Throughput Forecasting and Optimisation at the Phu Kham Copper-Gold Operation

D Bennett[1], A Tordoir[2], P Walker[3], D La Rosa[4], W Valery[5] and K Duffy[6]

ABSTRACT

The Phu Kham copper-gold deposit in Laos is an extremely heterogeneous orebody. The deposit has complex and variable mineralogical, geological and geotechnical properties, which affect plant throughput and metallurgical performance. An increased proportion of highly competent ores expected in future operations at Phu Kham has the potential to limit plant throughput.

To evaluate how to maintain current throughput rates over the life-of-mine (LOM), Phu Bia Mining Limited conducted a throughput forecasting and optimisation project for Phu Kham with the assistance of Metso Process Technology and Innovation (PTI). The project involved a review of the current blasting, crushing and grinding processes, and development of a throughput prediction model based on geometallurgical modelling for long-term planning. The scope also included identifying opportunities for increasing throughput and improving overall comminution circuit performance when treating the most competent ore types. A shorter term objective was to identify if and when secondary crushing or other process changes will be required to maintain the target throughput over the LOM.

The throughput prediction model consists of integrated site-specific models of the drill and blasting, crushing and milling operations. These models were developed, calibrated and validated using SmartTag™ ore tracking technology which links the ore source (and properties) in the mine with blasting and plant performance (throughput, grade, recovery, etc) in real-time. Geometallurgical ore domains were defined and blasting and comminution processes modelled using measured plant results, thus enabling short to long-term strategic planning and optimisation.

Metso PTI is also implementing a GeoMetso™ system at Phu Kham, which uses the SmartTag™ ore tracking technology to continuously collect plant data and automatically update the predictive models and block model in real time. This eliminates the need for further expensive ore characterisation tests, and improves the accuracy and predictive abilities of the geometallurgical models that were developed. This can improve long-term mine planning, and capital equipment purchases can be predicted well in advance of their requirement. In the short-term, the processing plant receives advance notice of the ore type(s) about to be processed and adjustments can be made to operating conditions to optimise plant performance.

BRIEF DESCRIPTION OF PHU KHAM OPERATIONS

Phu Kham open pit copper-gold mine is located approximately 100 km north-east of the Laos capital Vientiane. Phu Kham's geographical location and open pit mine are shown in Figure 1.

The Phu Kham geology is highly variable due to weathering, alteration, faulting and folding. The deposit consists of complex heterogeneous mineralogy horizons of copper-gold stockwork and skarn mineralisation as shown in Figure 2. Weathering and water table contact have created a soft leached zone, overlying transition zones with supergene chalcocite-dominant secondary copper mineralisation and clay-rich gangue. The rock mass strength and degree

1. MAusIMM, Principal Metallurgist, PanAust Limited, Level 1, 15 James Street, Fortitude Valley Qld 4006. Email: duncan.bennett@panaust.com.au

2. GAusIMM, Drill and Blast Superintendent, Phu Kham Operations, Phu Bia Mining Limited, PO Box 5559, Vientiane, Laos. Email: alan.tordoir@pbm.panaust.com

3. MAusIMM, General Manager – Technical Services, PanAust Limited, Level 1, 15 James Street, Fortitude Valley Qld 4006. Email: peter.walker@panaust.com.au

4. MAusIMM, Principal Consultant, Metso Process Technology and Innovation, Queensland Centre for Advanced Technology, 1 Technology Court, Pullenvale Qld 4069. Email: david.la.rosa@metso.com

5. FAusIMM, Senior Vice President – Global, Metso Process Technology and Innovation, Queensland Centre for Advanced Technology, 1 Technology Court, Pullenvale Qld 4069. Email:walter.valery@metso.com

6. Mineral Process Engineer, Metso Process Technology and Innovation, Queensland Centre for Advanced Technology, 1 Technology Court, Pullenvale Qld 4069. Email: kristy.duffy@metso.com

FIG 1 – Phu Kham geographical location and open pit mine.

