalcocite	Cu_2S	X, E, O, M	M
Chalcopyrite	$CuFeS_2$		M
Chrysocolla	$Cu_{2-x}Al_x(H_{2-x}Si_2O_5)(OH)_4 \cdot nH_2O, x < 1$	E, M	E, M
Copper	Cu		M
Covellite	$Cu^+_4Cu^{2+}_2(S_2)_2S_2$	X	M
Djurleite	$Cu_{31}S_{16}$	M	
Hematite	Fe_2O_3		M
Malachite	$Cu_2(CO_3)(OH)_2$	X, E, M	M
Pyrite	FeS_2	X, E, M	X, E, M
Silver	Ag	M	M

Ore minerals in these sediment-hosted stratabound copper deposits are typically associated with organic debris and other carbonaceous material. Locally, sedimentary features such as bedding, cross-bedding, paleochannels, and intraformational slumping also appear to control mineralization. The copper deposits are found in small, meandering stream channels and tend to be discontinuous, small, and low grade. The average thickness of mineralized zones is less than 2 m, but as many as four horizons or zones are found. Malachite, azurite, and chalcocite with local pyrite, quartz, and galena are disseminated within shear zones within the granite and gneiss. Malachite, azurite, chalcocite, and local chalcopyrite are disseminated or along thin seams within pore spaces in and cementing conglomerate, sandstone, and shale of the Abo Formation directly overlying the Proterozoic rocks. Copper minerals also replace fossil wood, carbon layers, and thin shales locally with carbonates.

MINERALOGY AND GEOCHEMISTRY OF THE DEPOSITS

The mineralogy of mineral deposits found in the Nacimiento and Zuni Mountains is presented in Table 4, and chemical analyses are in Appendix 1. Electron microprobe analyses of chalcocite in replaced wood from the Nacimiento mine show an average of ~400 ppm Ag (up to ~600 ppm Ag) substituting within the mineral (Table 5). While native silver has been

