The Bulk Sorting Potential Of The Cumo Deposit In Idaho, Usa

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ABSTRACT

The CuMo project in Idaho, USA, is a large scale, low-grade copper-molybdenum porphyry deposit. The mineralization style and early testing of drill core for particle sorting both indicated that there was sufficient heterogeneity in the CuMo mineralization to warrant further investigation for mineral sensing and sorting. This heterogeneity was verified through analysis of drill core data such that bulk sorting could be considered for CuMo. The bulk sorting envisioned for CuMo is conveyor-based, which allows for high-capacity sorting by multi-stage, multi-stream splitting. Three streams come out of the bulk sorting process – a waste stream, a mill feed stream, and a middlings stream that is further processed by particle sorting. The paper describes the analysis techniques for assessing bulk sorting that allow prediction of sorting mass pulls and grade enrichment at the block model level. Study results are shared. Benefits and limitations of the approach are discussed.

KEYWORDS

Mineral sorting, Bulk Sorting, Particle Sorting, Heterogeneity, Preconcentration

INTRODUCTION

The CuMo project in Idaho, USA, was recently the subject of a preliminary economic assessment (PEA) (SRK, 2019) where preconcentration techniques were assessed and incorporated into the study. New methods of assessing mineral deposit heterogeneity were explored, ultimately leading to an innovative approach to assess and predict the outcomes of bulk sorting. This paper describes these analysis techniques as well as preliminary results for the CuMo project.

CUMO GEOLOGY

The CuMo project is located 37 miles (60 km) northeast of Boise, Idaho, USA., in the Grimes Creek Mining Camp where extensive logging and mining has occurred since the 19th century. Molybdenum-copper-silver mineralization was first discovered by Amax Exploration in 1963, following up anomalous stream sediment samples. Amax appropriately named the deposit CuMo after its main component metals – copper (Cu) and molybdenum (Mo).

The CUMO deposit is typical of large, dispersed, low-grade molybdenum ± copper porphyry deposits that are associated with hybrid magmas typified by fluorine-poor, differentiated monzogranite igneous complexes. The local geologic setting is a series of Tertiary igneous rocks ranging in composition from quartz monzonite to rhyolite porphyry that intrude the Idaho Batholith. All phases appear to be co-magmatic and contain molybdenum mineralization. The deposit appears to be located at the intersection of two regional structural trends: a northeast structural trend, characteristic of the trans-Challis fault system, and an east –west trend that contains a Tertiary dyke system. Faults and mineralized structures identified to date dominantly trend to the northeast.

Mineralization on the CUMO property occurs in fractures and veinlets developed within various porphyry units and surrounding country rock of the batholith. The mineralization is associated with quartz monzonite porphyries, but high-grade sections often occur within the older Idaho Batholith quartz monzonite adjacent to or within porphyry bodies. Molybdenite (MoS_2) occurs in quartz veins, veinlets and vein stockworks, with individual veins ranging in size from hairline fractures to banded veins up to ten centimeters in width. Chalcopyrite occurs in the upper portion of the deposit and is associated with fracture-controlled secondary biotite alteration and dark chlorite-epidote-magnetite +/- pyrite alteration. Molybdenite mineralization generally becomes stronger at depth where the secondary biotite alteration gives way to subtle K-feldspar alteration. The vein or fracture-controlled mineralization is visibly evident in drill core and is one of the reasons why mineral sensing and sorting was initially contemplated for CuMo.

Four distinct metal zones are present within the deposit. Interpretation of down-hole histograms for Cu, Ag and Mo suggests the metal zones are part of a single, large, concentrically zoned system with an upper copper-silver zone (Cu-Ag), underlain by a transitional copper-molybdenum zone (Cu-Mo), in turn underlain by a lower molybdenum-rich zone (Mo), and an intense potassic alteration zone (MSI) that underlies the Mo zone.

PARTICLE SORT TESTING

To test the amenability of the CuMo deposit to sensor-based sorting, particularly particle sorting, rock-by-rock bench scale testing was undertaken. Two sampling and testing campaigns were completed: the first in 2015 on 100 drill core samples, and the second in 2016 on 400 samples. Samples were cleaned with high pressure air and then scanned on an x-ray fluorescence (XRF) device, followed by an electromagnetic device (SRK, 2019). X-ray readings for molybdenum (Mo) and copper (Cu) were recorded for each sample, and then the samples were sent to a laboratory for assaying of the Mo and Cu content.

