24-043

Geochemistry of Critical Minerals in Mine Wastes in New Mexico

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ABSTRACT

There are tens of thousands of inactive mine features in 274 mining districts in New Mexico (including coal, uranium, metals, and industrial minerals districts). However, many of these mines have not been inventoried or prioritized for reclamation. Many of these mines have existing mine wastes, generated during mineral production, which could have potential for critical minerals, especially since the actual mineral production was generally for precious and base metals and not critical minerals. The purpose of this project is to characterize and estimate the critical mineral endowment of mine wastes and "beta-test" USGS sampling procedures. This project is important to the state of New Mexico because critical mineral resources must be identified before land exchanges, withdrawals or other land use decisions are made by government officials. Future mining of mine wastes that potentially contain critical minerals will directly benefit the economy of New Mexico. Possible re-mining of mine wastes could clean up these sites and pay for reclamation. Furthermore, this project will include training of younger, professional geologists and students in economic and reclamation geology by the PIs.

INTRODUCTION

Since it was created in 1927, the New Mexico Bureau of Geology and Mineral Resources (NMBGMR) has collected published and unpublished data on the mining districts, mines, deposits, occurrences, and mills and is slowly converting historical data into a relational database, the New Mexico Mines Database (McLemore et al., 2005a, b; McLemore, 2017; geoinfo.nmt.edu/staff/mclemore/MinesinNewMexico.html). More than 9,000 mines are recorded in the New Mexico Mines Database and more than 7,000 are inactive or abandoned. The New Mexico Abandoned Mine Lands Bureau (AMLB) of the New Mexico Energy, Minerals, and Natural Resources Department estimates that there are more than 15,000 abandoned mine features in the state (www.emnrd.state.nm.us/MMD/AML/amlmain.html). The U.S. Bureau of Land Management (BLM) estimated that more than 10,000 mine features are on BLM lands in New Mexico and only 705 sites have been reclaimed (www.blm.gov/wo/st/en/prog/more/Abandoned_Mine_Lands/abandoned_mine_site.html). Most of these mines have existing mine wastes, generated during mineral production and exploration that could have potential for critical minerals.

Critical minerals are mineral commodities that are essential to the economic and national security of the U.S., and are from a supply chain that is vulnerable to global and national disruption. In the mining industry, *minerals* refer to any rock, mineral, or other naturally occurring material of economic value, including metals, industrial minerals, energy minerals, gemstones, aggregates, and synthetic materials sold as commodities. Thus, the term minerals include all inorganic substances, as well as hydrocarbons, such as oil and natural gas, and carboniferous deposits, such as coal. Many critical minerals are produced in other countries and 100% imported into the U.S. In many cases, mineral deposits are available in the world for specific critical minerals, but the real challenge for the Nation's economy and security is potential supply disruptions. Disruptions in supply chains can arise for any number of reasons, including natural disasters, labor strife, trade disputes, resource nationalism, conflict, and so on.

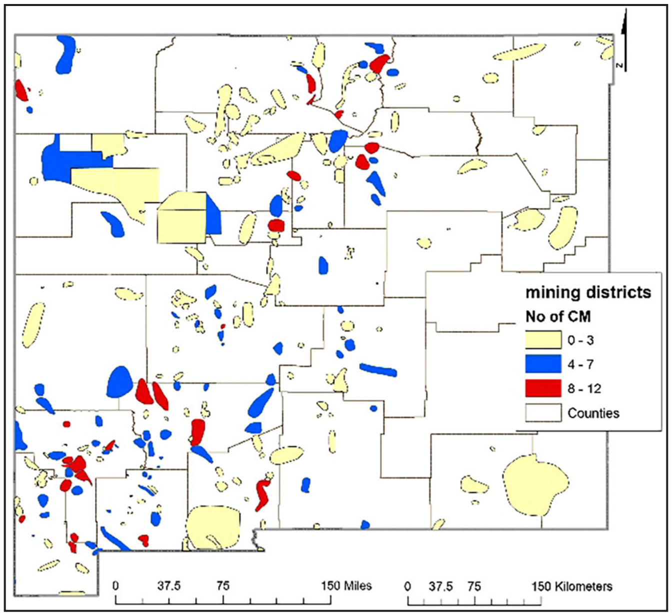

Figure 1. Map of mining districts in New Mexico that have critical minerals. Coal fields are not shown. Other areas in New Mexico, such as high-magnesium dolomites, lithium-bearing playas, and coal fields, are not found in specific mining districts and also have potential for critical minerals (CM)

