24-041

Fleet Efficiency Evaluations for Optimal Cycle Times Through Various Blast Designs in the Sorted Geological Formation Under Constrained Operating Conditions

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ABSTRACT

This paper examines the desired blast fragmentation results associated with mining fleet performance at Sidney Quarry of Pike Industries, A CRH Company by reducing cycle times and hauling less oversize material generated from the blast to the crusher to increase the overall plant throughput. We are constrained with blast patterns due to the poorly sorted and fractured seams in the quarry, which is angled at 35° NE and dipping at 80° and runs parallel to the Interstate-95 highway on the east of the quarry boundary about 600 ft, making it challenging to alter the blast patterns for optimal yield.

We evaluated multiple relationships between blast patterns in conjunction with loader diggability. Results analyzed include the digging hours, fleet cycle times, and the fragment size with the optimized blast design through 3GSM software to arrive at the optimal yield to maximize the crusher throughput.

Our primary objective is to focus on safety with efficient cycle times and clean floors & clean face generation for better operational efficiencies. Secondly, to optimize the crusher yield which is an integral part of quarry operation. Further, this paper provides the utilization of 3GSM blasting techniques in quarry applications with computer vision fragmentation analysis and VizaLogix, a fleet management software to analyze the cycle times sampling.

INTRODUCTION

The Sidney Plant, which produces ~650k tons/year (590k metric tonnes/year) supporting its vertically integrated asphalt plant for federal and state DOT projects, and local communities, is in Kennebec County, Maine, approximately 10 miles (18 kilometers) north of the state capital Augusta, and adjacent to the major east coast highway Interstate-95.

The stone is mined from the quarry by using conventional hammer drilling and non-electric blasting techniques and transported to the three staged crushing/grinding plants by a truck-loader mining fleet. A total of approximately 65k tons (59k metric tonnes) of waste material is mined each year at about a 0.1-unit waste to 1.0 unit of production rock. Quarry waste and overburden stripping ratios are expected to increase in the future and an optimal drill and blast program is very important to keep mining costs and productivity meeting the goals. A total of approximately 60 percent of the raw ingredients used in the Asphalt plant come from this quarry.

GEOLOGY

The rock type in the Sidney quarry is a Silurian rock of the Waterville Formation (Oshberg, 1968). The Quarry and the asphalt plant are mainly interested in mining gray pelite and quartzite wacke for aggregate production. In the future, the plan is to also mine the gray limestone (part of the formation) with 1-inch thick phyllite (Oshberg, 1968) interbedded in lower lifts on the west side of the quarry.

Skow is the name of the lowest lift and is currently under development. It gets its name from the contact line where the two stone units are mined together and named after a former Pike employee. The current pit consists of one bench with varied terrain, leaving the uneven bench height being 50–85 feet (15–25 meters).

The rock mass is extensively faulted and fractured. The fractures can be readily observed in the quarry highwalls.

Care must be taken when mining through these tall benches and thin beds angled at 35° NE and dipping at 80° into the quarry floor until it reaches a more manageable bench height. Although the bench has no cap (weathered) rock, the thin beds have massive blocks and tend to topple after each blast depending on the blast egress (quarry advancement). The muck pile will contain excessive boulders if this is not considered in the blast design.

A review of the geology in the field revealed the need to classify rock types based on rock properties (strength/density), chemistry (silica), and structure (bedding/fracturing) for drill and blast design criteria. Blasting this rock type will require a unique drill and blast design based on the rock characteristics to maximize fragmentation and reduce drill, blast, mining, and crushing costs. The optimization study under evaluation includes diggability and fragmentation for plant efficiency.

EQUIPMENT

With the current mining requirements and the production rate, most drilling is done with a one-top hammer drill and operated on a day shift. Blasted muck is loaded with a wheel loader into two haul trucks. The approximate haul distance from the blast zone to the primary crusher is 1750 feet (533 meters) with an average round trip being 3,500 feet (1,066 meters).