The results of the testing in the second campaign are provided in Figure 1. This shows the recovery of Mo and Cu as a function of sorting mass pull. The sorting mass pull is the cumulative weight percent of test samples sorted from highest XRF value to lowest for each of Cu and Mo. The metal recovery is the cumulative weight percent of the assayed metal content of those samples.

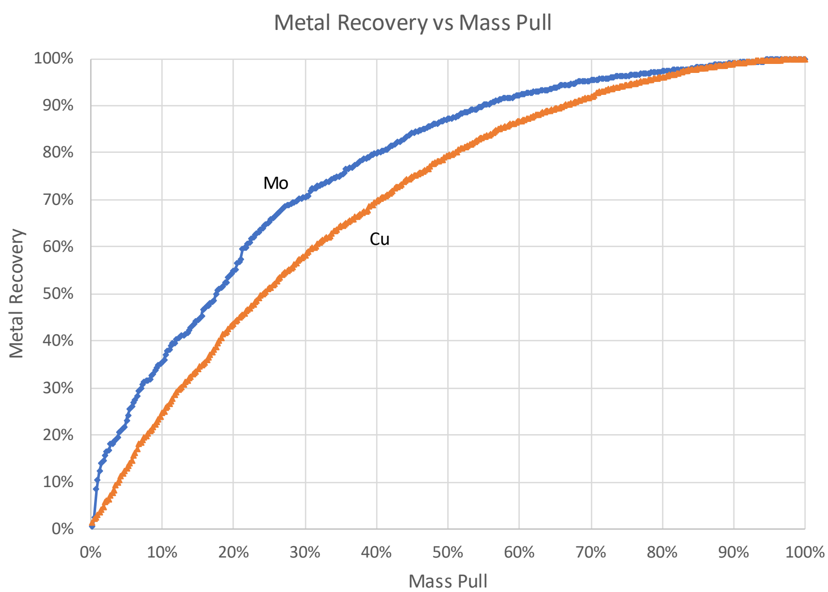

Figure 1 – Rock-by-rock independent sensory testing results

The results indicate that both Mo and Cu are responsive to sorting, particularly Mo. At 40% mass pull (as determined by XRF sensing), about 70% of the Cu is recovered and 80% of the Mo is recovered.

However, being a polymetallic deposit, where both Cu and Mo can co-exist, it is not possible to independently sort for the metals according to the relationships in Figure 1. Consequently, a recovered value parameter (RCV) is calculated from the Mo and Cu grades as well as their respective metal prices and mill recoveries. Similar to a net smelter return calculation, this allows for valuing the deposit, applying cut-offs, and in this case, setting a sort accept/reject value. In ranking the samples by RCV however, it was observed that the Cu recoveries suffered, not achieving 100% recovery across a broad range of mass pulls.

Consequently, a simple co-variate analysis was undertaken whereby a limit on Mo grades was applied to the samples to split them into two groups – one, Mo-poor and the other, Mo-rich. The Cu recovery-mass pull relationship (using Cu XRF grades) was applied to the Mo-poor samples, while the Mo recovery-mass pull relationship (using Mo XRF grades) was applied to the Mo-rich samples. It was found that a limiting Mo grade of about 0.020-0.025% gave the best results, balancing the upgrading of both Mo and Cu. Figure 2 shows the metal recoveries in two groupings. Above 200 ppm (0.02% Mo) is called Mo-rich and below 200 ppm is Mo-poor. As expected, recoveries for Mo are better in the Mo-rich group and for Cu in the Mo-poor group.