Rare earth elements (REE) and other critical minerals are essential in most of our electronic devices, such as cell phones, laptops, computer chips, batteries, magnets, wind turbines, hybrid/electric cars, etc. (Committee on Critical Mineral Impacts of the U.S. Economy, 2008; Long et al., 2010; McLemore, 2011; McLemore and Gysi, 2023). Other technologies are being developed like solar panels, water purification, desalination, magnetic refrigeration, and even more efficient light bulbs that require REE and other critical elements in their manufacture. A variety of minerals (Mg, REE, Co, Li, etc.) are required to manufacture batteries and some of these critical minerals are found in and even produced from New Mexico (Figure 2), including the mine wastes from previous mines.

Mine wastes have the potential to contain critical minerals, especially since the actual mineral production was generally for precious and base metals and not critical minerals. Therefore, any critical minerals that are found in the mineral deposit also would be found in the mine wastes (mine waste dumps, tailings, slags, etc.). Although some of these critical minerals are located in New Mexico, they have not been important exploration targets in the past because demand has been met economically elsewhere, mostly from China. However, with the projected increase in demand for critical minerals and the potential lack of available production from China and other countries, the New Mexico deposits including mine wastes are being re-examined for their critical mineral potential, and several areas of mill tailings are undergoing current exploration.

Not only are these data required to delineate favorable mine wastes for the USGS project, but identification and examination of critical minerals is a high priority of the NMBGMR. This project is important to the state of New Mexico because critical mineral resources must be identified before land exchanges, withdrawals or other land-use decisions are made by government officials. Future mining of potential critical minerals deposits will directly benefit the economy of New Mexico. Possible re-mining of mine wastes could clean up these sites or pay for reclamation. Furthermore, this project will allow training of the next generation of younger, professional geologists and students in economic and reclamation geology by the PIs. We plan to evaluate typical environmental characteristics of the mine wastes (acid base accounting, pH, leaching tests, etc.) of the mine features, because these evaluations will be required to obtain permits and provide a safe work environment during mining, reclamation, and/or waste reprocessing.

The purposes of this project are 1) to test sampling protocols of mine wastes in a variety of mine features (waste rock piles, stock piles, tailings, pit lakes, etc.), 2) to determine the potential for critical minerals in mine wastes in New Mexico, and 3) compare results between mining districts and types of deposits. Previous sampling of mine wastes in mining districts in New Mexico are compared to new sampling for the USGS mine waste project.

DESCRIPTION OF AREAS SAMPLED

The NMBGMR has been working on mine wastes since the 1950s. Samples have been collected for chemical analyses and other characterization data from several mining districts throughout New Mexico as part of prior projects: 1) an inventory and characterization of mine features and evaluation of mine wastes as part of the New Mexico AML project (geoinfo.nmt.edu/hazards/mines/aml/home.html), 2) a study on uranium transport, uranium source characteristics, and uranium legacy issues in New Mexico (EPSCoR, geoinfo.nmt.edu/geoscience/research/home.cfml?id=81&project=Uranium+Transport+and+Sources+in+New+Mexico+A+fiveyear+EPSCoR+program), 3) an assessment on the effects of the Gold King mine spill on the Animas and San Juan Rivers in northern New Mexico, and 4) specific mining district studies. More recently, three districts in New Mexico were selected for sampling and testing procedures for the USGS Earth MRI mine waste project.

Samples discussed in this paper were collected from several districts in New Mexico, as summarized in Table 1