The primary crushing system opening consists of a Lippmann 36-inch x 50-inch jaw crusher. The crushed rock (6-inch & minus) is fed onto a 48-inch belt conveyor and carried 200 feet (60 meters) to a transfer point with an elevated conveyor. The transfer point has a screen system that makes a base product if/as needed and conveys it out to a surge pile. The primary system's maximum capacity is 500 tons (450 metric) per hour. The equipment listed below is either brought in as a rental or under contract to use in the quarry.

Table 1. List of equipment used in the quarry

No.	Equipment	Model	Capacity
1	CAT Loader	988K	9 yd^3 (7 m^3)
1	Volvo Excavator	380	2.5 yd^3 (2 m^3)
2	CAT Haul Truck	770G	35 Ton (32 metric tons)
1	Epiroc Drill	Tier T40	4–5.5-inch bit diameter
1	Komatsu Hammer	PC 360	Exc. Rock Breaker

DRILL & BLAST OPTIMIZATION

Blasting is contracted to Austin Powder Company. The blaster in charge reports to the quarry management on a regular basis. Blasting occurs approximately twice per month. Shots average 35,000 tons (32000 metric tons). The blaster meets with the driller, engineer, and site supervisor to discuss the conditions of the shots. The blaster oversees every aspect of the blast, such as laying out the drill pattern, designing the delay sequence, choosing the explosives, checking the weather conditions, detonation, and seismic monitoring. The site supervisor will guard the area and the quarry engineer will propose the new design by auditing the shots and sharing the mine plan reconciliation.

A typical blast consists of a three-row staggered pattern; occasionally we may elect to use four rows for the production bench. Shots are delayed between holes down the row and progressed between rows. This allows good mixing action down the row and allows the first row to move out, so the second row sees only its own burden. Satellite holes are drilled as needed to break caprock (weathered) or any heavy burden present on the bench.

As the primary objective for the organizational leadership is "To develop, implement, and continuously improve a measurable drilling and blasting system that will optimize the total mining and crushing costs while ensuring compliance to safety and maintaining or reducing the environmental impacts."

Prior to this optimization study, the drill and blast Base Case in Sidney quarry was a 9 feet x 11 feet (2.75 meters x 3.3 meters) burden to spacing or a 10 feet x 10 feet (3 meters x 3 meters) burden to spacing square patterns drilled with a 4-inch diameter hole on a 65–75-foot (20–23 meter) bench with 3 feet (1 meter) of sub-drill and 15 ft (4.5 meter) of stemming. Non-electric detonation and gassed emulsion blasting agents were used at a powder factor of 1.34 lbs./yd3 (0.8 kg/m3). Drilling and blasting operations were contracted. The drilling used top hammer drill rigs with 4-inch drill bits with carbide inserts.

The current bench is approx. 70-foot (21 meters) tall, drilled with changes from 4-inch diameter boreholes on 10 feet x 10 feet (3 meters x 3 meters) to a 5 and ½ inch diameter 10feet x 12 feet (3 meters x 3.6 meters) burden to spacing respectively. Gassed emulsion blend is the primary explosive resulting in a loose muck pile with good loader cycle times. Most blasts egressed towards the north, as it is almost perpendicular to the quarry geology, and tends to have drill deviation of 4 feet.

Each shot was monitored to determine loader and crusher productivity and compared to the base case scenario to ensure that fragmentation remained optimal and did not affect productivity, used sensitized emulsion blended with ANFO providing an excellent performance to meet the requirements. An evaluation and comparison of the energy values of different percentages of gassing agents were conducted as a preliminary step to the formulation of the different blast designs, varying the product densities. The blaster-in- charge lets the product gas after loading the hole, to attain a 15% product raise to reduce the density from the normal 1.33 g/cc to 1 g/cc (Austin Powder, 2022 Revised).