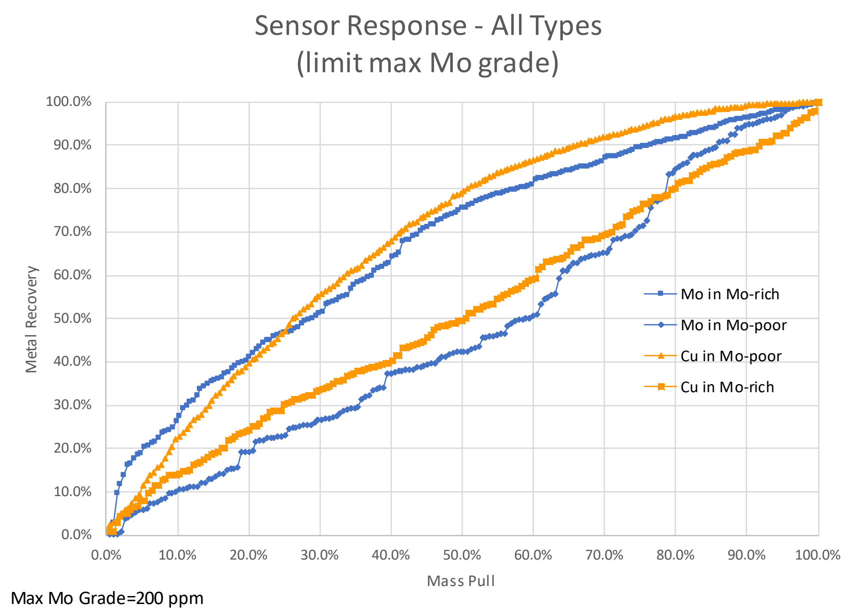

Figure 2 – Co-variate analysis, limiting Mo grades

HETEROGENEITY

The success of the particle sorting test program, combined with recognition that currently available particle sorting technology on its own would not be able to handle the processing rates envisioned for CuMo, prompted further investigation into the viability of bulk sorting. This required assessments of CuMo heterogeneity.

To assess the heterogeneity of the CuMo deposit, exploration drill hole data was analyzed. Two approaches were undertaken:

- Observing the effect of measurement scale on different heterogeneity parameters
- Assessing the relationship between bench composite grades and sample grades that make up those composites

Heterogeneity and Scale

Analysis of exploration drill core data at varying aggregation lengths gives an indication of how heterogeneous a mineral deposit is at different scales. For CuMo, the author assessed the mineralized zones

– oxide, Cu-Ag, Cu-Mo, and Mo. The drill holes were de-surveyed and sample intervals were assessed in the vertical direction – a proxy for mining bench height. Aggregation intervals of increasing length, centered on the sample intervals, were assessed for different parameters as presented in Figure 4 and Figure 5.

One way to look at the impact of scale on heterogeneity is to calculate the distribution heterogeneity for different aggregation lengths. Distribution heterogeneity for a dimensionless lot (Pitard, 1993) was used here. It is a unitless parameter relating mass and grade of a group (aggregation) to the overall population or lot. It is apparent in Figure 4 that for all mineralized zones, there is a decrease in heterogeneity with increases in scale. The OX zone is the most affected, and the Mo zone is the least impacted by increases in scale.

