# An economic and risk based appraisal of standardised waste management strategies: using fragmentation analysis to optimise the approach

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**Abstract.**

A technical research project has been instigated by Mine Environment Management Ltd (MEM) to determine how the application of fragmentation analysis to the characterisation, management and long-term planning of waste rock may provide opportunities to optimise project economics. Detailed laboratory-based heterogeneity testing including quantitative mineralogical analysis has been twinned with site-based fragmentation analysis to assess properties of as-mined waste at two operational sites. The technical assessment has involved analysis of geochemical and mineralogical properties across the range of particle size fractions represented by the mined waste product. The results indicate that fractionation of metal sulfides and carbonates as a result of fragmentation occurring during the mining process, is a key factor influencing the validity of a typical grade weighted cut-off grade and bulk property modelling approach to waste classification and modelling. It has been found that the geochemical properties of the waste as mined are not well represented by the bulk compositional values attributed in the waste block model. In addition, it has been found that if fragmentation analysis is used to inform economic assessment of long-term waste management costs, optimised waste management strategies can be identified that would otherwise have been missed.

## 1 Introduction

Typically waste characterisation classification systems used as part of long term mine planning based on industry best practice geochemistry methods (Price 2009) are translated into mine planning and operations by the utilisation of block models (Pearce et al 2013). These block models are generally developed by the mine site geologist that have developed the ore reserve and geological model and define waste based on discrete grade weighted cut-off grades to differentiate between waste and ore zones, and wastes of different geochemical or physical properties (Pearce et al 2013). The use of a cut-off grade approach reflects an underlying assumption that waste rock properties can be defined and treated in block models as having static and bulk characteristics in the same manner as ore. That is to say that, once mined, the waste material block has the same intrinsic property as defined from the averaged value obtained from the block model. In most cases the waste block model is integrated with the ore reserve block model, which in turn is generated from the geological block model. In general, the classification system used to define waste within these models is based on risk of acid and metalliferous drainage (AMD) and broad "catch all" definitions such as potentially acid forming (PAF) or non acid forming (NAF) are used (Price 2009). With respect to economic assessment, this approach typically assigns no economic "value" (negative or positive) to waste blocks irrespective of classification other than to consider load and haul costs for disposal. This lack of cost modelling is driven by the assumption that waste has no intrinsic value, and that additional costs of managing waste are adequately accounted for elsewhere such as in closure cost estimation. The adoption of these broad assumptions as part of typical waste management strategies is in many cases considered to reflect current best practice (MWEI BREF) given they are based on standardised and established mining approaches. The implication is that these approaches are considered to be adequate to capture risk and provide an optimised cost model for waste management. This study assess the validity of using waste characterisation methods that assume that the properties of the mined waste product can be accurately defined from grade averaged block modelling approaches. In particular the study focuses on the role of fragmentation that occurs during mining may have on project risk and economic assessment.