The evaluated scenarios changed the drill pattern from a square 10 feet x 10 feet (3 meters x 3 meters) to staggered patterns of 10 feet x 11 feet (3 meters x 3.3 meters) and 10 feet x 12 feet (3 meters x 3.6 meters) with 4-to-5.5-inch diameter blast holes.

Figure 1. Highwall face looking at the east

METHODOLOGY

Modelling

The 3GSM BlastMetrix software is a scientific tool used across CRH operating companies to design, model, or audit the blasts to help implement the drill and blast continuous improvement program. The 3D models from aerial imagery are the efficient valuable data source for designing, documenting, and quantifying surface blasts (Andreas Gaich M. P., 2020). With this tool, we analyzed the minimum burden on three-dimensional view and, more importantly, the inter-hole distances at the designed floor plane, which has been a key for loader diggability issues.

Explosive properties such as density, velocity of detonation, energy values, and energy partitioning were calculated for the type of explosives used. During the blast, drone photography/videography and seismographs were used to document the detonation to assist in developing the base case. The post-blast muck pile was then surveyed to determine the heave results. A fragmentation analysis was also performed.

This software modeling package deals with new methods for automatically designing surface blasts and improved quantification of the muck pile, both together aiming at a procedure that allows a stepwise, reproducible improvement of the blasting works. The main data source is aerial imagery from the DJI Phantom 4 Pro drone that generates a comprehensive 3D model from image processing algorithms. The following sections discuss the optimized design techniques using this tool.

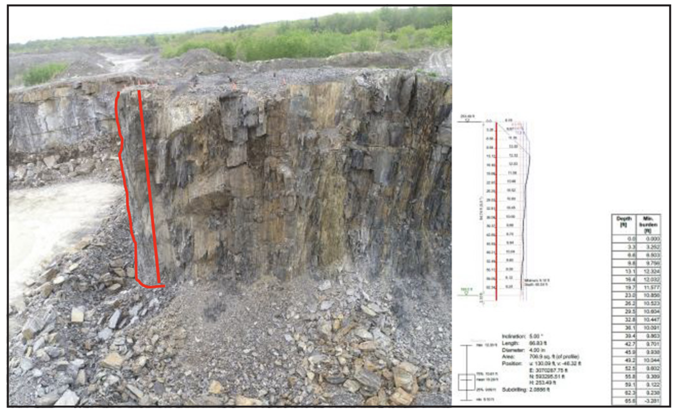

Figure 2. Minimum burden for the highwall face looking towards the north

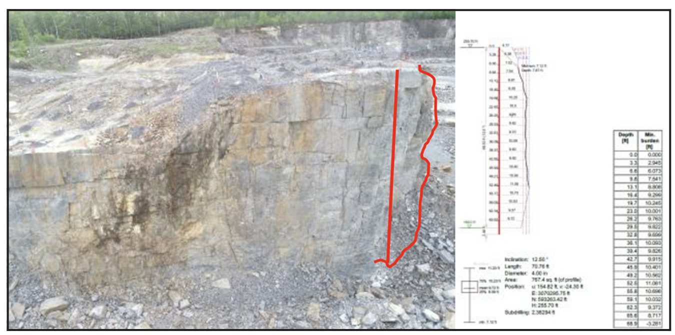

Figure 3. Minimum burden for the highwall face looking towards the east

Design Process

This process includes understanding the blasting results between both the traditional profiles and 3D modeling minimum burden acquired. The key focus in the design process is keeping the two main KPIs in the plan: fragmentation and volumes (which relate to the powder factor). Figure 1 shows the highwall face looking towards the east, where the mine development plan is reconciled for applying various blast design scenarios. Below case study is representing one of the optimized case of 4 inch blast hole.