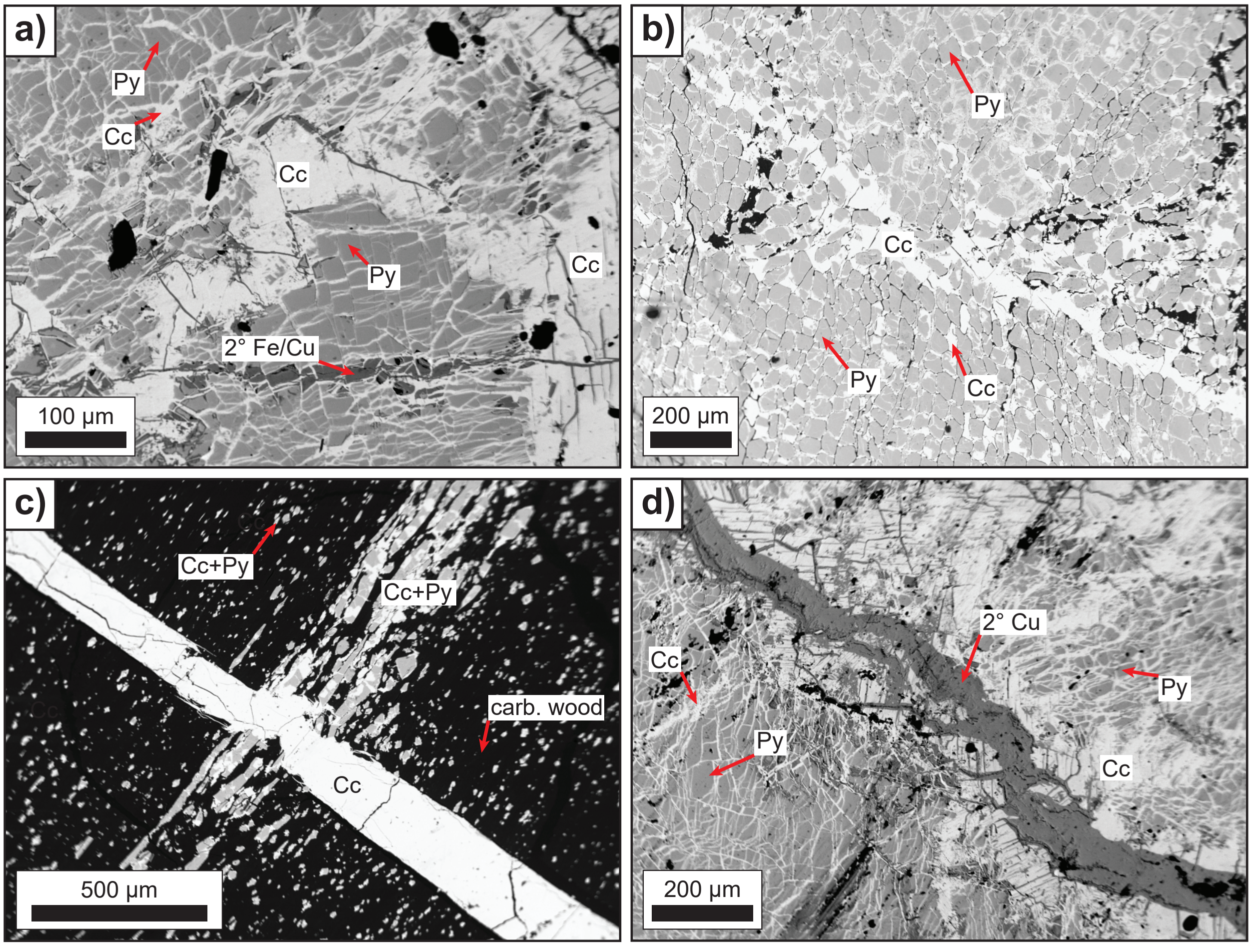

FIGURE 6. Backscattered electron images of chalcocite and pyrite replaced wood from the Nacimiento mine. (a) Chalcocite veinlets cutting and replacing pyrite that has replaced wood. Late secondary iron-copper veinlets are also observed (NAC4). (b) Chalcocite veinlets cut and replace pyrite which shows preserved plant cellular structure (NAC A). (c) Chalcocite and pyrite locally replace carbonized wood and are cut by a sharp chalcocite vein (NAC B). (d) A late, secondary copper vein (possibly spertiniite, though additional analyses are needed to confirm) cuts chalcocite, replacing pyrite along fractures (NAC4). Cc = chalcocite, Py = pyrite, 2° = secondary (iron-copper or copper minerals).

reported from the Nacimiento mine, none was observed in the studied samples. EMPA analyses of pyrite from the Nacimiento mine show an average of 1900 ppm Pb (Table 5). Chalcocite and pyrite are the dominant sulfide minerals present in replaced wood from the Nacimiento mine (Fig. 6). Minor amounts of secondary iron-copper and copper minerals fill late fractures (Fig. 6a, c). More analytical work, including XRD will be needed to confidently identify these phases.

CRITICAL MINERAL POTENTIAL

Sediment-hosted stratabound copper deposits throughout the world are known to have locally elevated concentrations of various critical minerals including cobalt, zinc, vanadium, uranium, gallium, germanium, indium, platinum group metals, rhenium, and possibly REE. Geochemical and mineralogical studies are required to properly evaluate whether a deposit has elevated critical minerals.

Selected samples were collected from sediment-hosted stratabound copper deposits in the Nacimiento and Zuni Mountains to examine their critical minerals potential by determining their mineralogy and geochemistry (Table 4; Appendix 1). Some samples in the Nacimiento and Zuni Mountains have elevated heavy REE. Samples from the Coyote district are elevated in cobalt; preliminary electron microprobe data suggest trace amounts of cobalt within chalcocite. Both Coyote and Zuni samples are elevated in heavy REE (Fig. 7), vanadium, and uranium. Arsenic is found in many of the samples (Appendix 1). The Eureka deposit has elevated barium. Bismuth is elevated in Zuni and Coyote samples.

