DEVELOPMENT OF LEADING PRACTICE WASTE GRADE CONTROL AMD CLASSIFICATION METHODS BASED ON DEPOSIT SPECIFIC MINERALISATION CHARACTERISATION AND MODELLING

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ABSTRACT

Barani and Ramba Joring are deposits located at the North Sumatra Martabe gold mine. Waste materials produced from the deposits are stored in an integrated waste storage facility (IWSF). The mine is an epithermal deposit of a high sulfidation system, but due to a very significant change in hydrothermal solution in all deposits, there are several types of mineralisation that are controlled by structure and lithology. AMD management commenced with acid base accounting (ABA) geochemical analysis system conducted for both deposits. The program has since been expanded to include implementation of a detailed waste grade control drilling and reconciliation program fully integrated into waste scheduling and mine planning operations, and is considered to be an example of leading practice in this area.

The Barani pit is dominated by quartz veins and is classified as low sulfidation system, it was analysed using the ABA method which showed that 75% of material has a total sulfur content <0.15% indicating a low risk of AMD. However, the presence of low level acid generating sulfate minerals, and limited carbonate content has identified that ABA is not a good guide for AMD classification and modelling. Detailed grade control drilling and reconciliation utilising the paste pH and ANC tests methods along with particle size based assessment has been implemented to optimise operational AMD control.

Ramba Joring is dominated by vuggy silica consisting of mineralisation associated with silica-alunite and massive-vuggy silica alteration zones. The deposit has a higher sulfur grade than Barani (average grade of 1%), however detailed testing using CRS and mineralogical analysis identified the abundance of natroalunite to interfere in sulfide sulfur estimates resulting in the ABA method to significantly overestimate AMD risk. Validation using kinetic testing demonstrated the NAG test to be a suitable method to optimise operational AMD control when implemented into grade control drilling.

1.0 INTRODUCTION

The process of characterising waste rock and incorporating classification systems into mine models such as geological block models and resource and reserve models for the purposes of mine planning has evolved significantly over the last decade. This has come about both from increased focus on mine waste characterisation but also because of the significant increase in computing power and sophistication of software accessible now available to carry out waste block modelling (Pearce 2012). Although this progress is undeniably a positive step towards improving waste management, the process of estimation through modelling prior to mining activities can only be considered a front end study. When it comes to ore extraction and mine planning and operational management, it is well established that the front end modelling of ore reserves is subject to significant limitations on accuracy. The “accuracy” of reserve models are inherently deposit specific and depend on many factors such as the extent of drilling carried out, resolution of models (block size), the complexity of the ore body etc. As such it is standard practice that during operations a process of model validation is likely to be required, which for the most part is completed using programs of grade control drilling and modelling. This exercise is typically carried out both to increase the density of sampling within the deposit being mined, improve the resolution of modelling (block size), and to allow reconciliation against the reserve model. The results of validation are then used to determine if adjustments need to be made to estimates made from the reserve model with regards to mine planning and ore/waste management plans. The value of this process for mine planning is clear for management or ore extraction, however the adoption of these processes as part of the management and extraction of waste rock is less commonly implemented to the same degree of rigour.

This paper outlines a case study where a very comprehensive waste grade control drilling, modelling and reconciliation program has been developed for waste rock management under the general principal that waste should be mined in the same way as ore. The study is presented as an example of “leading practice” for the practical implementation and integration of the process into a modern mine planning environment.

2.0 SITE BACKGROUND AND CONTEXT

The Martabe gold and silver mine is situated in northern Sumatra and comprises several deposits in steep terrain that are required to be developed in the optimal sequence for the best possible Net Present Value (NPV) return on the project. In addition, the waste from the excavations is a by-product to be scheduled and used for construction of the tailings storage facility (TSF). These plans need to be aligned to ensure the tailings can be contained relative to the production rate (Grohs and Pearce 2019). The TSF embankment construction includes potentially acid forming (PAF) waste that needs to be progressively sealed and rehabilitated to meet the closure requirements of the future.

The mine is situated approximately 3 kilometres north of the township of Batangtoru in a seismically active zone between the off-shore subduction zone and the trans Sumatran fault. The mining operation currently includes three open cut pits with a fourth in development stage, an integrated TSF and dual purpose valley-fill type waste rock storage facility (WRSF) and TSF embankment. Mine waste is used in construction of the WRSF / TSF embankment, including PAF waste rock, which needs to be scheduled for optimal use in construction activities in a manner that mitigates future acidic and metalliferous drainage (AMD) risks (Pearce et al 2017).