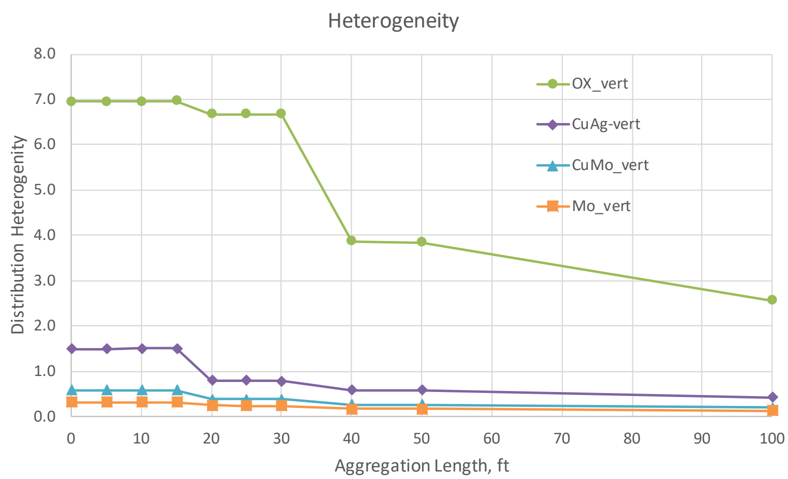

Figure 3 – Impact of scale on distribution heterogeneity

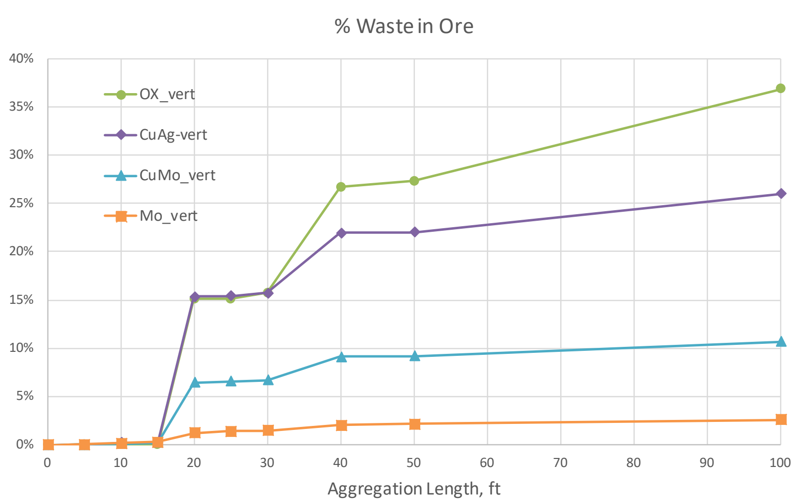

Figure 4 – Impact of scale on “Waste in Ore”

Figure 5 provides another measure of heterogeneity that is very informative. It is “waste in ore”, which compares sample intervals that are below a cut-off to aggregations in which they lie whose average grades are above the cut-off. Figure 5 shows that increasing aggregation length results in increasing waste in ore” and that such increases happen quickly, within the mining scale (e.g. 50 ft benches). However, the "waste in ore" largely flattens off for larger aggregation lengths. This suggests there is benefit to selectively mining or processing material at smaller scales to reject waste.

The main findings of this analysis for CuMo are that heterogeneity diminishes with increasing scale (or conversely, it increases with decreasing scale) and that the different mineralized zones at CuMo exhibit differing heterogeneity characteristics.

Composite-Sample Relationship

The other technique for assessing heterogeneity from drill holes interrogates the composite-sample relationship inherent in drill hole data. For this, bench composites were generated down all the drill holes, based on an expected 50 ft bench height. Then, the RCVs of the composites were calculated from the samples falling within the composites. RCVs were calculated from Cu, Mo, and Ag grades, as well as prices and recoveries.

The resulting relationship can be plotted as the number of samples versus the sample interval grade (RCV). These relationships are grouped by selected composite RCV ranges. Figure 6 shows the relationship of composite RCV ranges to the sample interval RCV counts within those ranges for the CuMo deposit (all mineralized zones).