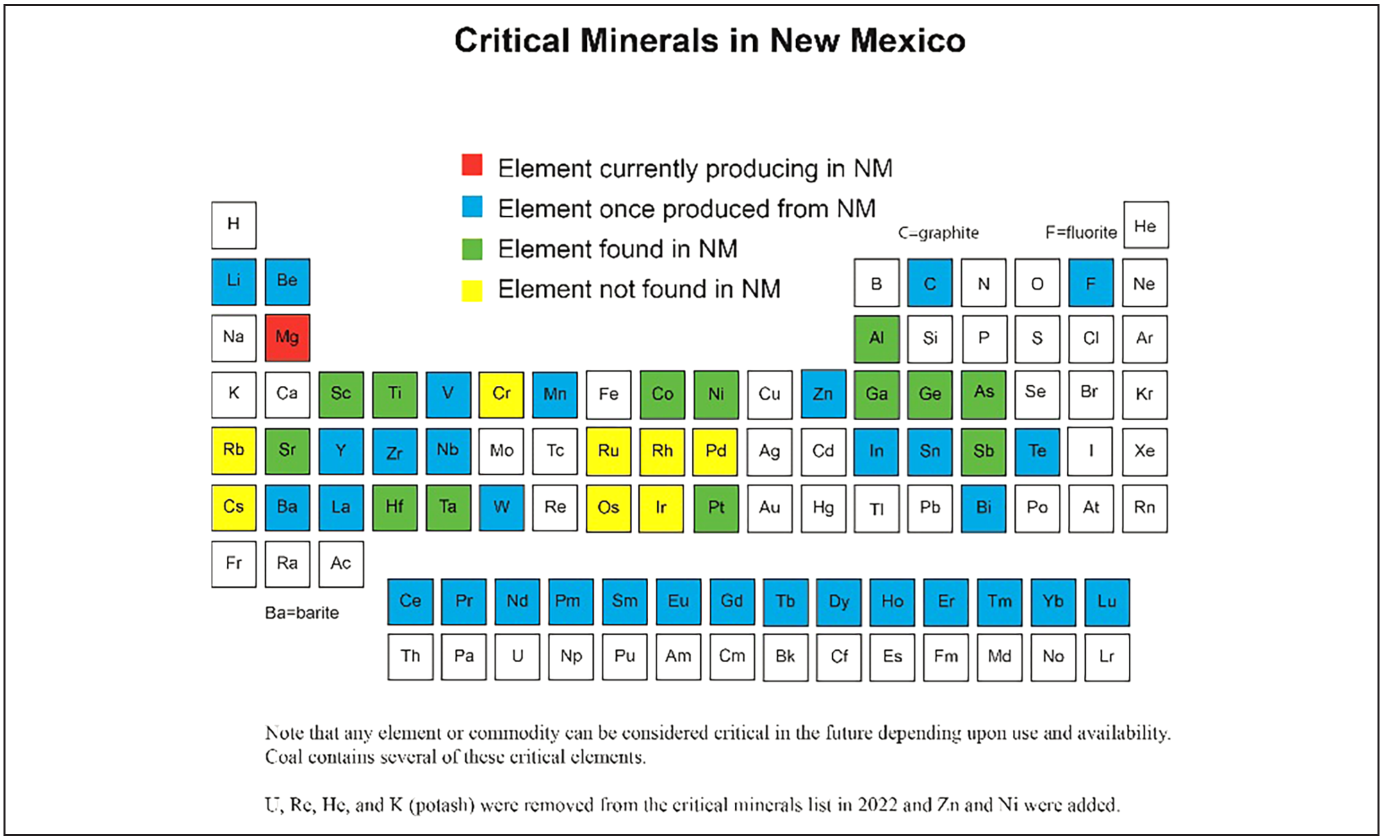

Figure 2. Periodic table showing critical minerals in New Mexico. Copper (Cu) was added as a critical mineral in 2023 by the Department of Energy (DOE)

and locations shown in Figure 3. Samples represent different types of mine features, including low-grade stockpiles, mine waste rock piles, tailings, and slags, as well as different deposit types.

METHODS

Inventory and Mapping of Mine Features

An important step in this study is to compile all published and unpublished data from existing mines and prospects within the mining districts of New Mexico in order to summarize the mining history and begin the inventory of mine features in the district. Mineral databases were examined, including the Mineral Resource Data System (MRDS) of the USGS, the Minerals Industry Location System (MILS) of the U.S. Bureau of Mines (USBM), U.S. Forest Service Abandoned and Inactive Mines database, and AMLIS (U.S. Bureau of Land Management, BLM). Published and unpublished reports and files at the NMBGMR were also examined. Using these data, mineral occurrences, deposits, mines, prospects, resources, tailings, and mills were identified, plotted, and entered in the NMBGMR New Mexico Mines Database (McLemore et al., 2005a, b; McLemore, 2017).