## 2 Fragmentation analysis

During the mining process blasting of ore and waste rock is designed and carried out to fracture the in-situ rock mass, to enable excavation and transport of the material. Run of mine (ROM) fragmentation is considered optimal when the material is fine enough and loose enough to ensure efficient excavation and loading operations. The blasting optimisation strategy is usually focussed on minimising total mining costs and maintaining the optimal ROM fragmentation characteristics (Kanchibotla et all 1999). Singh (2016) notes that *"the goal of efficient blasting is determined by investigating the relationship between blast design* *parameters and fragmentation. It is extremely important to make the connection between rock blasting results and their impact on the downstream operations. It is well accepted that fragmentation has a critical effect on the loading operations, but little quantitative information is available, upon which rational blasting strategies can be outlined".* Although this reference is made with regard to downstream ore processing, it should be obvious that this statement would also apply to the consideration of the impact of the fragmentation profile on AMD risk and resultant management costs of the waste rock generated. Given the general lack of consideration of AMD risk in the cost model adopted for blasting strategies, it is clear that this aspect likely represents a significant source of missed opportunities for optimised waste management planning at mine sites. Fragmentation analysis is a common technique (e.g. Nov 2013, Mohamed 2019) used as part of economic optimisation of mining projects. The analysis involves assessment of the particle size distribution of mined material at various stages in the mining process, typically after blasting has occurred. The most utilised method to quantify fragmentation is the determination of the size distribution using digital imaging processing techniques. This method being low cost and practical and is the second reliable method after sieve analysis. In this method, images acquired from excavators, haul trucks, conveyor belts etc. are delineated automatically by using digital image processing techniques and size distribution of fragmented rocks is determined (Mohamed et al 2019). In recent years development and adoption of new automated imaging technology has significantly reduced the cost of carrying out the process, and as such more and better data can be gathered at lower cost. The technique is used to a great extent to assess blasting efficiency in ore zones as the as-mined particle size of ore material is a critical input to processing efficiency and cost. The technique is also used in waste zones but mainly to determine blast efficiency as part of assessing blasting costs. Because particle size has long been known to be a critical factor in the assessment of AMD risk of waste materials, an opportunity was identified to explore the potential to utilise the technology to supplement waste characterisation and management process.

The PSD profiles for three waste types from an operational open-pit base metal mine site, were collected between June 2016 and October 2017. The fragmentation analysis was carried out using automated Orica cameras fitted to two shovels operating onsite during this period. Recorded data was linked with the corresponding blast, material block and material type by following the progress of the shovels daily. Approximately ~32,000 images of blasted waste rock from 178 blasting events were processed and analysed (Figure 1). The PSD profiles of the three waste types are very similar to each other, indicating that blasting produces a consistent waste material product with respect to particle size, which is independent of waste type. The fine fraction accounts for a relatively small proportion of the overall waste mass with <20% mass being <10cm diameter.

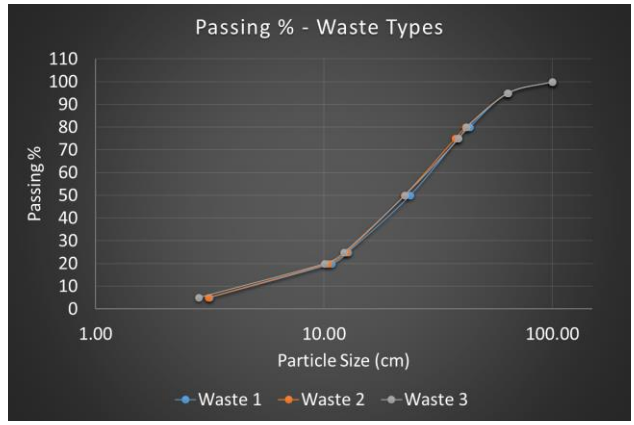


**Figure 1.** PSD profile for fragmentation analysis of 178 blasting events in open pit mining operations

Once the fragmentation profile for the blasted waste rock had been established, laboratory assessment of key particle size fractions was carried out to include compositional and mineralogical analysis.

## 2.1 Metal sulfide speciation

Nickel and copper concentrations for five, post-blast waste rock samples, was determined by four acid digest of the sample, followed by ICP analysis (Figure 2). The finest fraction of the samples (<2.36mm) has a notably higher concentration of Ni and Cu compared to the larger fractions indicating significant "upgrading" of metal content in the <2.36mm fraction. This effect was noted across all analysed samples. Mineralogical analysis was then carried out by Petrolab Ltd on one sample of <2.36mm size fraction and one >22mm size fraction samples using scanning electron microscopy (SEM). A polished block was prepared from each of the submitted sample fractions and carbon-coated to a thickness of 10 nm. Each block was analysed using a ZEISS EVO MA 25 scanning electron microscope (SEM) fitted with a Bruker xFlash 6|60 x-ray detector for energy-dispersive X-ray spectroscopy (EDX) analysis.