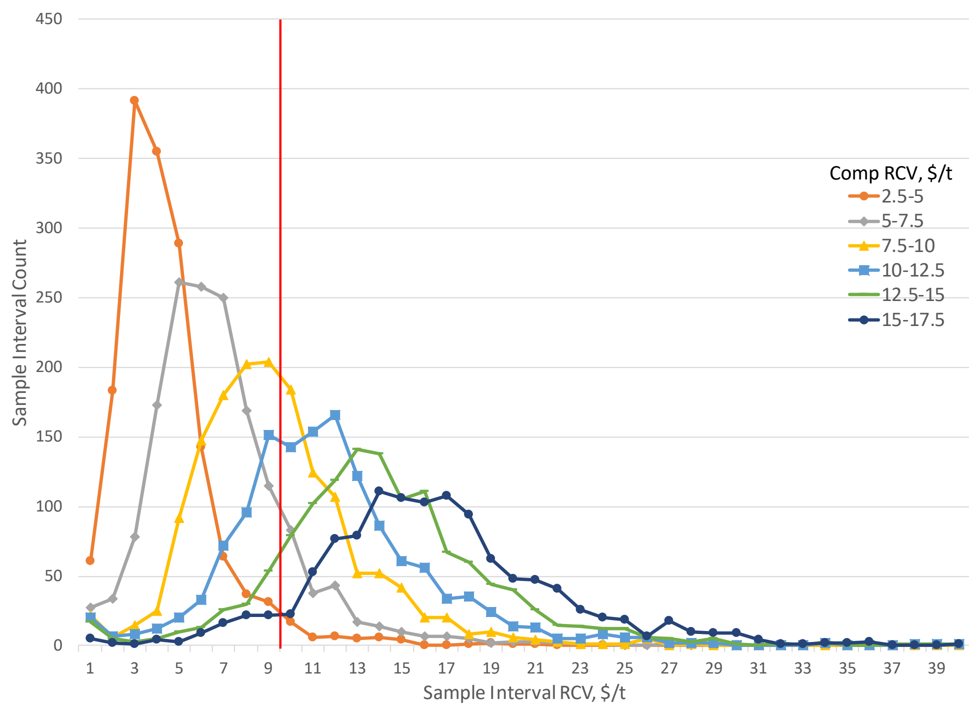

Figure 5 – CuMo composite-sample relationship

Figure 6 shows the composite-sample relationship for pre-selected composite RCV ranges. The composite ranges are set by $2.50/t increments, and within each range, the sample interval RCVs are counted in $1.00/t bins.

A red vertical line has been drawn at the $10/t RCV point, splitting the $9-10/t and $10-11/t sample intervals. This approximates the cut-off NSR for CuMo. Only six of the composite RCV ranges have been shown – three on either side of $10/t RCV.

There are two important observations of the composite-sample relationship for CuMo:

- Composite RCV ranges below the $10 cut-off ($2.50-5.00; $5.00-7.00; $7.50-10.00), which should all be waste, have sample intervals within them that are above the $10 cut-off ("ore in waste"). This is more pronounced for composite ranges nearer the cut-off.
- Composite RCV ranges above the $10 cut-off ($10.00-12.50; $15.00; $15.00-17.50), which should all be "ore", have sample intervals that are below the $10 cut-off ("waste in ore"). Again, this is more pronounced for composite ranges nearer the cut-off. There tends to be more "waste in ore" than "ore in waste" in general and as one moves away from the cut-off.

With the composite-sample relationship, it is possible with each composite range to assign percentages of material that would report to mill feed and waste about a specified cut-off.

These observations effectively point to the opportunity for sorting, if one can segregate material at the sample interval scale (or smaller, per the conclusion of the heterogeneity and scale analysis), one can remove waste from the mill feed and recover valued mineralized material from what would otherwise be waste.

SORT ANALYSIS OF DRILL HOLE DATA

The composite-sample relationship is key to undertaking a bulk sort analysis to predict outcomes. To adapt the composite-sample relationship to actual mining and sorting conditions, some adjustments are made. First, instead of simply counting samples at different grade or RCV values, sample lengths are used, providing more of a volume or tonnage relationship. As well, two factors are considered – dilution zone thickness at sample interval contacts and minimum thickness of sample intervals. The first represents possible mixing that can occur during blasting or in material handling. The grades in this zone are the average of adjacent sample intervals. The second factor typically considers thin intersections of sample intervals such as splits across bench composites. Considered values for dilution and minimum thicknesses at CuMo ranged from zero to two feet. In the end, a two-foot dilution zone per interval was used, with no consideration of minimum thickness.

The bulk sort analysis starts with considering grade control in the mine, whereby a sort feed cut-off determines what goes to the sort plant versus what goes to waste. Then, using the composite-sample relationships, several scenarios are run examining the impact of multiple cut-off grades. In addition to the grade control cut-off, two cut-offs for a given stage of sorting are configured. Material below the lower cut-off would be rejected as waste in the sort process, and material above the upper cut-off would represent feed to the mill. Material between the cut-offs is referred to as middlings. Successive sort analyses can be applied to the middlings to further the discrimination of waste and mill feed.

It was possible with these simulations of sorting, conducted directly on the drill hole data, to assess which combinations of cut-off grades produced the best results in terms of improved metal grades of the mill feed fraction and increased waste rejection. The impact of successive sorts could also be assessed. A final sort analysis however needs to be applied to the resource blocks in order to derive actual quantities, balancing metal recoveries and waste rejection in preliminary economics. The drill hole sort analysis results however provide a good starting point.