Waste rock piles and tailings were mapped using a handheld GPS, measuring tape and brunton, and or Lidar. Sketches of selected mines and associated mine features were compiled. The primary purpose of the field inventory was to accurately locate and describe the mine features, identify those features that required more detailed mapping, and identify those features suitable for sampling.

Project Databases

Databases were developed for this project (McLemore et al., 2022). Initially, data were collected and stored in MS Access databases. During the course of the project, to increase reliability, efficiency and security, data were migrated to MS SQL Server (SQLS) and the Access “front end” forms were reworked to connect to the external database server. Locational and other information of photographs taken in the field, thin sections, and hand samples are recorded in the SQLS database. Location and descriptions of samples referred to in this report are in the SQLS database.

TABLE 1. Summary of samples collected in the New Mexico mine waste study. Districts are summarized in McLemore (2017) and references cited there.

Mining District, County	Types of Mineral Deposits Sampled	Number of Samples	Types of Samples
Jicarilla, Lincoln	Gold vein	26	Mine waste rock piles
Jeter, Lucky Don, Socorro	Uranium vein	4	Mine waste rock piles
Rosedale, Socorro	Gold vein	22	Mine waste rock piles
North Magdalena, Socorro	Gold vein	6	Mine waste rock piles
Eureka, Grant	Copper vein	2	Mine waste rock piles, tailings
Lone Pine, Catron	Copper-tellurium vein	1	Mine waste rock piles
St. Anthony, Cibola	Sandstone uranium	4	Mine waste rock piles
Silverton, Colorado	Polymetallic vein	4	Mine waste rock piles
Lake Valley, Sierra	Carbonate-hosted Ag-Mn		Mine waste rock piles
Gallinas, Lincoln	F-REE-Ba veins	7	Mine waste rock piles
Copper Flat, Hillsboro, Sierra	Porphyry copper	53	Mine waste rock piles, tailings, slag
Steeple Rock, Grant	Au-Ag veins	14	Mine waste rock piles, tailings, slag
Coal mines, McKinley, Colfax	coal	7	Mine waste rock piles
Black Hawk, Grant	5-element arsenide veins	21	Mine waste rock piles, tailings
Magdalena, Socorro	Carbonate-hosted	4	slag
Estey, Zuni Mountains, Chupadera, Naciemeinto	Sandstone-hosted copper deposits	6	Mine waste rock piles, tailings, slag

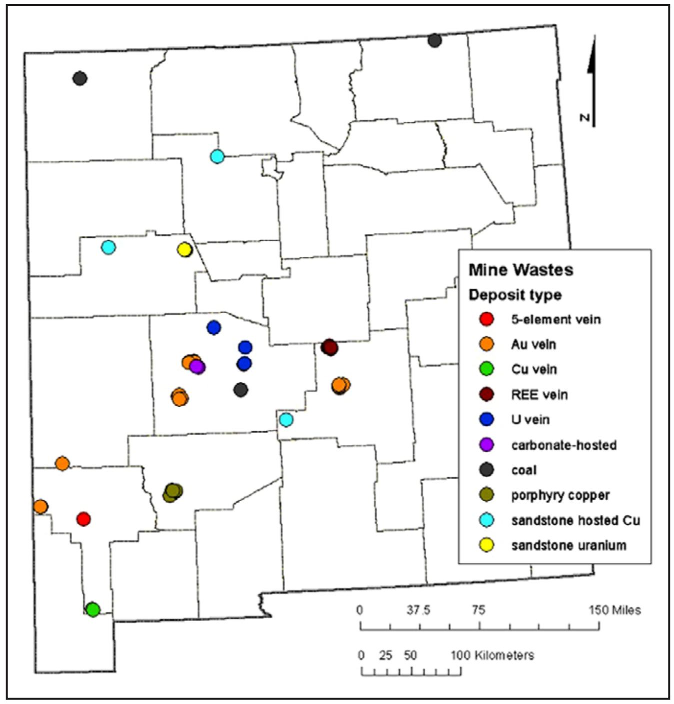

Figure 3. Location of areas sampled in the New Mexico mine waste study

Sample Collection

Mine waste features (defined as low grade stock piles, mine waste rock piles, gob piles, tailings, slag, etc.) vary in size, shape, composition, nature of source material, waste management approaches, influence by climate, and site accessibility. These variables will affect safety and access considerations. The number of samples, the type of samples, the sample locations, intervals, and other specific procedures depend on the safety, study's objectives, and equipment availability. Two separate splits of each sample are generally collected: one split for chemical analyses that is submitted to the chemical laboratory and a second split that is archived at NMBGMR.