2.1 Mine planning overview

The waste rock varies significantly both in geochemical and physical properties between the pits, and within each pit, presenting challenges for mine planning and execution of an optimal progressive mine closure strategy (Pearce et al 2017, Grohs and Pearce 2019). As such a number of detailed long and medium term practical mine planning and management practices have been developed at the site to guide operations.

The long term planning method requires consideration of waste delivery from existing and future pits to ensure that the progressive closure strategy is sustainable over life of mine

operations. This requires that LOM planning considers pit optimisation in terms of mining for waste delivery as well as ore.
Short term planning practices include execution of a detailed program of waste grade control drilling, sampling, modelling and validation within all mine pits simultaneously to produce an integrated detailed waste grade control model that is reconciled monthly with the LOM reserve waste model. The validated waste grade control model is then used to inform a rolling three month forward waste delivery and placement plan to guide TSF construction (build plan). Placement of waste material at the TSF is then subject to detailed validation testing to confirm placement is in accordance with the material placement specification and sequencing within the embankment.

2.2 Mine deposit geology and geochemistry

The Martabe site is characterised as an epithermal deposition (e.g. Foley et al 1987) of a high sulfide system, which is characterized by the presence of leaching or sulfuric acid leaching and interaction with the wall rocks, shown by the vuggy texture, and occurrence of breccia . The alteration zones in the Martabe area are distinguished into four types, massive silica-vuggy silica at the centre, followed by the advanced argillic dominated by quartz-alunite and quartz-dickite-kaolinite, and then to the outside it is occupied by Argillic (Illite-Smectite) and the latter is a propylitic alteration that consists of chlorite-calcite and trace epidote (Mandradewi et al 2014) This alteration pattern demonstrates the process of progressive neutralisation of the hydrothermal acid solution from the centre towards the outside through interactions with the host rock and groundwater and decreased temperature.

The change of hydrothermal solution is very significant in all deposits in the area, thus causing several types of mineralisation which are usually controlled by structures that can be differentiated based on texture and alteration type that are related to the composition of hydrothermal solutions as mineralisation carriers. The mineralisation in Barani which is located in the southeast is characterised by quartz veins with little vuggy silica, while Ramba Joring is dominated by vuggy silica. Both ore and waste contain sulfide which is high and increases according to the depth. The sulfide is present in rock masses both as dissemination and filling in the cavity/massive vein systems, usually pyrite.

Analysis of mineralogy that has been carried out has identified the primary sulfide pyrite as being the main source of acid generating potential in both Barani and Ramba Joring. In addition to primary sulfides, sulfate minerals are identified which differ between the pits based on differences in mineralogy. In Barani, acid forming secondary sulfates have been identified that include minerals such as jarosite. Large scale kinetic tests have demonstrated the ability of the acid sulfate minerals to rapidly dissolve in the presence of water and release acidity and metals into solution. In Ramba Joring the main sulfate mineral identified is alunite which after large scale kinetic testing has been identified to be less soluble and produces low levels of acidity or metals on contact with water or after weathering. Acid neutralising minerals have been identified to include calcite and ankerite present mainly in argillic alteration type materials, and a large number of clay minerals present include kaolinite, dickite, Illite and smectite depending on the level of alteration (with argillic material having the highest content of clay).

3.0 WASTE CLASSIFICATION AND MODELLING APPROACH IN RESERVE MODEL

The assay database used to construct the reserve models used for mine planning includes tens of thousands of results of analysis from exploration, resource and infill reserve drilling campaigns. This includes standard parameters such as sulfide sulfur using SCIS (sodium carbonate insoluble sulfur) method, total sulfur (Leco), calcium (ICP), and key metals (copper, arsenic, lead by ICP). From these parameters initial waste block models were created using acid base accounting (ABA) approach. The maximum potential acidity (MPA) is derived from wt% SCIS (assumed to be sulfide S), and the acid neutralisation capacity (ANC) based on the wt% Ca (assumed to be calcite). The net acid producing potential (NAPP) is then determined from deducing the ANC value from the MPA value and values coded into the model based on cut off criteria for waste classes.

Although the initial model created in the reserve model based on SCIS and Ca were useful as a general guide to volumes of materials with high/low AMD risk, it was found from detailed assessment that the deposits of Barani and Ramba Joring are complex and differ with respect to key mineralogical aspects that relate to AMD risk assessment. This means that identification of appropriate geochemical testing methods to further characterise the materials, and methods to classify materials within the mining block models has been a key priority for the site operations. Extensive geochemical testing carried out on samples from the drill hole assay database (used to create the waste block model within the reserve model) indicated that the ability to characterise and model the waste materials is impacted because of differences in mineralogy with respect to AMD risk.