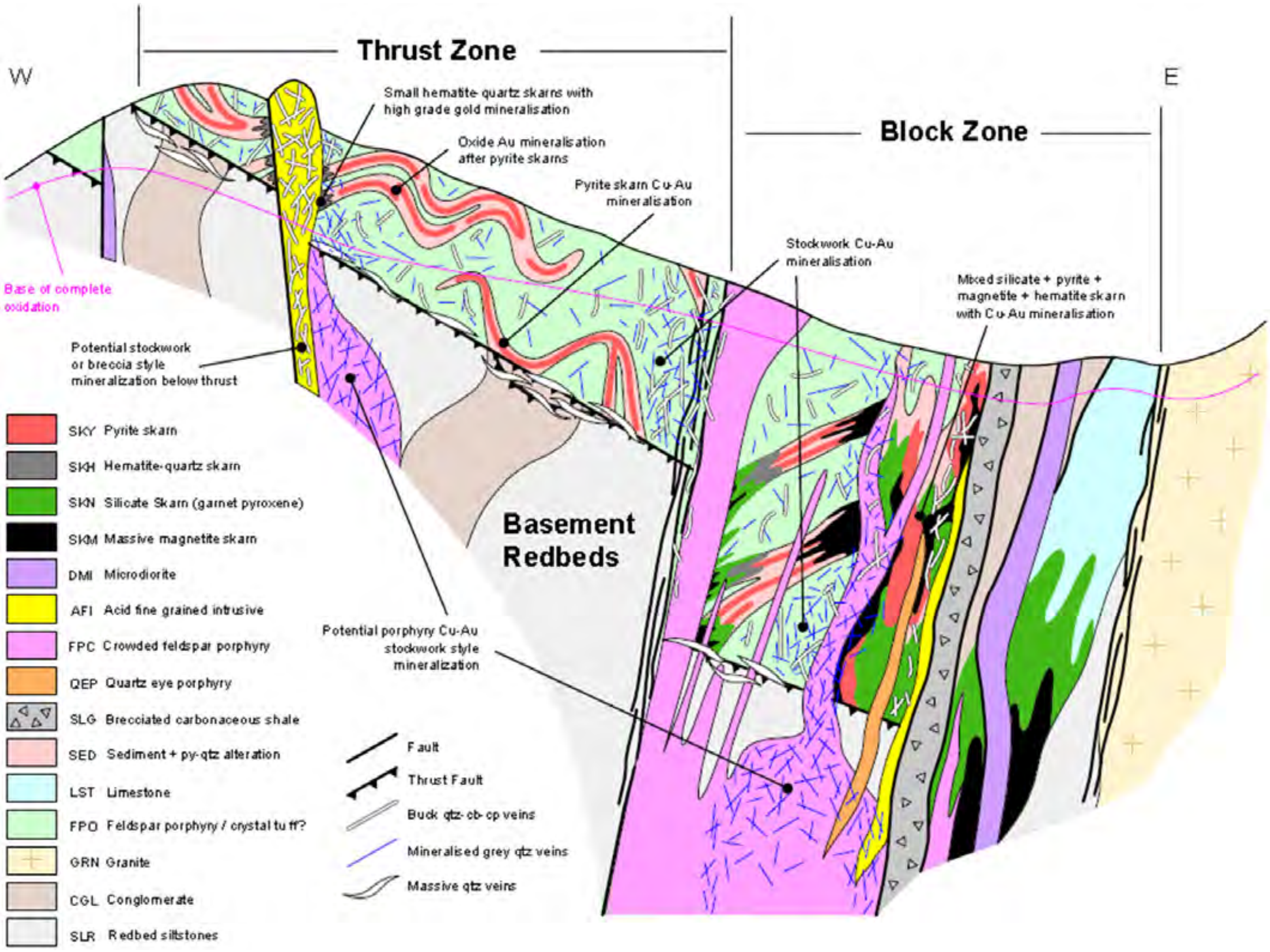

FIG 2 – Phu Kham geological zones.

of weathering vary considerably across the deposit with extremely competent (hard) rock found in the deeper levels. Such variability causes a large range of plant throughput and metallurgical performances.

The operation comprises a large conventional open pit mine feeding ore to a process plant consisting of crushing, grinding and flotation to recover copper and precious metals. Expansion of the Phu Kham process plant in 2012 increased the maximum design capacity from 14 Mt/a to 18 Mt/a through additional grinding and rougher flotation capacity. Further expansion of the cleaner flotation and regrind circuits in April 2013, as described by Bennett, Crnkovic and Walker (2012), effectively debottlenecked the plant with throughput of up to 20 Mt/a achieved with softer ores.

Currently, crushing is performed in a single stage with a gyratory crusher. The grinding circuit consists of a (semi-autogenous grinding) SAG mill and two parallel ball mills each in closed circuit with hydrocyclones. Following this, the flotation circuit, which comprises of roughers, regrind and several cleaning stages, produces a copper-gold concentrate containing 22–25 per cent copper, 7 g/t gold and 60 g/t silver. The Phu Kham flow sheet is provided in Figure 3.