Water sampling of mine waters occurred during this phase of the project but is not discussed in this paper. Future reports will describe the sampling and critical minerals potential of mine waters.

The first step is to examine the geology and topography of the mine feature. If a feature is large and includes topographical or other distinguishing features (e.g., benches, separate piles, tailings color, etc.) that point to a change in composition or site management, then the feature should be split into separate sample units. A scintillation counter can be used to identify more radioactive zones in the mine feature as separate sample units. Several types of samples can be collected: composite, select, or profile samples

Figure 4. Arrows pointing to subsamples forming a composite sample of a waste rock pile at Copper Flat

as described below. Location, type of sample, and other descriptive data were entered into the project database. Samples are archived at NMBGMR for future examination.

A *composite sample* of the mine feature is collected once sample units have been identified in a particular mine feature. Composite samples of waste rock piles were collected, using procedures developed by Munroe (1999) and the U.S. Geological Survey (USGS) (Smith et al., 2000; Smith, 2007; McLemore et al., 2014; USGS 2023 memo). This type of sampling is developed by the USGS and poses no stability or erosion risks of the waste rock piles or tailings. Each sampling unit should be subdivided into at least 30 cells of roughly equal area. To do this, flags/markers are placed equidistant from each other forming a rough grid, where the flag/maker represents the center of each cell (Figure 4). If a particular subsample location is inaccessible, an alternative may be selected as close to the original location as possible. GPS locations should also be recorded simultaneously, while placing flags/markers or while removing flags/markers after sampling. The overburden or overlying surface material (i.e., leaves, grass, roots, cover material of tailings, etc.) is first removed. Care should be taken when removing the cover material from tailings to avoid dilution. Collect each subsample using identical procedures. Collect the desired volume into the required sieve size (e.g., 2 mm and 4 mm for tailings and waste rock piles respectively), and sieve into a single decontaminated bucket or bag, making sure to homogenize as you sample (Figure 5). For tailings samples that are wet upon collection, the samples should be air dried prior to sieving and any particle agglomerates, which can form especially upon drying a wet sample, should be disaggregated before sieving. You can collect chip samples as well (especially for waste rock piles where a large percentage of the material is coarse) from the over-sieved material into a separate bucket or bag and broken into chips to remove weathering surfaces. Finally, all the composite samples (fines and coarse) should be thoroughly homogenized again and then transferred into appropriately labeled sample containers.

Select samples include hand specimens of mineralized rocks (including ore samples), grab samples of the mine wastes, samples from individual cells, etc. from anywhere in the mine feature and are collected for specific purposes (to identify minerals, separate chemical analyses, etc.). These samples are collected separate from the composite sample. The volume or number of samples collected is highly dependent on the type of laboratory test to be conducted and the availability of the sample. Remove weathering surfaces from rock samples. If the purpose of sampling is for geochemical analysis, break samples into smaller chips. Grab samples should be collected directly from the mine waste feature or the base of the slope to avoid sampling just float material. Store the sample in a well-labeled bag.

Profile samples are generally collected along a vertical exposed section of the mine feature (Figure 6). The soil profile may be exposed, or a small pit may be dug to reveal a profile. The depth of the pit is dependent on depth of the mine waste feature. Use a small trowel to clean the surface of the profile gently to prevent the boundary lines from caving in. Identify the changes in different lithologies (i.e., color, thickness, depth texture, grain size, etc.) and record them in the field notebook. Collect samples carefully by scraping directly into a well-labeled sample bag, (include sampling depth on the sample bag) or decontaminated container using a small trowel or scoop to avoid cross-contamination from different lithologies. In addition, sample from the midpoint of the profile as much as possible, sampling the boundary can result in mixing lithologies. Assign

Figure 5. Sieving mine waste rock pile samples

Figure 6. An oxidized profile in a mine waste rock pile, Copper Flat, New Mexico

one GPS location and waypoint to the pit and different sample IDs to each lithology sampled in the profile.