- In Ramba Joring it has been found that the direct method of sulfide sulfur analysis using SCIS method is not accurate in estimating sulfide content. The SCIS method involves chemically removing the sulfate sulfur by boiling a sample in sodium carbonate solution and analysing the residue which is interpreted to be sulfide sulfur. In general, most sulfates are readily soluble in sodium carbonate solution, while most sulfides are insoluble in sodium carbonate. However sulfates of alunite ($K_2(Al_2OH)_6(SO_4)_4$) are only partially soluble (e.g. Alpers et al 1989). As such the SCIS method on material containing these minerals will result in erroneously high estimations of sulfide sulfur. Detailed testing using alternative methods of sulfide sulfur analysis such as mineralogical approaches (XRD), alternative sulfide sulfur methods such as chromium reducible sulfur (CRS) and the NAG test indicated that the alunite content was significantly impacting the ability of the SCIS method to determine true sulfide content. Based on results of testing it was determined that the alunite content determined from mineralogical data present in the reserve model (ASD data) could be used to adjust the SCIS value reported in the assay database. However this approach was associated with a high degree of error and so can be considered qualitative in nature, and as such it was concluded that the only reliable means to classify materials from this deposit would be by using a grade control program during mining.
- In Barani the presence of soluble acid generating sulfate minerals was identified through detailed testing using ANC tests where reporting of negative ANC values allowed the identification of the acid salts. Due to the low concentration of these minerals, it was not possible to use ASD data in the drill hole assay database determine the presence of the acid salts in the reserve block model. In addition comparison of sulfide sulfur and total sulfur (present in the drill hole assay database) was also not able to be reconciled with the presence of these minerals due to the presence of non acid forming sulfates (gypsum). As a result it was concluded that the only reliable means to classify materials would be by using a grade control program during mining.

Table 1 highlights key modelling parameters used in the reserve model and identified limitations of using data from drill hole assay database used to form the reserve model:

Table 1. Reserve modelling parameters

Reserve model parameter	Barani	Ramba Joring
Total sulfur	Total sulfur of limited benefit due to poor link with acid sulfate content (once sulfide content deducted)	Total sulfur of limited benefit for AMD classification due to inaccuracy of sulfide sulfur determination due to high alunite content
MPA (derived from SCIS)	Provides accurate estimate of sulfide content and acid forming potential from sulfide oxidation	Sulfide sulfur analysis impacted by alunite content, if used for ABA overestimates acid forming potential
Alteration mineralogy by ASD	Jarosite minerals present at levels too low to detect by ASD	Alunite minerals present at high enough levels to detect and characterise using ASD data. Alunite zone created as wireframe in model based on ASD data.
ANC (calculated from calcium)	Presence of acid salts means estimation of ANC not possible using parameters in drill hole assay database	Where present calcium linked to carbonates so provides accurate estimate of ANC
NAPP (MPA-ANC)	Modelled NAPP does not identify materials with acid sulfate risk	Modelled NAPP has high degree of uncertainty due to impact of alunite on SCIS data

It is important to note that in the case of Ramba Joring mineralogy is able to be modelled in the reserve model only because Analytical Spectral Device (ASD) data using near-infrared spectroscopy has been included in the reserve model dataset. As such zones where waste mineralogy is dominated by alunite can be included as a discrete domain in the reserve model (after wireframe modelling of ASD data has been integrated). This finding therefore also demonstrates the value that ASD data can provide when used as part of waste characterisation and modelling within reserve model as without it modelling the alunite zones would be significantly more difficult. The identification of this mineralogical control factor is key because it presents an opportunity to reclassify materials within the reserve model that using SCIS data alone would be determined as high risk. This has considerable influence on the LOM waste materials delivery plan as the lower risk material has been identified as a critical material for use as part of the outer growth medium profile of the TSF construction. As such identification of this material is critical and may allow this zone to be significantly thicker than would otherwise be possible.