SORT ANALYSIS OF RESOURCE BLOCK MODEL

The composite-sample analysis provides relationships between bench composite RCV and sample interval RCV. However, for sort analysis of blocks, selecting drill hole composite-sample relationships based on matching exactly the composite RCV grades of bench composites and resource model blocks is not possible due to the volume-variance effect (Harding & Deutsch, 2019; Coombes, 2019). Block models generally have lower grades than the underlying drill hole data. To compensate, the drill hole composite-sample relationships were re-expressed on a percentile RCV basis. Ranges or "bins" of percentile composite RCV (in 10% intervals) were thus set up for the drill hole composites and the corresponding composite-sample relationships were re-estimated.

Then, using the 3D mineral resource block model, a sort analysis for blocks contained within the resource pit shell was performed. The percentile RCV of a resource block is compared to the percentile RCV ranges for the composites to select the applicable composite-sample relationship for sorting. Again, by applying an RCV cut-off for waste and another for mill feed, each RCV composite percentile range in the block could be segregated into three products, waste, mill feed, and middlings, according to the composite-sample relationship.

To maximize the benefit of bulk sorting, and to take advantage of increased heterogeneity at smaller scales, multiple stages of bulk sorting were considered for CuMo. The middlings product of a sort became the feed for a subsequent sorting stage. As well, the middlings product streams were split in two to further reduce the volume of batches to increase the heterogeneity for sorting. While this is done in numerical analysis, there is the understanding that all material handling in the sorting process, including stream splitting, is to be done without mixing in order to maintain maximum heterogeneity.

To determine the composite-sample relationships that would apply to subsequent stages of sorting, the RCV of the middlings was re-calculated from the recovered Cu, Mo, and Ag. This RCV value was compared to the drill hole composite analysis to derive the corresponding composite percentile RCV range. The composite-sample relationship for this range was then used to predict the results of bulk sort.

Using the original composite-sample relationship at each sort stage is seen to be conservative. As was observed for CuMo, the smaller the scale observed, such as at a later stage bulk sort, the greater is the heterogeneity (provided mixing is minimized), thus improving discrimination around cut-off grades. The limitation for the CuMo project is the drill hole sample length (10 ft) which precludes shorter interval heterogeneity analysis.

Bulk sort analyses were conducted both on all mineral zones combined and on the mineralized zones individually. While there were some differences, they were minor. That, plus operational challenges in predicting or detecting which zone is being processed at any given time, led to using the sort analysis for all zones combined for the study.

Final Bulk Sort Parameters

For the CuMo study, three stages of bulk sorting were run on the block model. The grouping of cut-offs which appeared to produce the best economic results were as follows:

- Grade control cut-off RCV = $7.50/ton
- Stage 1 Bulk Sort – Lower cut-off = $7.50/ton; upper cut-off = $20.00/ton
- Stage 2 Bulk Sort – Lower cut-off = $7.50/ton; upper cut-off = $17.50/ton
- Stage 3 Bulk Sort – Lower cut-off = $7.50/ton; upper cut-off = $15.00/ton

Re-use of the same cut-offs (e.g. the lower cut-off segregating waste from middlings) is allowed as it is recognized that any bulk sort is not precise and that sort products will continue to contain a mix of material across the full range of sample grades.

The outcome of the block sorting analysis are blocks coded with tonnages of waste, mill feed, and middlings. Grades were calculated for each of these fractions in each block. As well, sorting costs were determined by applying $0.10/ton for each bulk sort stage as well as an initial primary crushing cost of $0.20/ton, which applies to all material fed to the sorting plant. This version of the block model was then used for mine planning.

For mine planning, Lerchs-Grossman pit optimization with Geovia's Whittle™ software was used. The block model output from the bulk sorting analysis contained the quantities and enhanced Cu, Mo, and Ag grades of mill feed which drove the revenue side of the optimization (as well as milling costs and G&A). The sort feed (greater than $7.50/ton RCV) was flagged in the model to drive mining and primary crushing costs. The bulk sorting costs, accumulated for the three stages of sort, were also applied to the sort feed. The result was a traditional LG optimization analysis which was used to select eligible ultimate and interim phase pit shells.