PROJECT BACKGROUND AND SCOPE

Following circuit expansions in 2013, Phu Kham processing plant design capacity was increased to a nameplate capacity of 18 Mt/a. As mining extends deeper into the deposit, the operation will experience an increased proportion of highly competent ores which will have the potential to limit plant throughput, in particular through the SAG mill. Insufficient comminution data in the mine block model created a lack of confidence in the ability to predict mill throughput, particularly in the later years of the mine life.

Phu Bia Mining commenced a throughput forecasting and optimisation project in 2012 to evaluate how to maintain the target throughput over the LOM. Metso PTI was engaged to conduct a full Process Integration and Optimisation (PIO) project. The main objectives were to:

- review the current blasting, crushing and grinding processes, identify opportunities for increasing throughput, and improve overall comminution circuit performance when treating very competent ore types
- develop a throughput prediction model based on geometallurgical modelling for long-term planning and optimisation
- identify if and when secondary crushing or other process changes will be required over the LOM to maximise plant throughput.

METHODOLOGY OVERVIEW

Metso's PIO methodology involves the development of integrated operating and control strategies from the mine to the plant that maximise throughput, minimise the overall energy consumption, cost per tonne, and maximise profitability. This requires an understanding of the physical properties and composition of the orebody, where the valuable mineral is located within it, and what mineral associations exist between the ore and gangue.

The process starts with ore characterisation to define domains within the orebody that will behave similarly throughout the blasting and comminution processes. The SmartTag™ ore tracking system developed by Metso PTI (La Rosa *et al*, 2007) is used to track the characterised ore from the mine, through the crusher and finally into the grinding mills. With the ore source and characteristics known, detailed audits of the blasting and processing operations are used to develop site-specific predictive models for each operation (blasting, comminution, separation). Using these predictive models, the blast design is optimised to generate optimal run-of-mine (ROM) fragmentation for all ore types, and downstream processes can be adjusted accordingly. The models also allow prediction of throughput and recovery performance for each ore domain, and when combined with the mine plan can be used for forecasting, planning and optimisation purposes.