A practical independent validation check of the material classification adopted in the reserve model based on AMD risk has been achieved through a number of studies that include:

- QA/QC analysis using the chromium reducible sulfur method (CRS), XRD and NAGpH testing was completed to provide comparative analysis data to compare sulfide sulfur (SxS) data obtained from the SCIS method. The results indicate that for grades of <3% SxS, where alunite is present >10%, then CRS results are <0.15%, NAGpH >3.6 and NAG acidity <5 kg/t H_2SO_4. Taken together the results indicate that the alunite rich material has very low to negligible sulfide content and has a low potential to release significant acidity.
- Kinetic testing assessment using IBC leach tanks to assess samples of Ramba Joring material over a range of sulfide sulfur grades and alunite contents was initiated to

provide data on drainage chemistry and AMD risk. The results to date indicate that material that was indicated from SCIS data to have sulfide grades of between 0.5-2%, and where alunite content from ASD data was >10% and where NAGpH values of >4 were recorded, has a very low release rate of acidity or mobile metals.

- Oxitop testing indicates that samples of material which reported SxS results of between 0.5-2%, and where alunite content from ASD was >10%, have low oxygen consumption rates <0.5 kg/t/yr O2. This data indicates that reactive sulfides are not present at appreciable levels.

4.0 WASTE CLASSIFICATION AND MODELLING APPROACH IN GRADE CONTROL MODEL

Based on the validation work carried out for the reserve model parameters, practical grade control validation criteria have then been developed that can be demonstrated to both accurately determine AMD risk and are able to be practically implemented into grade control drilling modelling. The practical implementation of AMD parameters into grade control modelling is an important and often overlooked point as in many cases geochemical validation criteria area developed based on geochemical test outputs that are not able to be successfully modelled as part of integrated ore/waste grade control modelling. For example, although NAGpH has been identified as a suitable test to identify lower risk alunite material (where sulfur is present as alunite not sulfides) a pH value is not strictly suitable for estimation modelling purposes as model estimation uses variography to average values between samples but pH being a log value cannot be averaged. Based on assessment of appropriate values for model estimation purposes, NAG acidity and ANC values have been selected for GC model estimation purposes as these inputs are compatible with the integrated ore/waste GC model.

In recognition of the influence of deposit mineralogy over the ability to create accurate waste models in the reserve modelling process, a specific testing schedule tailored to each deposit was determined as part of development of grade control assessment. An overview of the use of typical laboratory geochemical testing methods for grade control in each deposit based on comprehensive validation testing, and field scale kinetic testing is provided in Table 2.

Table 2. Classification testing overview for grade control program

Classification test	Barani	Ramba Joring
Sulfide sulfur	Provides accurate estimate of sulfide content and acidity potential from sulfide oxidation	Provides comparable means to compare against reserve model data
Paste pH	Found to overestimate contact pH compared to kinetic test data	Not used as NAGpH used as main acid forming determinant
Rinse pH	Provides more accurate estimate of pore water pH than paste pH	Not used as NAGpH used as main acid forming determinant
ANC	Reporting of negative ANC values allows estimation of acid salt content	Not used as NAGpH used as main test for classification

NAGpH	Not used in Barani	Provides accurate estimate of overall acid forming potential of material

4.1 Application of ore grade control principals to waste rock management

Due to the varying nature of the deposits and need for immediate placement to final profile in the TSF construction, a waste grade control philosophy has been implemented resulting in waste being defined similarly to ore control through detailed sampling, modelling and classification for optimum construction placement and AMD risk management. The operational waste management practice developed at the site includes detailed grade control drilling which comprises an integrated operational program carried out in both waste and ore zones. Sampling in waste zones for AMD analysis is carried out at 12.5-25m centres and composite samples are taken over 1m depth intervals for laboratory analysis. This results in generation of >1,000 samples per pit, per month, for AMD analysis. The GC waste block model is then constructed using this extensive testing data such that the block size is able to be constructed at a higher resolution (12.5m) than the RM (25-50m).