**Table 1.** SEM analysis results showing metal sulfides (pentlandite and chalcopyrite) and dolomite in <2.3mm fraction as weight %.

| Mineral phase | <2.36mm | >22mm |
|---|---|---|
| Pentlandite | 0.16% | 0.03% |
| Chalcopyrite | 0.2% | 0.06% |
| Dolomite | 0.44% | 0.08% |

Table 1 shows the results of the mineralogical analysis. Higher concentrations of Ni-bearing pentlandite, and Cu bearing chalcopyrite were reported for the <2.36mm fraction, where the highest concentrations of metals were recorded. The results indicate that blasting-related fragmentation significantly concentrates metal sulfides in the finer fraction, likely because of the presence of metal sulfides in veins/fracture fills. Cut-off grades for ore and waste at the site are defined based on metal sulfide content (processing is only effective at recovering metals from sulfide content). The significantly higher metal sulfide grades in the <2.36mm fraction therefore present an opportunity for metal recovery from this "waste" if this material were to be separated and processed as ore. The higher metal sulfide content and fine grain size both enhance the potential processing/recovery efficiency and lower cost.

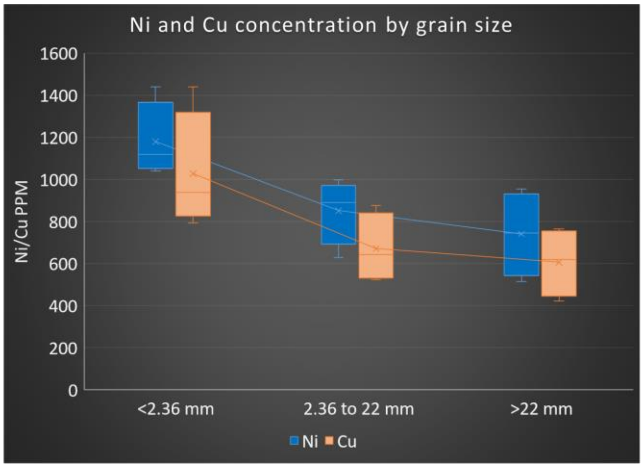


**Figure 2.** Box plot showing range, median and average concentrations of nickel and copper by particle size for 5 samples of waste rock post mining that have been spilt into 3 grain size fractions (15 samples total)

The higher surface areas and higher sulfide content of the fine fraction can cause an order of magnitude increase in sulfide oxidation rates and AMD loading making it the highest relative AMD risk. The results are important because the concentrating of metal sulfides in the finer fraction will increase the potential for AMD production relative to the assumed characteristics of the "bulk" material properties, estimated in the waste characterisation and block model. The block model assumes that all rock mass of the same grade-weighted-average value has the same geochemical properties. The further implication is that, conversely because metal sulfides are concentrated in the fines, the coarser materials will have a significantly lower AMD risk profile (lower grade, smaller surface area). As such, material that has been classified as higher risk with respect to AMD may be mined so as to have a significantly lower risk profile by optimising the waste blasting pattern in relation to fines generation. This highlights an opportunity to reduce waste management costs: the bulk of the high-risk classified material in the waste model and schedule can potentially be reclassified as lower-risk.

Figure 3 shows sulfur release from 2:1 leach tests carried out on different grain size fractions of the same sample. The >22mm fraction produces little if any sulfate. This lower reactivity reflects the lower metal sulfides present, and the low surface area, resulting in significantly lower AMD risk profile of this material. All of the fine fraction sample results exceeded the >22mm sulfur release amount significantly. In the block model the material is considered to have homogenous properties, however, the actual AMD risk profile of the grain size fractions represent order of magnitude differences. The relatively small volume of fine fraction material compared to the bulk highlights the overall benefit that separating this fine material would have on lowering waste management costs overall.