TABLE 5. Summary of electron microprobe analyses data.

Chemistry of chalcocite from the Nacimiento Mine (n = 12)				
Cu	Fe	Ag	S	Total
75.36±1.2	0.38±0.35	0.04±0.02	22.75±3.06	98.53±2.52
Chemistry of pyrite from the Nacimiento mine (n = 4)				
Fe	Pb	S	Total	
46.46±0.14	0.19±0.05	53.63±0.23	100.27±0.4	

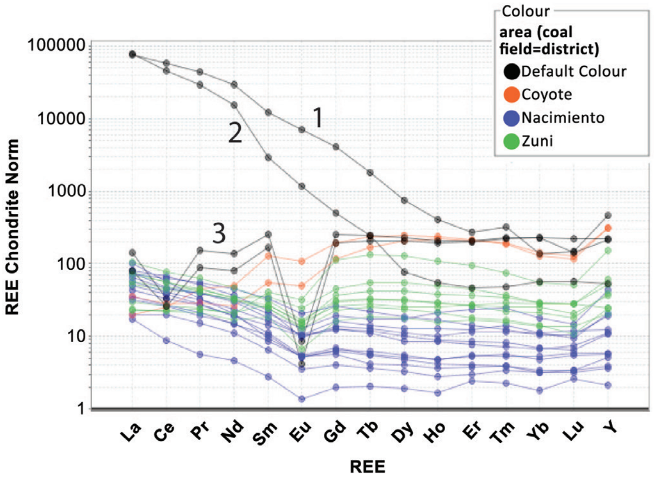

FIGURE 7. Chondrite-normalized REE plot. Chondrite values from Taylor and McLennan (1985). Black lines are representative REE analyses of major deposits in production, for comparison. 1 = Mt. Weld laterite deposit (https://lynasrareearths.com/wp-content/uploads/2019/05/Increase_in_Mt_Weld_Resource_Estimate_1068363.pdf), 2 = Mountain Pass, Ca carbonatite deposit (Verplanck et al., 2014), 3 = Zudong, China, ion-adsorption clay deposit (Li et al., 2019).

PRELIMINARY CONCLUSIONS

Most of these sediment-hosted stratabound copper deposits are low to moderate grade, low tonnage, and too widely distributed to allow mining and mineral processing that is economic. The grade and tonnage of these deposits may be amenable to vat leaching / solution extraction electrowinning processes and several deposits could be trucked to a central processing facility. Concentrates would have to be shipped to Miami, Arizona, the nearest smelter. These deposits are generally low in silica and are not suitable as silica flux material for copper smelters, where silica values greater than 95% are desired. However, an increase in copper and silver prices and interest in critical minerals have renewed interest in some of the larger deposits. For example, historic reserves are reported for the sediment-hosted stratabound copper deposits at 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 data). Selected samples from Nacimiento, Coyote, and Zuni districts have elevated heavy REE, vanadium, cobalt, and arsenic, but additional studies are required to fully characterize these areas and determine whether any economic potential for critical minerals exists. Ultimately these deposits must have sufficient copper and silver concentrations and tonnage to be considered economic; the critical minerals would be byproducts and, if they could be recovered, would increase the overall resource. Additional samples need to be collected and examined from the other sediment-hosted stratabound copper deposits in the state.

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Appendices can be found at
https://nmgs.nmt.edu/repository/index.cfml?rid=2024001

A gas pipeline cuts across a ridge of Todilto Formation on the west limb of the Tierra Amarilla anticline. This photo is looking west from the Twin Mounds stop on the first-day field trip of this conference. The presence of the pipeline reminds us of the nearby oil- and gas-rich San Juan Basin, the importance of geologic resources for New Mexico's past, present, and future, and the challenges of transitioning to alternative forms of energy in the face of climate change.