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Geochemistry of Critical Minerals in Mine Wastes at Hillsboro and Steeple Rock Districts, New Mexico

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ABSTRACT

Critical mineral endowment of mine wastes in two mining districts in New Mexico (Copper Flat at Hillsboro and Carlisle-Center mines in the Steeple Rock district) will be characterized and estimated. “Beta-testing” of USGS procedures was performed. Potential critical minerals at these deposits include As, Bi, Te, Zn, Co, Ni, Mg, Mn, and fluorite. pH and particle size of samples were analyzed to determine weathering and migration potential of heavy metals. Soil pH was also measured to determine the potential for Acid Rock Drainage. The pH of the waste rock piles ranged from 3.66 to 5.67 which indicates fine- grained pyrite or sulfide oxidation. The samples collected from the tailings however, showed a different range of pH, from 6.30 to 8.62, probably due to the presence of carbonates. Difference in particle size fractions and its distribution along the slope are generally influenced by natural occurrences (e.g., gravity and pre-mining hydrothermal alteration) and operational activities such as material piling or dumping. Future work includes analyses of mineralogy and particle size correlation and estimation of critical mineral endowment of these mine wastes at New Mexico.

INTRODUCTION

According to the Energy Act of 2020, a critical mineral is a non-fuel mineral or mineral resource that is crucial to the U.S.’s economic and national security with a potential disruption in its supply. Most of our electronic equipment, such as smartphones, laptops, computer chips, wind turbines, hybrid, and electric cars, etc., depend on these rare earth elements (REE) and other critical minerals. This coupled with the anticipated rise in demand for critical minerals and the potential shortage of production capacity from China and other nations has made it necessary to examine and evaluate the New Mexico mine wastes for their critical mineral and future mining potential. There are about 15,000 abandoned legacy mine features varying from shallow prospect pits to deep mine shafts in the 274 mining districts in New Mexico (NM) (including coal, uranium, metals, and industrial minerals districts). There is a need to classify these wastes to understand their composition, properly estimate the quantity, and evaluate the potential economic value. Since most of the earlier operations and exploitation were focused on precious and base metals, it would be good to now turn our attention to examine these wastes for potential critical minerals.

It is also necessary to perform paste pH tests and particle size analyses on samples collected since these factors can affect weathering and the migration of heavy metals. Acid rock drainage (ARD) or acid mine drainage (AMD) is a concern for mine waste management (Karlsson et al., 2018) and soil pH is an effective indicator for ARD.

The Hillsboro district has had over a century worth of mining history with no to little reclamation. This, coupled with Copper Flat’s porphyry copper deposit and carbonate-hosted Ag-Mn and Pb-Zn deposits makes it an interesting location for these studies (Munroe, 1999). The Carlisle-Center mines in the Steeple Rock district, west of Silver City, is characterized by a low sulfidation volcanic epithermal system which contains Au-Ag veins and other deposit types making it another interesting site for this research

(McLemore, 2000). Both sites have waste rock piles and tailings available for sampling.

The benefits of this project are to ensure prospects for critical minerals in New Mexico are not lost to urbanization, settlement, or other land use. This project would ensure that there are data and archived samples for future studies and advance research as these mine features may not be accessible after reclamation. Future mining of mine wastes that potentially contain critical minerals will directly benefit the economy of New Mexico, as well as potentially fund reclamation.

MAIN OBJECTIVES

The purpose of this project is to:

- "Beta-test" USGS procedures for sampling mine wastes.
- Determine the acid generating potential of mine waste in NM
- Characterize and estimate the critical minerals endowment of mine wastes in two mining districts in NM (i.e., Copper Flat at Hillsboro and Carlisle-Center mines in Steeple Rock district).

THE STUDY AREAS

Figure 1 shows the study areas of the mine waste project. However, my focus areas would be the Carlisle-Center mines in the Steeple Rock district and Copper Flat mine in the Hillsboro district, which are in southwestern New Mexico.