A minimum burden profile shown in Figure 2 looking at the highwall face towards the north, and Figure 3 shows towards the east. This geometric entity consists of a borehole on the corners or open face, to fulfill the minimum burden criterion at best (i.e., minimum burden equals design burden) or vice versa (Andreas Gaich M. P., 2020). The software also has an algorithm capable of aligning boreholes

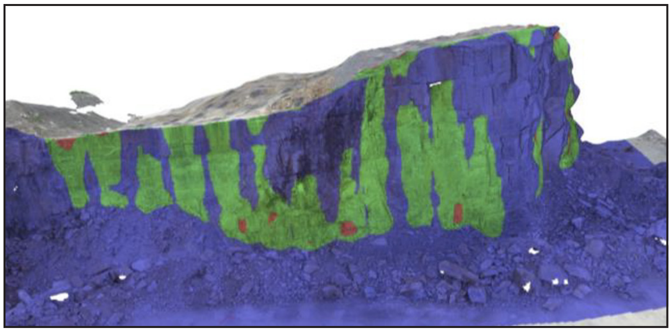

Figure 4. Minimum burden for the entire highwall face (optimized) looking towards the east. Legend. Green-10 feet (3 meters), Red – 9 feet (2.7 meters), and Blue – 11 feet (3.3 meters)

in a way that they follow the crest automatically while still preserving the minimum burden (Figure 4).

Regardless of whether the design basis is an automatic or traditional method, a unique digital record of the design pattern and the blast site is of prime importance for getting reproducible conditions. A collaborative loop is created for quantifying the results of a blast, changing the design, quantifying the next blast, and comparing it with the previous result. This repeated application and objective comparison allow successively to improve blasts, both economically and from a safety aspect.

OPTIMIZED BURDEN FACE AND VOLUME DETERMINATION

Operations general volumes of interest for production schedule purposes include:

- Volume of the muck pile (Flight to be performed before and after digging the muck pile) and
- The corresponding bank volume (Flight to be done before the blast and can generate volumes).

Volumes are determined directly from 3D models using BlastMetrix. The prerequisite is that they share a common coordinate system (NAD83 state plane). The difference between the 3D models then reflects the volumetric change. Another point is taking the images for the 3D models at the right time. For example, all material from a previous shot is already removed and an unobstructed view of the bench face is possible. Figure 5 shows 3D modeled volume measurements for the pattern yield. The obtained bank volume is approx. 34,500 tons (31,300 metric tons) (14,500 yd^3 or 11,000 m^3). On the other side, it showcases the bank volume that results from comparing 3D models of the bench face pre- and post- blast.

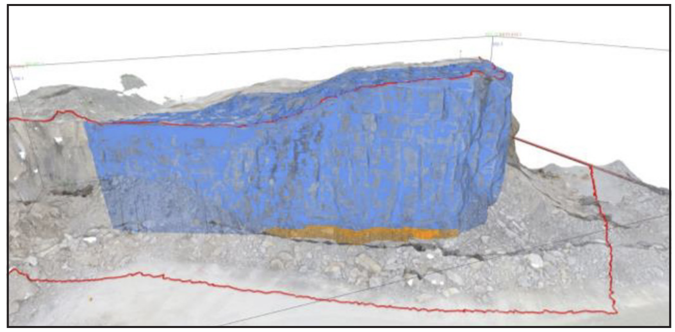

Figure 5. Volume calculated in the BlastMetrix with the designed pattern

Muckpile Volumes

As part of CRH America's best practices, Pike gathered the volume from the 3D modeled volumes rather than the typical blast volume calculator provided by the blasting contractor (ISEE Blasters Handbook, 18th Edition, 2020).

$$\text{Blast Volume} = \frac{\begin{pmatrix}\text{Burden} \times \text{Spacing} \\ \times \text{Face Height} \times \text{No. of Holes}\end{pmatrix}}{27} \quad (1)$$

The volume calculated from 3D model is highly accurate providing us with more accurate KPIs, including the powder factor and blast cost per ton.