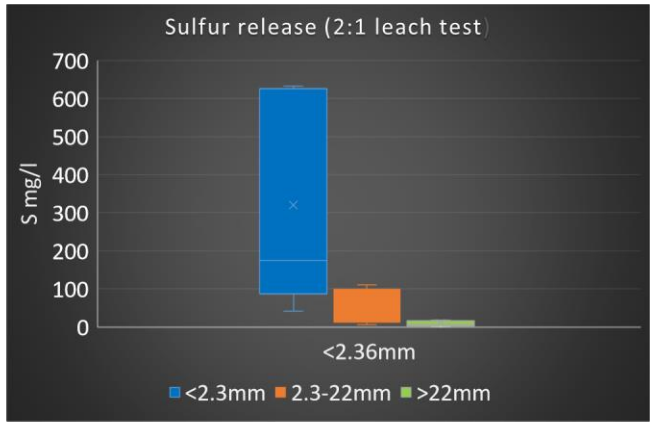


**Figure 3.** Box plot showing range, median and mean values for sulfur release in 2:1 leach tests for 5 samples split into 3 grain size fractions (15 samples total)

## 2.2 Carbonate speciation

Results from mineralogical analysis shown in Table 1 indicate that the carbonate dolomite is also concentrated in the <2.36mm fraction. This observation is important as the presence of carbonates in mine waste in the finer fraction is a key factor in AMD risk mitigation. Buffering of acidity generation by carbonate minerals is most significantly influenced by the finer particle size fractions where carbonate mineral reactivity rates are orders of magnitude higher.

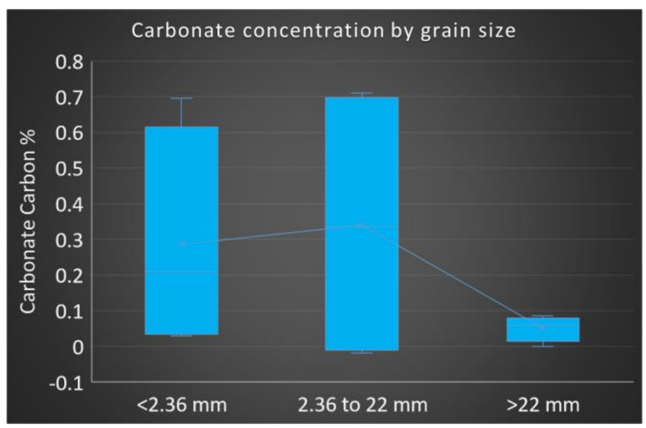


**Figure 4.** Box plot showing range, median and mean values for carbonate carbon for 5 samples split into 3 grain size fractions (15 samples total)

Analysis of carbonate content by grain size fraction for the 5 samples (Figure 4) shows carbonates are significantly concentrated in the finer fraction (2.36-22mm fraction as well as the <2.36mm fraction). The

>22mm fraction has a much tighter range and values are very low indicating that the >22mm fraction is almost devoid of carbonates. The results suggest that concentrating of carbonates in the finer fraction will significantly increase potential buffering potential relative to the "bulk" properties. As such waste management costs could be reduced if material that was classified as higher risk in the waste model because of insufficient carbonate buffering, could be re-classified as lower risk because of higher relative carbonate to sulfide content. In addition further opportunity can be identified to utilise high carbonate, low sulfide material which may have uses such as alkalinity producing cover, source material for "limestone" drains, source material for alkaline material to "blend" with higher risk material etc.