Some general precautions in sampling include the following. All equipment should be cleaned to prevent cross-contamination of the sample. Sampling tools (buckets, sampling bags, shovels, trowels, and sieves) should be constructed of materials suitable for environmental sampling (typically stainless steel, plastic, or aluminum). Devices plated with chrome or other materials should not be used as they can introduce contaminants to the samples. All equipment used for sampling should be rinsed with deionized water and air-dried prior to use. Wear disposable gloves while sieving to avoid contamination.

The samples are transported from the field to NMBGMR, where each sample is prepared for analyses. Selected samples are cut and chips sent for preparation of polished thin sections. The prepared samples are then sent to a laboratory for chemical analyses. NMBGMR standards are submitted blind to the commercial laboratory with each sample batch to assure analytical quality.

Geochemical Analyses

Geochemical data are a critical part of geologic mapping and for evaluation for critical mineral resources central to the mission of Earth MRI. Geochemical analyses of samples collected for this study were determined by the USGS laboratory and by ALS Laboratory (description of methods can be found at ALS Geochemistry Fee Schedule USD (2).pdf and in future reports). Samples were submitted to the laboratories where sample preparation occurred. Duplicate samples and standards were analyzed and uncertainty of analyses is generally <5%. Specific analytical methods for each element and additional quality assurance and quality control (QA/QC) are available on request. Chemical plots were created using ioGAS-64 (ioGAS™ - REFLEX (reflexnow.com)). Chemical analyses will be published in future reports.

Petrography and Mineralogy

Hand sample descriptions of both sawed samples and thin sections were entered into the project's SQLS database. Polished thin sections of selected samples of the igneous, altered, and mineralized rocks were made by Quality Thin Sections. Thin sections were scanned in both plane and plane polarized light, and selected photomicrographs were taken. Mineralogy of selected samples was determined by visual and petrographic, X-ray diffraction (XRD), and electron microprobe methods.

X-ray diffraction (XRD) analysis was performed on either whole rock or mineral separates performed on a PANalytical X- Pert PRO® diffractometer at the NMBGMR X-ray Diffraction Laboratory. Analyses were conducted using 45 kV X-ray beam tension and 40 mA X-ray beam current. XRD scans were identified using X'Pert HighScore Plus® software, which identifies intensity peaks and matches patterns to a Powder Diffraction File database. XRD data will be available in the final report. Petrographic descriptions, including mineralogy and texture, of thin sections using plane, plane polarized, and reflective light were entered into the SQLS database.

RESULTS

Potential for Critical Minerals

Figures 7, 8 and 9 shows some of the chemical plots of mine waste samples from mining districts in New Mexico.

Potential for Acid Rock Drainage

Acid rock drainage (ARD) is formed when sulfide minerals are oxidized by meteoric water or atmospheric exposure (i.e., weathering). Field characteristics of potential ARD in mine waste rock piles include identification of pyrite and/or jarosite and low pH. The rate of sulfide oxidation depends on reactive surface area of sulfide minerals, oxygen concentration and solution pH. ARD potential can be