Carlisle-Center (Steeple Rock)

The Carlisle-Center mines in the Steeple Rock district, west of Silver City, are an example of a low sulfidation, volcanic-epithermal system and contain Au-Ag veins among other deposit types. Known critical minerals in the district include As, Bi, Te, fluorite, and Zn. Exploration in the district began about 1860, but production was not reported until 1880. An estimated $10 million worth of metals were produced from the district between 1880 and 1994, which includes approximately 151,000 ounces Au, 3.4 million ounces Ag, 1.2 million pounds Cu, 5 million pounds Pb, and 4 million pounds Zn, mostly from the Carlisle and Center mines (McLemore, 1993). In the Steeple Rock district, there are 6 distinct types of mineral deposits (base-metal (Ag, ±Au), Au-Ag (±base metals), Cu-Ag, fluorite, Mn, and high- sulfidation disseminated Au deposits) that are spatially related to two types of alteration assemblages (1) acid-pH (alunite, kaolinite, quartz or acid-sulfate) and (2) neutral-pH (propylitic to sericitic) (McLemore, 1993, 1996, 2000). The Center mine operated during the 1990s and further exploration occurred at the Carlisle mine during the 1990s. Both mines are flooded and have waste rock piles on the surface, which have been sampled. Tailings are also present at the Carlisle mine and have also been sampled for this project.

Copper Flat (Hillsboro)

The Copper Flat mine in the Hillsboro district, east of Silver City is an example of a porphyry copper deposit, among other related deposit types. Known critical minerals in the district include Te, As, Bi, Mg, Mn, and Zn. Copper Flat has proven and probable reserves of 45.5Mt of ore at a reported grade of 0.45% Cu, 0.14g/t Au, 2.3 g/t Ag and 0.0015% Mo. The district consists of Cretaceous andesites surrounded by Paleozoic sedimentary rocks and Quaternary alluvial fan deposits. A quartz monzonite stock (74.93±0.66 Ma) with a breccia pipe is located in the center of the district and a series of latite dikes radiate outwards from the quartz monzonite. The quartz monzonite porphyry and the latite dikes are co-genetic. Replacement deposits, which occur near the porphyry deposit, are also genetically related to porphyry deposits. The Copper Flat porphyry copper deposit consists of Cu, Au, Mo, and Ag disseminations and quartz veins in the breccia pipe. Propagating outward

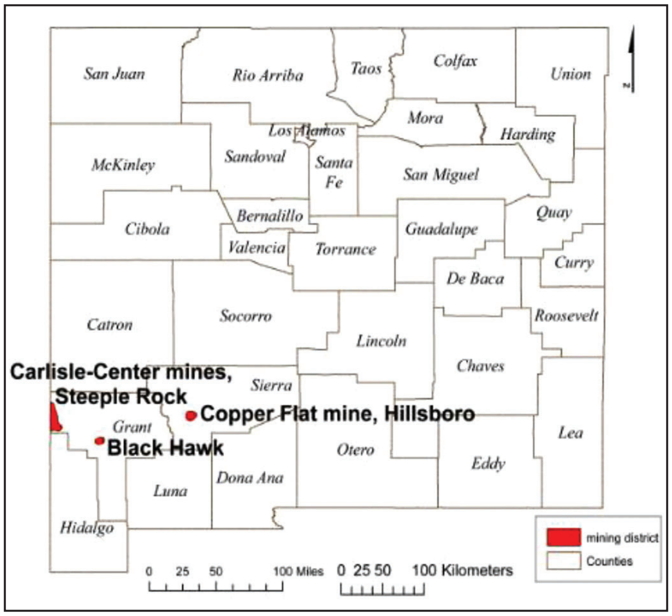

Figure 1. Location of the Copper Flat at Hillsboro, Black Hawk in Burro Mountains, and Carlisle-Center mine in Steeple Rock areas, southwestern NM

radially from the Copper Flat porphyry are Laramide veins hosted by many of the latite dikes.