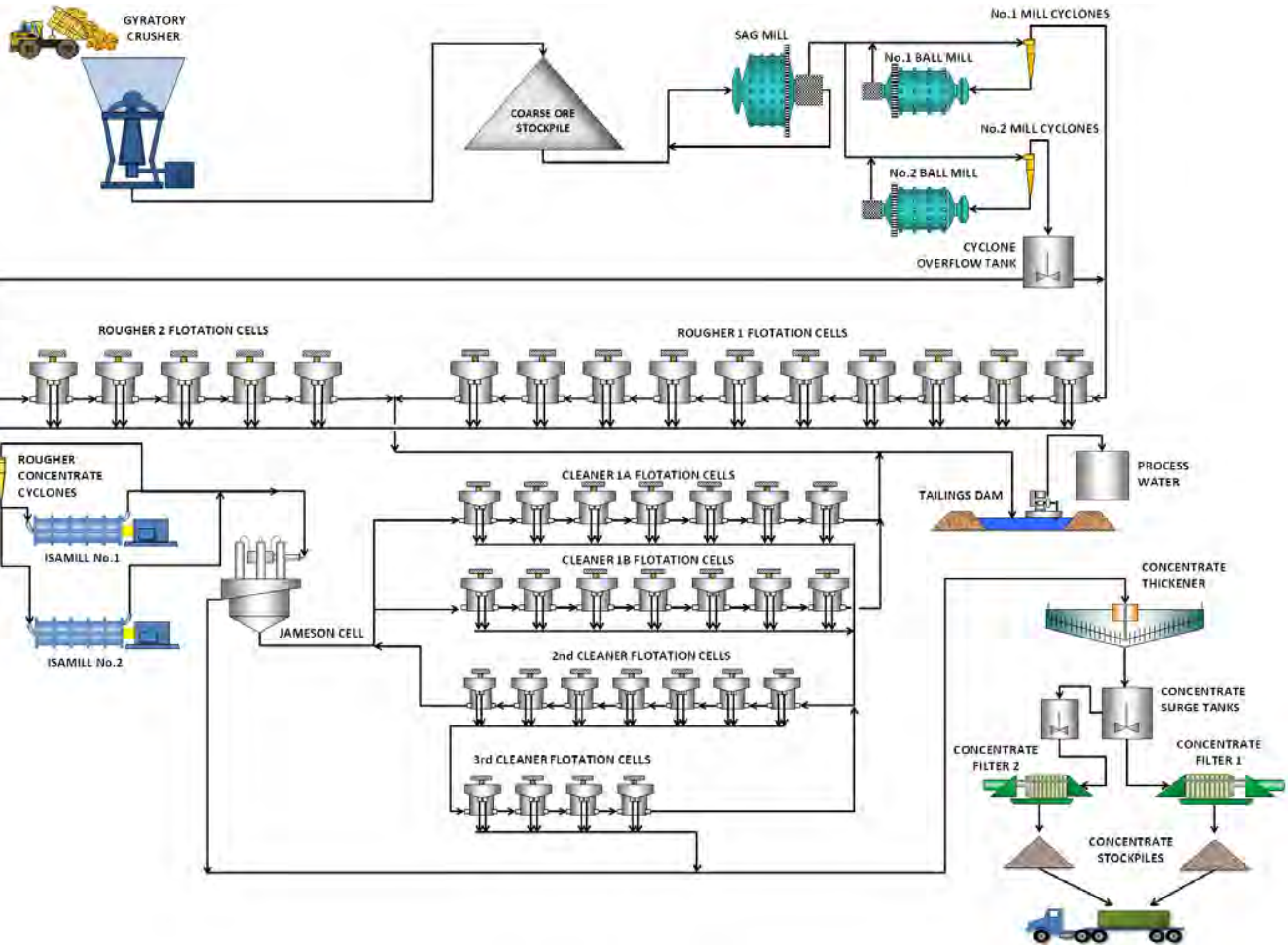

FIG 3 – Phu Kham flow sheet.

The SmartTag™ system is also used to increase the accuracy of geometallurgical modelling and update the block model automatically. The ore is tracked from the mine through the process with SmartTags™ and linked with the plant control system (DCS) to provide actual plant performance data (throughput, recovery, grade, etc) for each ore type and associated blast conditions. These data are automatically compared with model predictions and updated in the block model using the SmartTag™ software. Incorporation of the actual plant data into the block model in real time eliminates the need for further expensive ore characterisation tests. More accurate data in the block model improves mine planning, and the plant receives advance notice of the ore type about to be processed. Adjustments can then be made to blast designs and operating conditions to optimise performance.

ORE CHARACTERISATION

The optimisation methodology starts with ore characterisation in terms of structure, strength and comminution properties. These are used to define ore domains within the geotechnical block model with similar blastability and fragmentation properties.

Rock structure is determined by the *in situ* joints and fractures and can be quantified with rock quality designation (RQD), fracture frequency, and joint mapping. Rock strength can be measured with laboratory tests such as point load index (PLI), drop weight (DWi) or SMC tests, bond ball mill work index (BWi). The unconfined compressive strength (UCS) is a common measure of strength and can be estimated from PLI values to reduce laboratory testing requirements. In general terms, the rock structure affects the coarse end of the ROM fragmentation, while the strength (hardness) affects the generation of fines. Improved plant throughput can be achieved by manipulating ROM fragmentation through optimisation of blasting to reduce top size and increase fines, especially for SAG mills.

At Phu Kham, ore domains were defined based on the RQD (for structure) and PLI (for strength) values in the geotechnical block model. This resulted in a matrix of nine ore domains as shown in Figure 4. Ore within a domain will produce similar ROM fragmentation for a given blast design.

An increase in harder ores is expected in the future at Phu Kham as the pit deepens, and has the potential to reduce throughput. Consequently, the focus of the project was on increasing throughput and improving overall comminution circuit performance when treating the hardest ore types. Therefore, the hardest ore available was selected for a trial blast and was followed by detailed auditing of the blasting and processing operations. For the trial blast, RQD data was obtained from the geotechnical block model, and point load tests were conducted on muck pile samples. These indicated that the trial blast consisted of moderately hard, but reasonably low quality, jointed and fractured rock.

BLAST MODELLING AND SIMULATIONS

One of the main objectives of the project was to develop strategies to maximise mill throughput to maintain LOM operational targets even when treating harder ores. This can be achieved by improving ROM fragmentation through optimisation of blasting practices. A reliable model of blast fragmentation is required to determine the effect of changing blast parameters on ROM fragmentation.