### 2.3 Implications for mine planning

Key findings of the assessment are that:

(a) Fractionation may render larger particle sizes (>22mm) effectively inert when in the mine model they may be classified as having high AMD risk. As such a large potential cost saving can be identified by separating and re-classifying this material as lower risk material
(b) Fractionation can cause carbonates to concentrate in the finer particle sizes which means that an alkalinity generating material could be created by screening this fraction out.
(c) Fractionation causes significant upgrading in metal sulfide content in finer fractions meaning that metal grades move closer to that of ore than waste. There is an opportunity for this material to be separated and processed thus representing a source of recoverable metals.
(d) Fractionation of metal sulfides into the finer grain size means that AMD risk may be underestimated by standard block modelling approach. This is because the model uses grade weighted cut off grades to determine waste class, which in turn is based on the relative reactivity of materials from laboratory testing at specific sulfide grades.
(e) The separation and processing of the finer fraction with higher metal content presents an opportunity to significantly reduce project AMD risk. This is because the finer fraction with high metal sulfide fraction comprises the majority (>80%) of the potential total AMD risk from bulk mine waste mass. Processing of the material allows both removal of metals into product that will be sold offsite, and also the removal of the sulfide content to a different waste stream (tailings).
(f) The use of fragmentation analysis to guide blasting patterns in waste zones may provide benefits as the physical properties of the waste product can be controlled at the source. Blasting can be tailored to produce a finer or coarser waste product that may allow some control over AMD risk, and may provide opportunities to recover both metals and carbonates that may provide positive cost benefits.

## 3 Conclusions

The use of waste "block models" to assess waste properties as part of mine planning, and the generation of waste schedules, has been increasingly used across industry over recent times. The research carried out by the authors demonstrates that this approach should be viewed with caution, and further may be resulting in missed opportunities for optimising waste management economics. Classifying materials based on bulk grade weighted averages without assessing the actual properties of the as mined waste product may result in underestimation of potential AMD risks, and may result in recoverable metals being discarded in the waste stream. Fragmentation analysis has been identified as a potential means to assess the relative change to both the AMD risk profile, and metal recovery potential of the as mined waste. New technology allows for in-situ assessment of fragmentation during the mining process meaning that optimising the blasting process itself may realistically be used to "change" the AMD risk profile of the waste product and introduce another layer of AMD risk management. Further, this study demonstrates that opportunities to improve project economics can be identified such as identifying the recovery potential of potentially economic metals from material previously classified as "waste" along with recovery of carbonates that may have "value" on site for use as part of risk mitigation strategies.

## 4 References


Mohamed F, Riadh B , Abderazzak S Radouane N , Ibsa T (2019). Distribution Analysis of Rock Fragments Size Based on the Digital Image Processing and the Kuz-Ram Model Cas of Jebel Medjounes Quarry. Aspects in Mining & Mineral Science.

MWEI BREF: Best Available Techniques (BAT) Reference Document for the Management of Waste from Extractive Industries, in accordance with Directive 2006/21/EC; EUR 28963 EN; Publications Office of the European Union, Luxembourg, 2018; ISBN 978-92-79-77178-1; doi:10.2760/35297, JRC109657.

K. Singh, M.P. Roy, R.K. Paswan, Md. Sarim, Suraj Kumar, Rakesh Ranjan Jha (2016). Rock fragmentation control in opencast blasting, Journal of Rock Mechanics and Geotechnical Engineering 8

Noy. M.J. 2013. Automated rock fragmentation measurement with close range digital photogrammetry. In: the 10th International Symposium on rock fragmentation by blastic, new Delhi, India. Measurement and Analysis of Blast Fragmentation

Pearce.S.R et al (2012), Managing closure risks by integrating acid and metalliferous drainage studies with mine scheduling – real world examples in: Proceedings of Mine Closure 2012, editors: Andy Fourie and M Tibbett, Australian Centre for Geomechanics, pp. 801-814

Price (2009) Prediction Manual for Drainage Chemistry from Sulphidic Geologic Materials MEND Report 1.20.1

Kanchibotla, S. S., Valery, W. and Morrell, S. (1999). Modelling fines in blast fragmentation and its impact on crushing and grinding. Explo'99: A Conference on Rock Breaking, Kalgoorlie, WA, 7-11 November 1999. Melbourne: AusIMM