The U.S. Bureau of Mines collected and analyzed selected samples from the mineral deposits surrounding the copper porphyry deposit. Chemical analyses of the veins range from 8–64,600 ppb Au, <0.2–590 ppm Ag, 40–57,337 ppm Cu, <1–475 ppm Mo, 57–8906 ppm Pb, and 138–17,026 ppm Zn (Geedipally et al., 2012). Carbonate-hosted replacement deposits are found distal from the center. Chemical analyses of the carbonate-hosted deposits range from <5–99 ppb Au, 1–<50 ppm Ag, 131–173 ppm Cu, 2–140 ppm Mo, 30–>10,000 ppm Pb, and 123–>20,000 ppm Zn (Geedipally, 2012). As much as 130 ppm Te and 3400 ppm Bi also are found.

The mine was operated for three months in 1981 and mine features include mine waste rock piles (dumps), a pit lake, acid seeps, and tailings. A low- grade stockpile, mine waste rock pile and tailings have been sampled.

METHODOLOGY

Additional sample techniques developed by USGS staff, the BLM (Bureau of Land Management, 2014), USGS, and EPA standard methodologies are being used for sampling (see McLemore et al., 2024. In order to ensure that the necessary safety protocols are followed, a Site Health and Safety Plan (HASP) has been prepared. This includes the location and driving instructions to the closest hospital, the necessary personal protective equipment, site-specific hazards and how they are addressed and emergency procedures.

Data collection, general geologic mapping (GIS), sampling of waste and rock piles, laboratory studies, determination of engineering qualities by using the geologic and geochemical data to determine potential of acid production within the wastes, estimation of the volumes and tonnages of waste and rock piles, and general stability analyses of structures by physical examination and particle size analysis.

PRELIMINARY RESULTS

Paste pH

The acid base account (ABA) method was used to determine the acid generating potential of samples collected. Using the C and S concentrations and the NaGph (i.e., measured paste pH), the below formula was then applied:

$$\text{AP (kg CaCO}_3\text{/tonnes)} = 31.25 \text{ x S (\%)}$$
$$\text{NP (total C)} = 83.3 \text{ x C (\%)},$$
$$\text{NNP} = \text{NP} - \text{AP},$$
$$\text{NPR} = \text{NP/AP}$$

Paste pH conducted on the waste rock piles ranged from 3.66 to 5.67 which indicates oxidation of fine-grained pyrite or other sulfides. The samples collected from the tailings however showed a slightly different pattern in pH, ranging from 6.30 to 8.62, probably due to the presence of carbonates. Figures 2 and 3 are ARD plots showing the acid forming potential of the various samples collected from the mine tailings and waste rock piles. Some samples from the tailings in copper flat mine in Hillsboro falls in the "uncertain" and "potential acid forming" quadrants and should be treated with care. Most waste rock pile samples, however, fall within the non-acid forming field and may be suitable for backfilling. All tailing samples from Steeple Rock fall

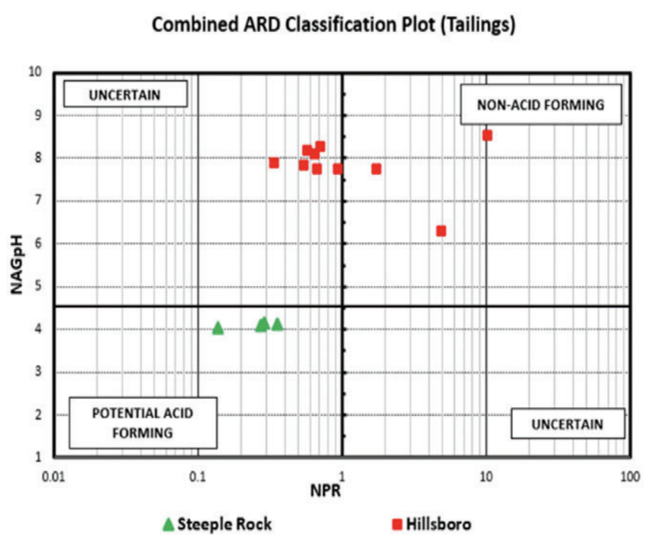

Figure 2. Acid rock drainage (ARD) plot of tailings at hillsboro and steeple rock