The Metso PTI blast fragmentation model, which is sensitive to the major parameters known to affect blasting performance, was calibrated using the ore characterisation data and design parameters from the audited blast. Image analysis of the ROM size distribution produced by the trial blast was used to calibrate the coarse size fractions. A limitation of image analysis techniques to determine ROM size distributions is that they cannot effectively delineate fines; therefore, the size distribution of the primary crusher product belt cut sample was used to correct the fine portion of the curve. A comparison between the measured and model generated ROM size distribution is shown in Figure 5. The model predictions correlated well with measured values at both the coarse and fine ends of the particle size distribution. This demonstrated that the model was quite accurate in predicting ROM fragmentation, and suitable for simulation studies.

Simulations were conducted using the blast fragmentation model to investigate the impact of changes in spacing, burden, stemming length and blasthole diameter on ROM fragmentation. The parameters of the current blast design and five selected scenarios (with 115 mm diameter blastholes) are provided in Table 1. The corresponding model predictions of ROM size distribution are shown in Figure 6.

As expected, simulations indicated that tightening the blast pattern to increase the powder factor (PF) resulted in a significant increase in the fines generated in the blast. Reduction of stemming length also generated more fines and reduced the top size of the rock due to the increased explosive

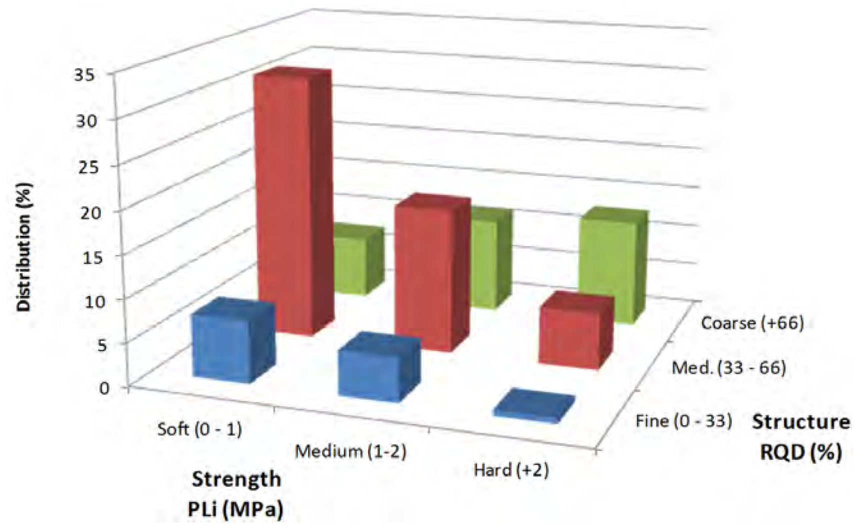

FIG 4 – Definition and distribution of ore domains at Phu Kham.

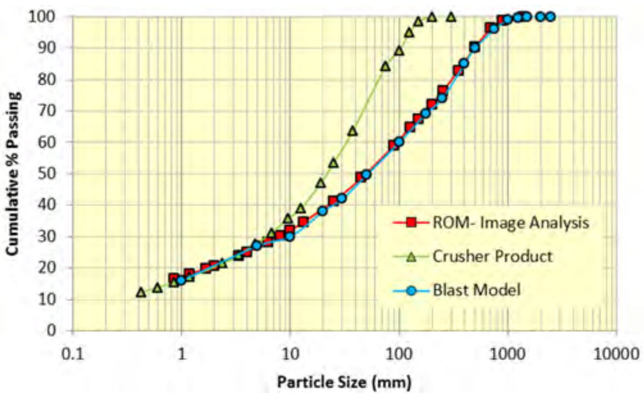

FIG 5 – Blast fragmentation model.

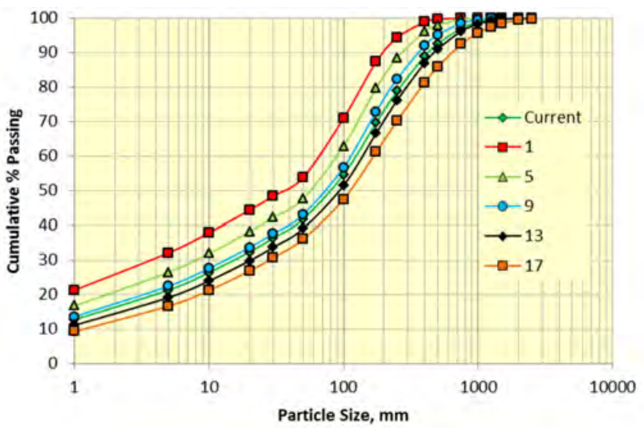

FIG 6 – Selected blast fragmentation simulation results.

energy at the stemming horizon. These simulations indicated potential to increase throughput by increasing the fines and reducing the top size of the ROM fragmentation by optimising the blasting parameters.