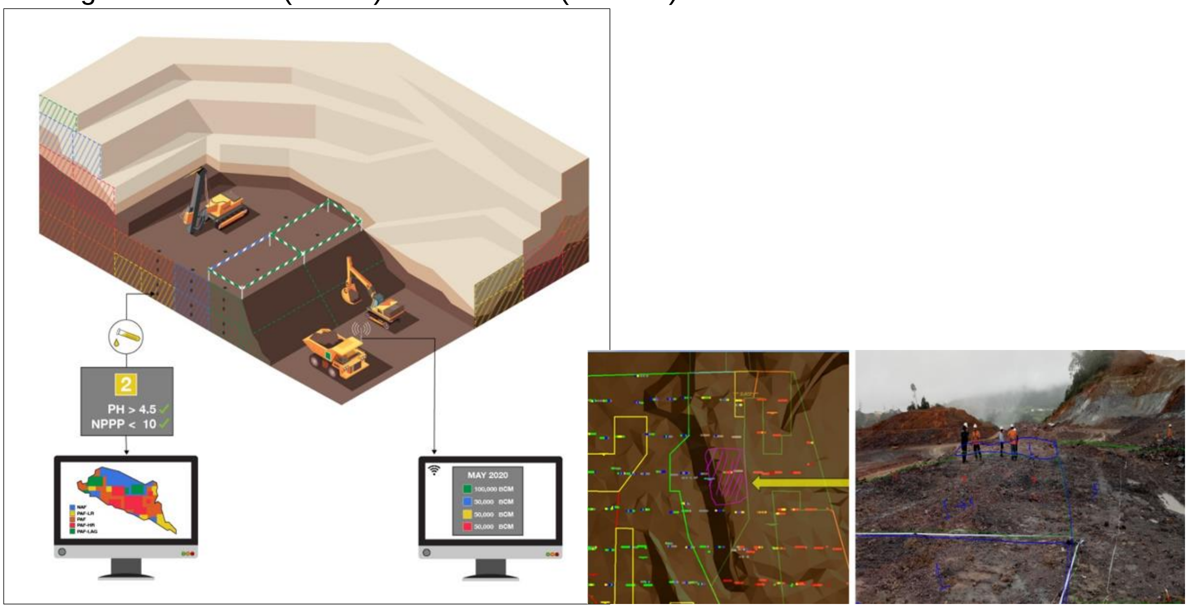

Fig. 1. Grade control assessment concept used as part of short-term planning

Full reconciliation between the waste grade control and reserve waste model is also carried out monthly to provide constant feedback on variance in predicted vs actual waste volumes and quality, and to validate the reserve AMD model. Reconciliation refines the rolling three month waste schedules for placement within the embankment to ensure specific elements of the closure strategy can be realised.

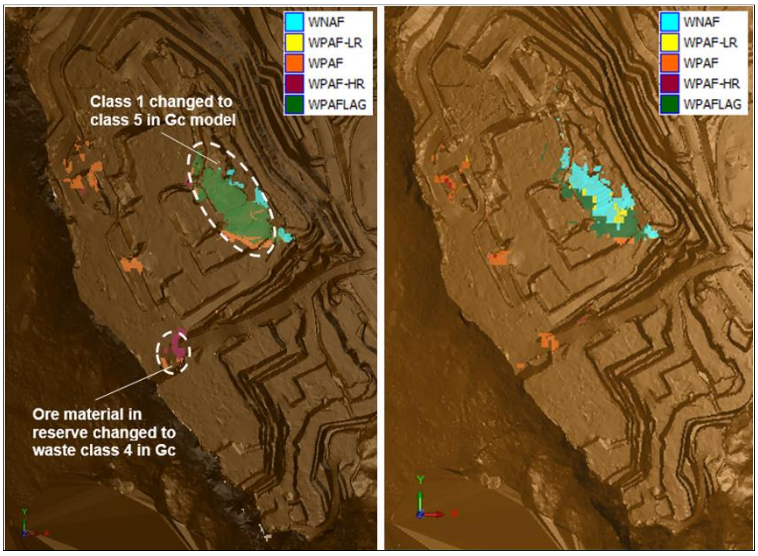

Fig. 2. Conceptual figure showing reconciliation between grade control (LHS) and reserve block models (RHS).

Figure 2 shows a comparative graphic reconciliation between the grade control block model based on ore control RC close spaced drilling on the left and the long term planning Reserve model block model based on exploration diamond drilling and resource development RC drilling on the right. The monthly variance is determined from these comparisons. Note the variations in classification between the reserve model and more detailed grade control model is tracked for further long term planning improvement.

5.0 CONCLUSIONS

The use of integrated front end block modelling that includes both ore and waste zones as part of mine planning has gained widespread recognition in the industry as providing an important tool to be used as part of LOM waste management. In addition the tool has been demonstrated as a key enabler of the optimisation process when it comes to the LOM planning process. However, these models are only as accurate as the data used to compile them, and as this study demonstrates are in many cases impacted by many factors including the resolution of the models and the deposit specific nature of mineralogy (with respect to estimation of AMD risk). With respect to the ore extraction process the uncertainties associated with front end modelling (i.e. resource/reserve models) has long been known, and as such detailed grade control programs are often required to be implemented during operations. This study demonstrates a case study where the practical implementation of an intensive and integrated waste grade control drilling, modelling and reconciliation program has been successfully implemented on an active mine site, at a scale analogous to that carried out for ore zones. When taken in totality the authors consider this program to be a potential example of industry leading practice in the area of waste rock operational management and planning.

6.0 REFERENCES

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