FRAGMENTATION ANALYSIS

The fragmentation analysis was performed using BlastMetrix, transforming the images into a 3D distribution of the expected fragmentation. The entire muck pile was modeled, Figure 6 and Figure 7 show the resultant 3D models after particle detection and distribution curve. Particles are colored according to their size, highlighting

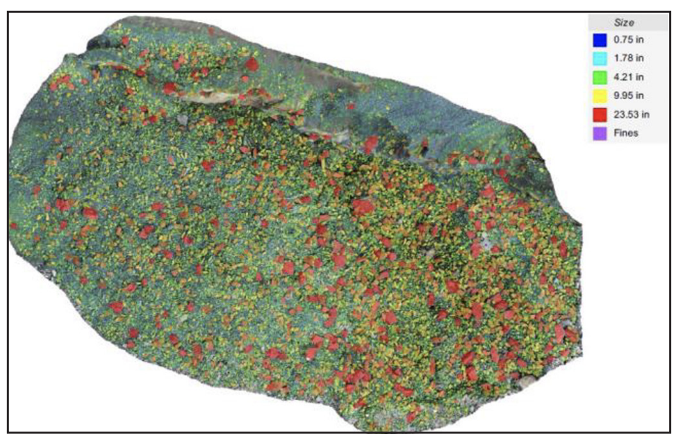

Figure 6. 3D fragmentation model built using BlastMetrix

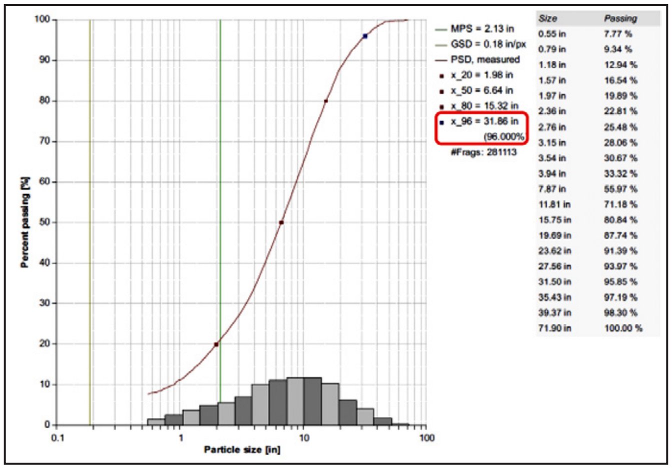

Figure 7. Muck pile particle distribution curve generated for P80; highlighted the percentage of passing the material through the primary stage crusher

any oversize material. Note that such analysis provides only those particles that are visible on the surface. However, gathering the data during mucking becomes more observable

CYCLE TIMES KPIS

Significant capacity balancing efforts were put in when evaluating cycle times. We utilized vizalogix software to incorporate GPS telematics to capture cycle times. Figures 8 & 9 shows the improved TPOH and reduced cycle time curtailing the overall mining efficiency.

Vizalogix provided a more accurate view of cycle times in quarry operations by evaluating long-term data trends helping fleet studies within Pike's day to day site productivity management. Operators can work naturally without feeling constantly observed, enabling the collection of authentic data sets. The platform seamlessly integrates all data into customizable dashboards. Vantage Point's predictive analytics facilitates informed decision-making by combining data streams from telematics (Vantage Point, 2023).