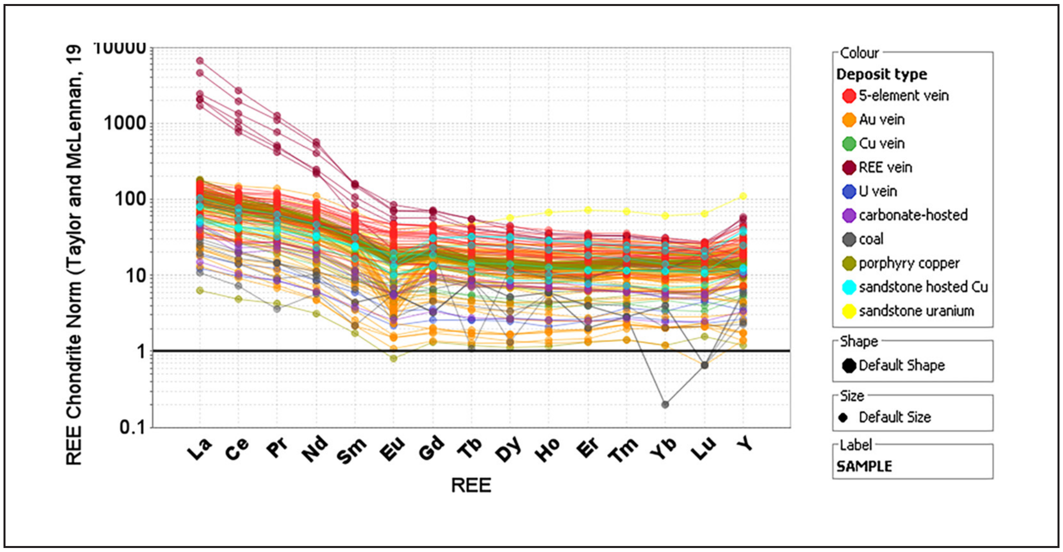

Figure 7. Chondrite-normalized (Taylor and McLennan, 1985) rare earth elements (REE) for samples from mining districts and different deposit types in New Mexico. See Table 1 for summary of districts sampled and Figure 3 for locations

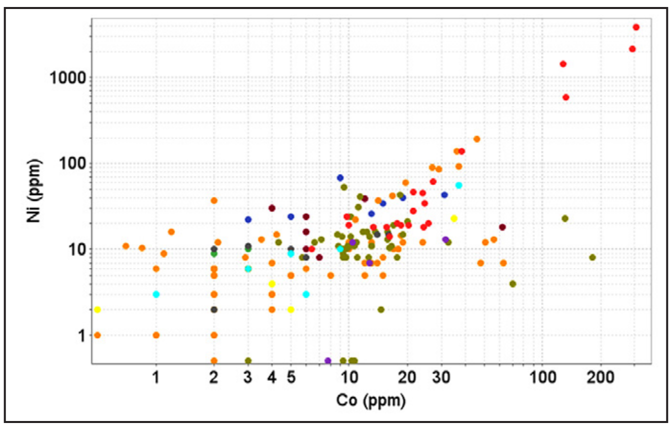

Figure 8. Ni verses Co for samples from mining districts in New Mexico. See Table 1 for summary of districts sampled and different deposit types, and Figure 3 for locations. Legend is in Figure 7

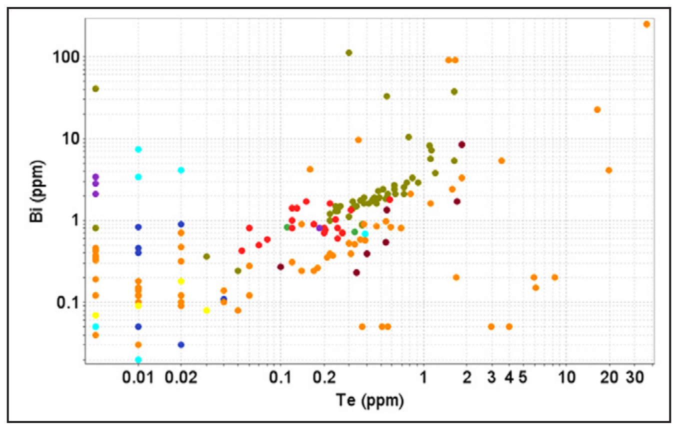

Figure 9. Bi verses Te for samples from mining districts in New Mexico. See Table 1 for summary of districts and different deposit types sampled, and Figure 3 for locations. Legend is in Figure 7

determined by Acid Base Accounting (ABA) and Net Acid Generation (NAG) tests.

The ABA procedure consists of two separate tests; the acid potential (AP) test and the neutralization potential (NP) test. ABA was calculated and plotted on the ARD classification plot for waste rock pile samples from the various mines (Sobeck et al., 1978). The assumption is that all C in the samples are as $CaCO_3$ (no organic carbon) and that the NAG pH equals the measured paste pH of the sample. The formula used include:

AP (kg $CaCO_3$/tonnes) = 31.25 x S (%)
NP (total C) = 83.3 x C (%),
NNP = NP – AP,
NPR = NP/AP

This type of geochemical analysis can be used to develop site-specific criteria for the identification of potential acid generating rock types. Paste pH is a simple, rapid, and inexpensive screening tool that indicates the presence of readily available NP (generally from carbonate) or stored acidity. The outcome of the test is governed by the surficial properties of the solid material being tested, and more particularly, the extent of soluble minerals, which may provide useful information regarding anticipated mining-influenced water quality. For example, acidic paste pH values in combination