Simulations were conducted for each of the nine ore domains (using both 115 mm and 127 mm blasthole diameters). This allows the blast design to optimised for each of the ore domains, and a 'cookbook' is generated which provides a 'recipe' (ie an optimised blast design for each ore domain). Blasting according to this cookbook provides a more consistent and optimised feed size distribution to the downstream processes, increasing throughput, process stability and efficiency. Following the cookbook avoids excessive blasting in softer ore domains, thus reducing energy consumption and costs, and preventing the excessive production of ultrafines that can be detrimental to some downstream processes. This has been successfully applied by PTI at several other large open pit operations globally (Rybinski *et al*, 2011; Burger *et al*, 2006). The final definition of the blasting cookbook at Phu Kham is ongoing.

SMARTTAG™ ORE TRACKING

To link the process performance with ore characterisation and blasting outcomes, the ore from the trial blast was tracked from the mine through the process using SmartTag™ ore tracking.

The SmartTag™ ore tracking system developed by Metso PTI allows parcels of ore to be tracked from the mine, through the crusher and finally into the grinding mills, as shown in Figure 7. The SmartTags™ are built around robust passive radio frequency (RFID) transponders. They do not have an internal power source, so they can remain in stockpiles and ROM pads for extended periods of time. Antennas to detect the SmartTags™ are located at critical points in the process ahead of the milling circuit; tags can be detected a number of times and provide valuable information on material movements. In particular, they make it possible to link the spatial data associated with the ore in the mine to the time-based data of the concentrator.

At Phu Kham, SmartTag™ antennas were installed under the crusher product and SAG mill feed conveyors. The installation on the SAG feed belt is shown in Figure 8. SmartTags™ were inserted into the stemming column of every blasthole for the audited blast. The origin of each SmartTag™ is saved with its unique identification number (ID). As the SmartTags™ and associated orepass the antennas in the process plant, the system automatically records the time and tag ID, thus the source of the ore being processed at any given time is known. During the project at Phu Kham, this ensured that ore from the trial blast was being fed to the concentrator during the plant audits, and allowed correlations to be established between ore origin and process performance.

TABLE 1
Selected blast designs.

	Current design	Scenario 1	Scenario 5	Scenario 9	Scenario 13	Scenario 17
Rock quality designation (%)	25					
Unconfined compressive strength (MPa)	60					
Bench height (m)	10					
Burden (m)	3.5	2.6	3	3.4	3.8	4.2
Spacing (m)	4	3.2	3.6	4	4.5	4.9
Subdrill (m)	1					
Stemming length (m)	3	1.8	2.2	2.5	2.8	3.2
Explosive type	70% emulsion					
Density (g/cc)	1.15					
Powder factor (kg/m^3)	0.69	1.34	0.99	0.76	0.58	0.46
Powder factor (kg/t)	0.26	0.5	0.36	0.28	0.21	0.17
Change in powder factor (%)	-	94.2	43.5	10.1	-15.9	-33.3

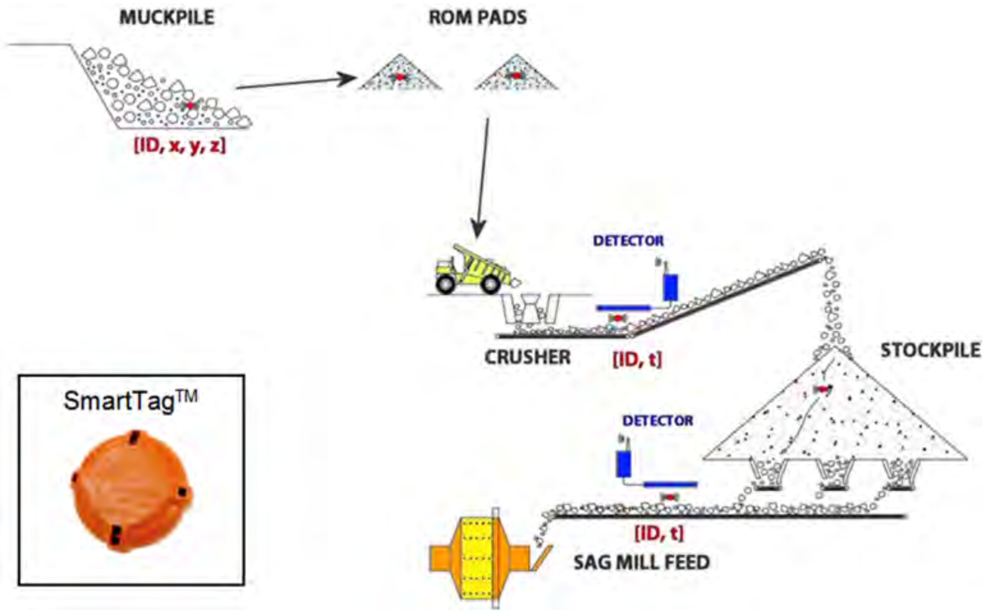

FIG 7 – SmartTag™ ore tracking.