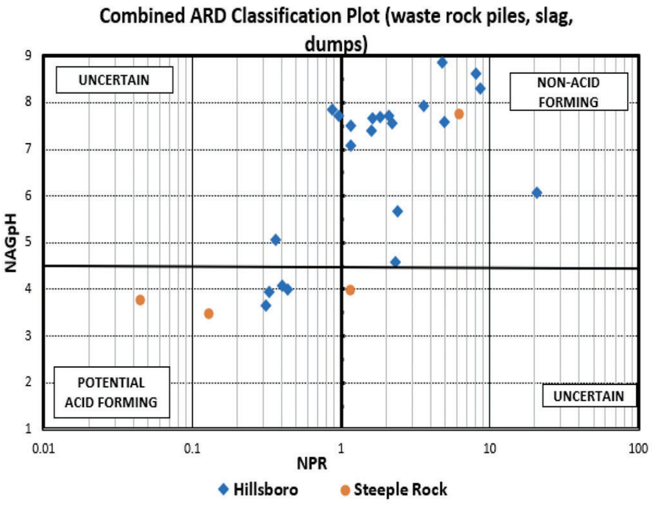

Figure 3. Acid rock drainage (ARD) plot of waste rock piles at hillsboro and steeple rock

in the "potential acid forming" and have a high chance of potential acid mine drainage.

Particle Size Analysis

Figure 4 shows the results of particle size analyses done on samples collected at the top, middle and bottom of the waste rock pile. The curve shows fine particle fractions are evenly distributed along slope of the waste rock pile. Also, the coefficient of uniformity (Cu) and the coefficient of curvature (Cc) which is used to classify soil was computed accordingly. The average Cu and Cc values are 6.3 and 0.7 respectively, which indicates the samples are poorly graded sand. Figure 5 is a plot of particle size distribution of composite samples from Carlisle- Center, which indicates samples collected in the area range are well graded sand.

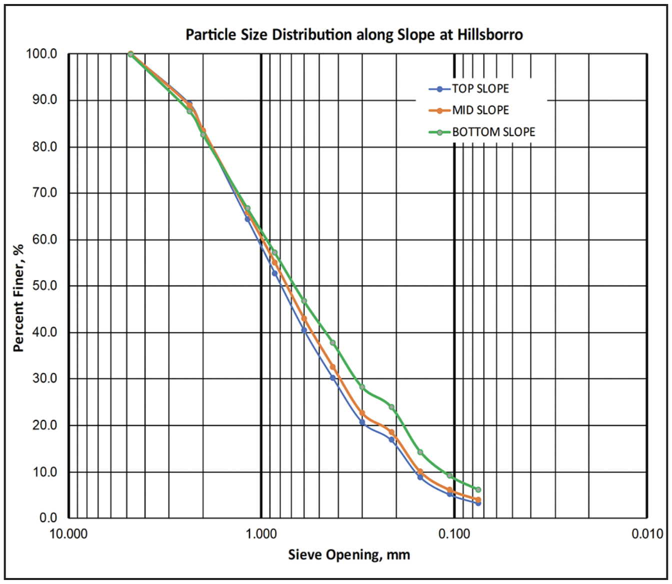

Figure 4. A plot of particle size distribution along rock pile slope at Copper Flat mine