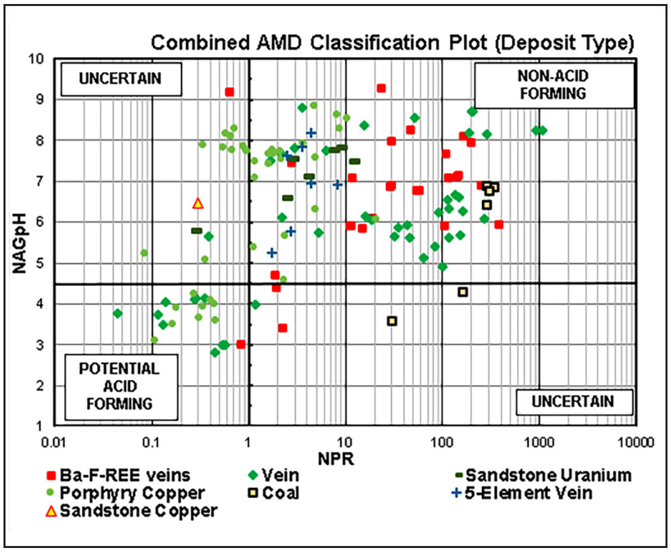

Figure 10. Acid Rock Drainage (ARD) plot of waste rock pile at mines examined during the NMBGMR mine wastes project

with elevated sulfate sulfur generally suggest the presence of acidic sulfate salts that potentially could cause short-term or long-term water quality issues.

PRELIMINARY CONCLUSIONS

A sampling protocol has been developed that can estimate the chemical composition of mine wastes, including low-grade stockpiles, mine waste rock piles, tailings, and slags. Larger mine features are divided into areas for sampling. Composite samples are collected from cells within the sample areas and homogenized into a single sample. Elevated critical minerals are found in some of the mine features in New Mexico and these features should be evaluated for potential re-mining. The critical minerals are dependent upon deposit types. Possible re-mining of mine wastes could clean up these sites and pay for reclamation.

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24-044

Geochronology and Critical Mineral Potential of Selected Laramide Porphyry and Related Deposits in Southwest New Mexico

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ABSTRACT

Southwestern New Mexico is part of a large belt of Late Cretaceous to Eocene copper porphyry deposits found in Arizona, New Mexico, and Mexico. These deposits are the result of arc magmatism that occurred during the Laramide orogeny. Recently, attention has been brought to other commodities that can be extracted as by- and co-products, many of which are critical minerals. A new compilation of the geochronology of these deposits shows two main pulses of magmatism that produced mineralized deposits and, along with new dates by the author, shines new light on the geologic history of these deposits and the role it plays in critical mineral abundance.

INTRODUCTION

Copper porphyry deposits are some of the largest and most well-known copper deposits found in the world. They produce three-quarters of the world's copper supply, half of the molybdenum, and a large portion of the gold [1]. In addition to these primary commodities and co-products, many significant by-products are also produced from these deposits, which include Platinum Group Elements (PGEs), Te, In, Ga, Ge, Re, and others. Many of these elements are of increasing importance in the face of the coming green-energy transition, have important defense and national security uses, or are subject to supply chain issues due to the reliance on imports. As such, the United States Geological Survey has designated many of these commodities as critical minerals, while copper has been recently designated a critical energy material by the Department of Energy. Due to these reasons, copper porphyry systems have an increased importance in the future of mining, and increasing the domestic mining capability in the United States is critical.

Southwest New Mexico lies at the eastern end of the southwest Laramide porphyry belt stretching from Arizona into western New Mexico and northern Mexico (Figure 1). These deposits are responsible for a large portion of domestic copper production in the United States, and include world-class deposits. These deposits are largely Laramide in age, ranging from ~75–45 Ma [2][3]. While most of the larger deposits are well-known in age, some of the smaller deposits and prospects lack modern geochronology. This is especially important as there is overlap of Laramide and mid-Tertiary deposits in the same area, leading to some confusion as to the age and nature of some deposits. Mid-Tertiary deposits are the result of extensional tectonics, and as a result are more alkaline and have different geochemical characteristics, mineralogy, and commodities than Laramide deposits, which could have an effect on which critical minerals could be present. New and improved $^{40}Ar/^{39}Ar$ geochronology of various deposits in southwest New Mexico has settled the debate on whether some districts are Laramide or mid-Tertiary.