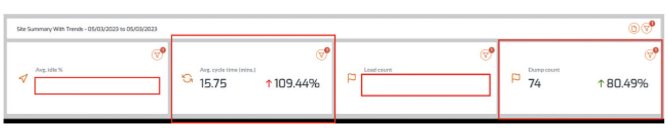

Figure 8. Cycle time and dump count before blast optimization

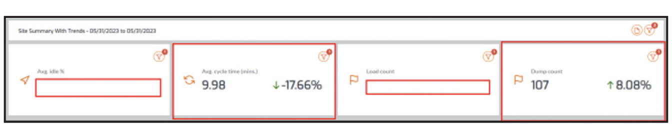

Figure 9. Cycle time and dump count after blast optimization

KPIS VALIDATION

Pike utilize PEAK software (Plan, Execute, Analyze, and Know) for the KPIs validation, the system visualizes selected KPIs over time and allows the correlation of different parameters according to selection. These include but are not limited to Powder Factor, Blast Pattern Matrix, and Cost per Ton. Fragmentation analysis is plotted against the crusher opening size. Another approach is to keep the S/B ratio fixed but adapt the powder factor and plot it against P50 and P80 to reveal better loading situations. So, the suggested blast optimization procedure is based on tracking several KPIs, adapting design parameters and quantifying the result.

As a part of this study, we included the loader operator, foreman, and crusher operator's feedback regarding the diggability of the muckpile and observations of Primary and Secondary Crusher throughput. It was determined that the modified designs and resulting fragmentation has a 10% to 12% increase in crusher throughput. Our goal is to achieve an "optimum" muck pile that greatly influences overall mining and crushing costs. This target has not yet been reached but the quarry management has been thriving to improve one KPI at a time.

The program has been developed and implemented at Sidney Quarry operation and has been followed across CRH Americas. The muck pile goals were purposely set high to give a picture of what the "optimum" muck pile might look like. The blaster, engineer, and quarry manager evaluate each blast immediately after detonation. PEAK KPIs data is considered when deciding how to lay out each subsequent blast.

Explosives costs have varied depending on the type of experimentation being conducted but have generally remained consistent. Crusher throughput is a key parameter for assessing the blasting performance at a given site, and it has steadily increased in the last three years shown in Figure 10.

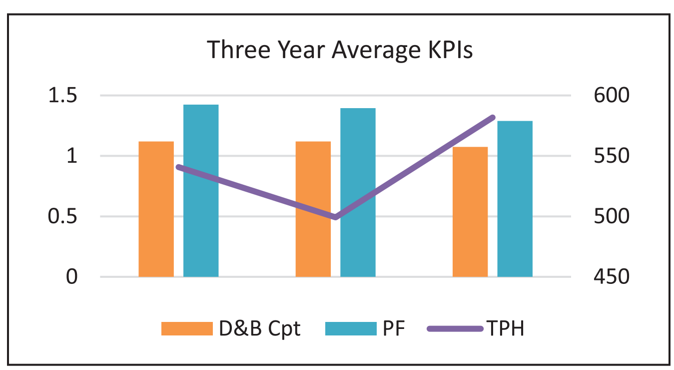

Figure 10. Avg 2022, 2021 and 2020 Resp. KPIs Correlation Chart

CONCLUSIONS

The study accomplished approx 15% reduction in drill & blast costs and increased manpower utilization by:

1. Reducing the cycle time by an average of 5 min yielding more truck dump count at the crusher dump.
2. Optimization of the Base Case by increasing pattern size from a square 10 ft. x 10 ft. (3-meter x 3 meter) drill pattern to a staggered pattern size of 10 ft. x 12 ft (3 meters x 3.6 meter).
3. Increased pattern and hole diameter size allows the use of two drills 4-inch on the top bench and a 5.5-inch drill on the new bench.
4. Use of shot service fee as a cost-effective alternative to the contractor loading and blasting.
5. This shot service fee lets the contractor to drill continuously and keep drilling for subsequent shots with either drill available, increasing drill productivity and efficiency.

The entire improvement program has only recently been fully implemented. However, it has become apparent that small improvements in shots have good returns in overall mine costs. All costs associated with drilling are included in this analysis, including labor, maintenance, fuel, lubricants, supplies, and depreciation. The fixed costs have declined steadily since 2020, however, the variable costs went up with global inflation.

As a result, Pike plan to spend the capital on both the processing and asphalt plants upgrades to meet the needs of local markets or support existing customers. Because of these reductions in cost, the Quarry continues to deliver production rock to the plant at lower cost despite having to mine ever-increasing overburden and tailings.

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24-042

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