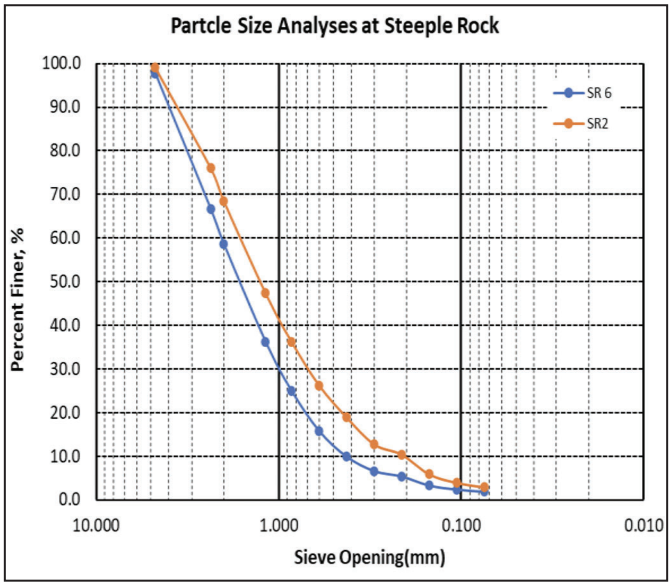

Figure 5. A plot of particle size distribution of composite samples from Carlisle-Center

X-Ray Diffraction (XRD)

XRD was conducted on samples to better understand the mineralogy. In this paper we show a few interesting plots from XRD analysis. Figure 6 and 7 shows XRD spectra of composite samples from Hillsboro and Steeple Rock respectively. Mineralogy is summarized in Table 1.

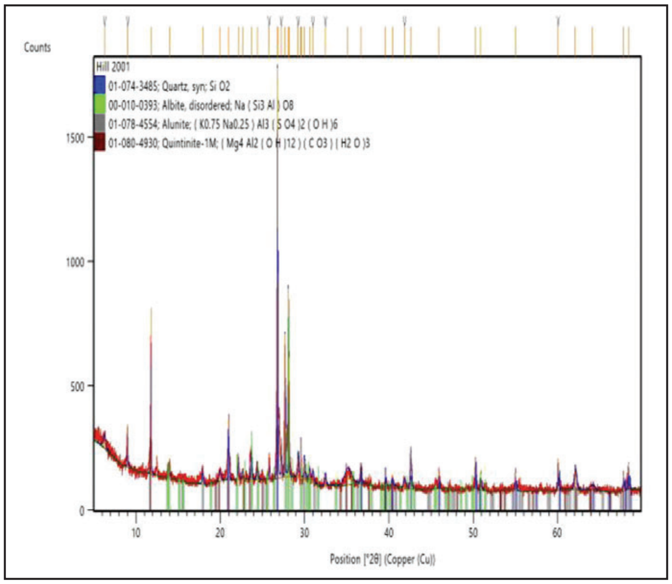

Figure 6. XRD spectra of SR 6 (composite sample)

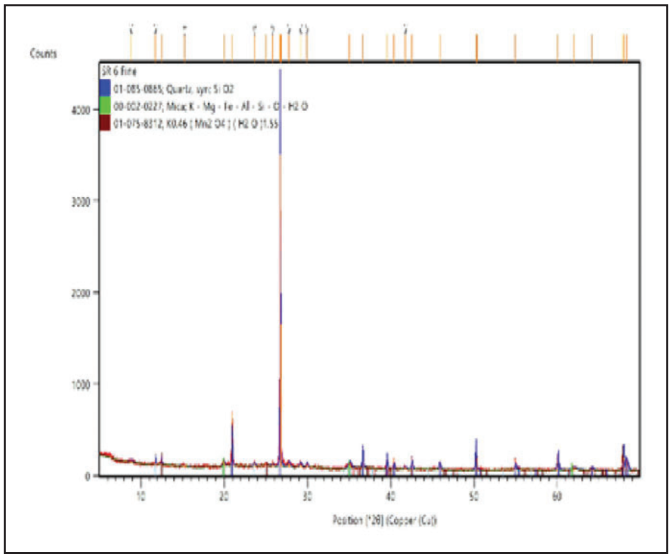

Figure 7. XRD spectra of Hill 2020 (composite sample from tailings)