Note that LG optimization only used the outcomes of bulk sorting. Adoption of particle sorting for the project came later and remains a possible enhancement to future strategic mine planning.

SORTING PLANT

The following describes the sorting systems adopted in the CuMo study.

The bulk sorting plant, located downstream of the primary crusher, consists of a series of stages of splitting of streams, measuring their metal content, and then sorting. The schematic in Figure 7 shows the elements of a three-stage bulk sort plant.

Prior to the sorting plant, there would be a diversion mechanism that would allow the crushed material to bypass the sorting plant. This would be for emergencies, to not disrupt the flow of material to the mill. A future improvement could be to place an analyzer on the conveyor belt directly after the primary crusher to determine whether crushed material needs to go to the sorting plant in the first place.

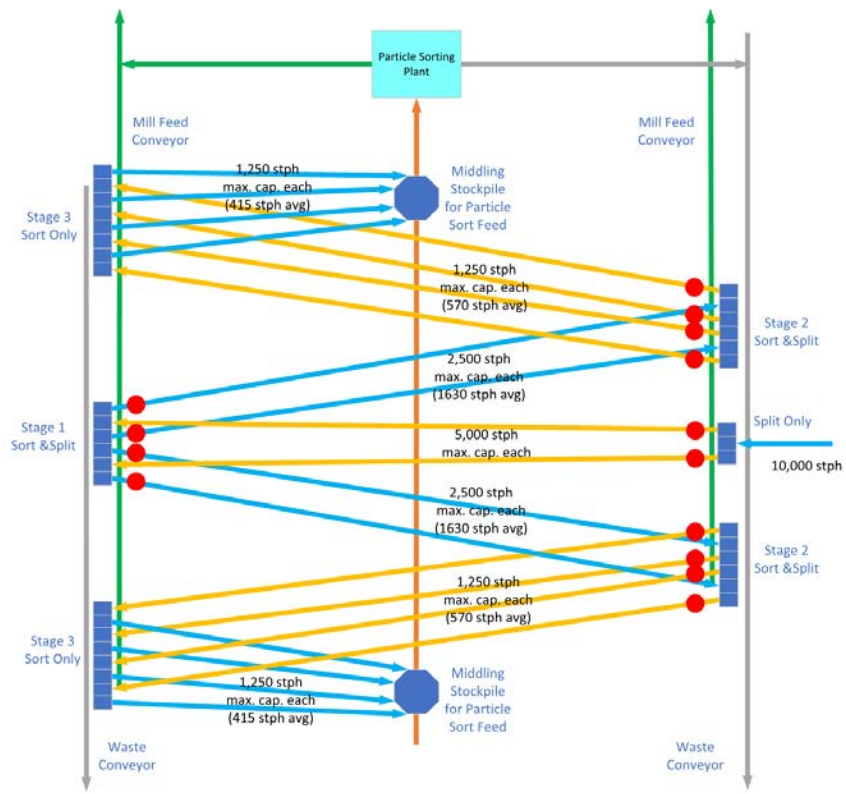

Figure 6 – Schematic of 3-stage bulk sorting plant + particle sorting (modified from CWA Engineers, 2019)

Material feeding the plant (nominally 10,000 tph) is immediately split in two, and two penetrative elemental analyzers (round dots in Figure 7), such as prompt gamma neutron activation analysis (PGNAA) analyzers, measure the stream. To make a measurement, such analyzers require a batch of material on the belt to average readings over. For instance, in the case of Scantech's Geoscan analyzers, this is 30 seconds of belt travel time. The length of conveyor from this first analyzer position to the sorting point is dictated by this 30 second interval and the travel speed of the belt. So, a belt traveling at 12 ft per second would require a conveyor length of at least 360 ft between analyzer and sort point. Alternate technologies are being developed to shorten the required measurement interval.

At the sorting point, a signal is received from the analyzer to indicate what the approaching material consists of (mill feed, waste, or middlings). A rapid diversion mechanism then diverts the stream to receiving chutes and conveyors accordingly. Figure 8 illustrates a diversion system to facilitate the re-direction of a stream. As the intellectual property is not presently protected, details of the rapid diversion mechanism are omitted.