FIG 8 – SmartTag™ antenna installation under the semi-autogenous grinding feed belt.

COMMINUTION MODELLING AND SIMULATIONS

A comprehensive grinding circuit survey was successfully conducted on 4 February 2013 when the circuit was treating ore from the trial blast (as determined by SmartTag™ ore tracking). At the time of the grinding survey the plant was operating under SAG mill limiting conditions, with a total mill load of 29 per cent and mill power draw of 12.0 MW.

Ore samples collected during the site survey were sent for ore characterisation tests, including drop weight (DWT) and Bond ball mill work index (BWi) testing. These tests provide ore parameters required for comminution modelling, and the results from the survey sample are provided in Table 2. The A*b and t_a parameters are determined from the DWT. The A*b value for the ore puts it in the 'moderately soft' category in terms of resistance to impact breakage, and the t_a value falls into the 'soft' range for abrasion resistance. The BWi test conducted at a closing sieve size of 106 µm resulted in a BWi of 13 kWh/t, indicating 'medium hardness' with respect to ball milling.

TABLE 2
Drop weight and Bond ball mill work index test results.

Ore type	A	b	A*b	t_a	BWi (kWh/t)
Belt cut sample	57.8	1.06	61.3	0.67	13

The survey data and measured ore parameters were used to develop and calibrate site-specific comminution circuit models using JKSimMet. The models correlated well with measured data and were considered suitable for simulations and throughput forecasting.

INTEGRATED ANALYSIS – OPPORTUNITIES TO INCREASE THROUGHPUT

The ROM size distributions generated in the blasting simulation study were used as inputs to the comminution models. This allowed changes to blasting practices and comminution circuit operation to be evaluated with respect to the entire operation. This integrated approach was used to determine effective operating strategies to increase throughput when processing harder ores. The results indicated that:

Implementing a tighter blast pattern to increase powder factor (PF) would improve ROM fragmentation and increase throughput. With the existing 115 mm blastholes, a tighter pattern could increase PF to 1.34 kg/m^3 (currently 0.69 kg m^3) and increase SAG throughput by four per cent. For 127 mm blastholes, the PF could be increased to 1.41 kg/m^3 and increase SAG throughput by 6.5 per cent.

Further increases in throughput could be achieved by combining the blasting changes with a reduction in primary crusher closed side setting (CSS). Simulations predicted that a 15 per cent reduction in CSS could increase SAG throughput by more than eight per cent for the 127 mm blastholes.

The changes to blast designs increase the amount of fine material in the SAG feed and reduce the top size of the ROM size distribution, while reducing crusher gap primarily affects the amount of coarse particles in the SAG feed. Therefore, these are complementary strategies for increasing throughput.

THROUGHPUT FORECASTING

One of the primary objectives of the project was to develop a throughput forecasting model based on geometallurgical modelling for long-term planning and optimisation. This was achieved using the integrated site-specific models for blasting and comminution with the Phu Kham LOM plan.

The LOM ore delivery plan provided by Phu Kham was used along with the geotechnical block model to determine the ore characteristics for each period. The structure (RQD) and strength (Is50) results over the LOM are shown in Figure 9, and indicates an increase in both over time until the end of 2019 before sharply dropping off again until the end of the mine life. This corresponds to mining in the deeper, more competent areas of the orebody before some shallower cutbacks late in the mine's life. As is common with long-term mine plans, the resolution of the schedule reduces closer to the end of the mine life. Note that Is50 can be used as a proxy for UCS, which is an important input to the blast fragmentation model.

The ore characterisation values over the LOM block model were used with the site-specific blast fragmentation model to determine the ROM size distribution for each period. The standard (existing) blasting pattern and one of the high energy blast designs were used at this stage; designs from the blasting cookbook could be included once these are finalised. The resulting ROM size distributions were used in the comminution circuit models to predict the throughput of the circuit for each period in the ore delivery schedule.