Table 1. District's mineralogy

Location	Mineralogy
Copper Flat Mine, Hillsboro	These samples consist of mostly rock forming minerals (i.e., quartz, K feldspar, albite, and some micas/ muscovite). They also include clay minerals commonly seen are the OH clays (e.g quintinite and hydrotalcite), altlered micas (eg.illites) and smectitites. Alunite is present, which is an indicative of acidic precipitation of SO4 and calcite which was present in samples from tailings.
Carlisle- Center, Steeple Rock	Most samples were mostly quartz and minor micas. The slighlty darker samples were rich in Mn oxides. Another interesting mineral found in some of the samples which were typically yellowish in color was beaverite which is a Pb-Fe-Cu sulfate.

Geochemistry Analysis

Geochemical analysis was done by the USGS. Figure 8 shows a chondrite-normalized REE plot of samples from Copper Flat and Carlisle-Center mines. The results show light REE enrichment of up to 200 times chondritic values at Hillsboro, however thisit is not attractive for economic recovery. Hillsboro samples have higher light REE enrichment as compared to Steeple Rock samples.

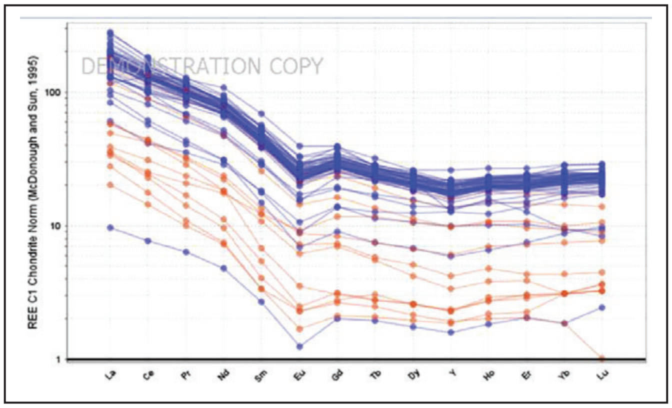

Figure 8. A chondrite-normalized REE plot (McDonough and Sun, 1995) of samples from Copper Flat (in blue) mine and Carlisle-Center (in orange)

Endowment

Mineral endowment generally refers to the quantity of minerals present in a specific region irrespective of whether it has been discovered or not (Davis et al, 2020). We computed for critical minerals (i.e., Bi, Co, Cu, Ga, Te, Zn, Zr) endowment in kilograms for the tailings at Copper Flat mine with a volume of approximately 518753 m^3 and an assumed bulk density of 1430 kg/m^3. The minimum, maximum, and mean endowment was then obtained by multiplying the minimum, maximum, and mean concentrations of these critical minerals by the mass of tailings. See the results in Table 2. It is also important to note that these endowment values only help us to understand the potential availability of these minerals and do not necessarily mean a measure of resources or reserves.

Table 2. Critical mineral endowment

Endowment (kg)	Min	Max	Mean
Bi	964	1,706	1,276
Co	4,228	7,937	6,880
Cu	256,669	574,166	402,918
Ga	13,353	15,578	14,243
Te	178	363	302
Zn	28,931	53,411	44,027
Zr	174,327	210,676	194,393

PRELIMINARY CONCLUSIONS

The S present in samples from Carlisle-Center mines are mostly acid forming and can potentially cause acid mine drainage which can dissolve other minerals. Samples from Copper Flat that are nonacid forming may be used as back fill material.

Most of the waste rock pile at Copper Flat is characterized by mostly relatively coarse sand fraction, which is cohesionless, however the presence of calcite and gypsum provides a cementing bond, which may improve slope stability. Further geotechnical analysis is recommended to understand the slope stability conditions better.

Future work would be focused on analyzing geochemistry of different particle fractions to ascertain any existing correlation between mineralogy and particle size. Also, bulk density test should be conducted to compute for the mass of mine waste piles

and thus estimate the critical mineral endowment of the studied mine waste areas.

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