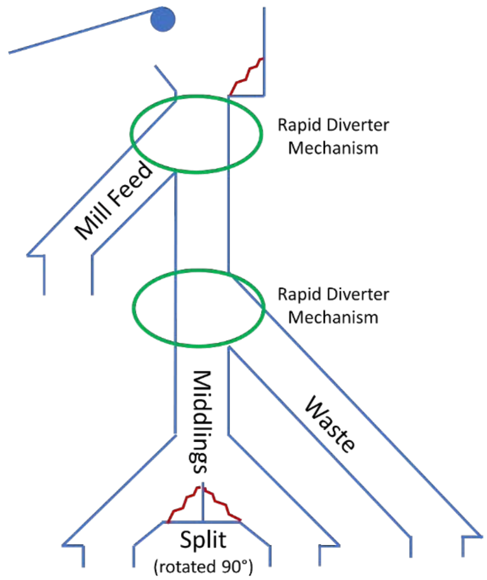

Figure 7 – Schematic of bulk sorting diversion system (modified from CWA Engineers, 2019)

The CuMo sorting plant would consist of three stages of sorting. Each stage will produce mill feed, waste, and middlings products. The mill feed from each stage will be sent directly to the coarse mill feed stockpile in front of the mill, while the waste will be conveyed to a truck load out bin for delivery by haul truck to waste rock facilities.

The middlings portions of each stage would become feed for subsequent sorting. To take advantage of the increased heterogeneity that comes with smaller scale (Figure 4), the middling streams of the first and second sort are split in two to reduce the 30-second batch size (Figure 8).

In order to ensure maximum mill feed recovery, particle sorting using XRF based sorting machines would be done taking feed from stockpiles or bins containing the middlings from the third stage of the bulk sort (Figure 7). Up to eight lines would feed 350 to 400 short tons per hour into particle sorting modules. Based on XRF particle sorting technology, each module would consist of multiple sorters to handle different size fractions. Augmentation of sensor efficiency could be achieved with additional sensing technology (e.g. x-ray transmission), though this was not considered in the study.

SORTING OUTCOMES

The sorting outcomes for one of the scenarios, after bulk and particle sorting, are provided in Table 1. It shows tons and grades of Cu, Mo, and Ag for the sort feed and ultimate mill feed.

Table 1 – Sort feed versus mill feed

	Mtons	MoS_2 %	Cu %	Ag ppm
Sort Feed	2,190	0.059	0.094	2.68
Mill Feed	1,582	0.075	0.107	3.04
Sort Impact	-28%	28%	13%	14%

As can be seen, rejection of waste and notable improvement in mill feed grade, particularly for MoS_2, is possible through sorting.

CONCLUSIONS

A viable methodology for assessing the outcomes of bulk sorting has been presented for the CuMo project. Integral to this is understanding mineral deposit heterogeneity. It has been shown that even a porphyry style deposit, such as CuMo, possesses heterogeneity at the sub-bench scale. Although CuMo was sampled at a relatively coarse interval of 10 feet, even at this scale, there is sufficient heterogeneity to justify bulk sorting. It was also observed that heterogeneity increased at smaller scales, so conceivably, shorter interval sampling could result in even more favourable sorting predictions.

In the end, the preliminary work on CuMo resulted in upgrades from sort feed to mill feed of 28%, 13%, and 14% for Mo, Cu, and Ag respectively.

Future work remains in validating the heterogeneity and sorting analyses methods presented here. This is being done with existing operations that have installed either bucket-based or conveyor-based sensing systems. As well, application of the composite-sample relationship across varying scales and stages of sorting requires further study.

For CuMo specifically, it is recommended to continue assessments of heterogeneity and sorting options for the different mineralized zones (i.e. Cu-Ag, Cu-Mo, etc.) and to validate appropriate mineral sensing technology for both bulk sorting and particle sorting at CuMo. Smaller interval sampling, possibly by core scanning technology, could facilitate heterogeneity analyses at smaller scales, and investigation into material handling technologies could parallel this to take advantage of smaller scale discrimination.

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