Note that the comminution circuit models also require ore parameter inputs which are normally determined from laboratory testing. Metso PTI maintains a large database of ore characterisation data which allows the comminution ore parameters to be determined based on correlations with the strength data (Is50) available in the geotechnical block model. The Phu Kham ore Is50 strength values and comminution parameters were determined to fit close to the Metso PTI database correlation range, providing confidence in the comminution parameters within the block model.

The inherent variability and maximum plant capacity were accounted for in the throughput forecast model. Statistical analysis of historical plant data (PI data) indicated that the variability in plant throughput to be in the order of ±10.7 per cent. The plant throughput was capped at 2600 t/h, which was determined to be a conservative limit given the plant variability and historical plant performance. The throughput forecast until 2019 is shown in Figure 10.

A further objective of the project was to evaluate whether or not a secondary crushing circuit or other process changes would be required over the LOM to maintain throughput. The throughput forecast results indicate that the annual throughput target can be achieved until 2018. However, in 2019 when the hardest and blockiest material is scheduled to be delivered, the annual throughput is predicted to be significantly less.

A secondary crushing circuit represents a significant capital investment. Therefore, firstly, the changes to blasting practices and comminution circuit operation identified earlier in the project were investigated to determine whether these could sufficiently increase throughput. These changes included increasing blasthole diameter (as larger blastholes are capable of generating finer fragmentation), tightening the blast pattern to increase powder factor and reducing the primary crusher CSS, as discussed previously. Simulations indicated these changes alone would achieve an ore processing rate of only 1700 t/h in 2019. Further simulations were conducted incorporating secondary crushing into the circuit in 2019. These simulations indicated that the annual throughput target could be achieved with the current blast pattern if the ore is secondary crushed down to a feed size F_{80} of around 40 mm. This suggests for the current LOM plan secondary crushing would be required for 2019 only to achieve the target throughput.

GEOMETSO™ – AUTOMATED GEOMETALLURGICAL MODELLING

Geometallurgy integrates the disciplines of geology, mining and metallurgy with the aim of developing proactive operating strategies as a function of ore variability. Geometallurgical modelling requires a detailed understanding of the relevant ore properties, and models of how these ore properties will affect the performance of the blasting, crushing, grinding and separation stages, in terms of throughput, recovery and product grade. This is the foundation of the predictive models and throughput forecasting implemented at Phu Kham; linking the plant performance with ore properties.

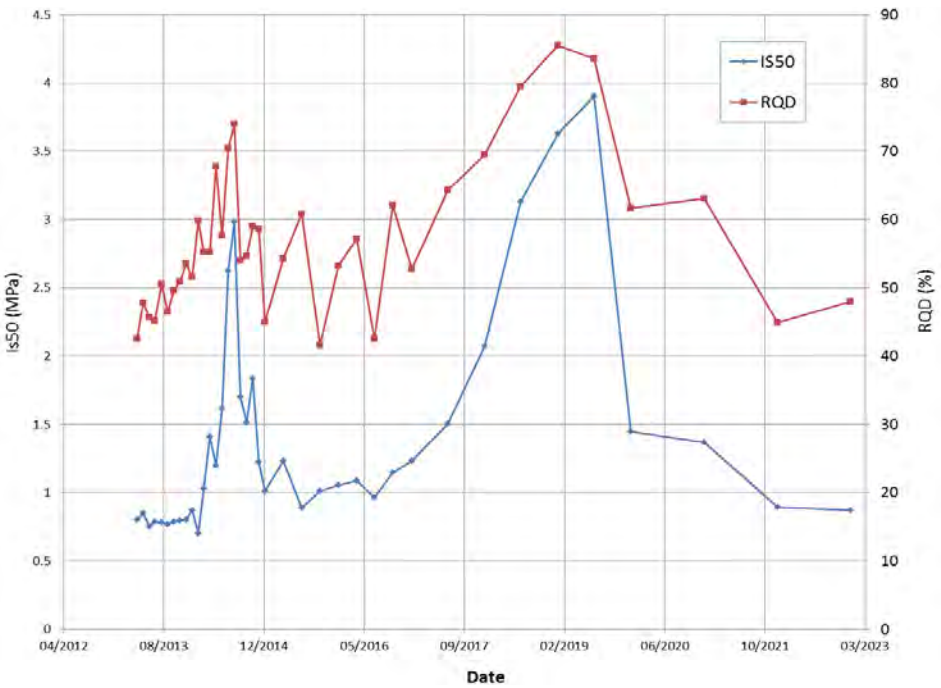

FIG 9 – Average Is50 and rock quality designation values over the mine schedule.

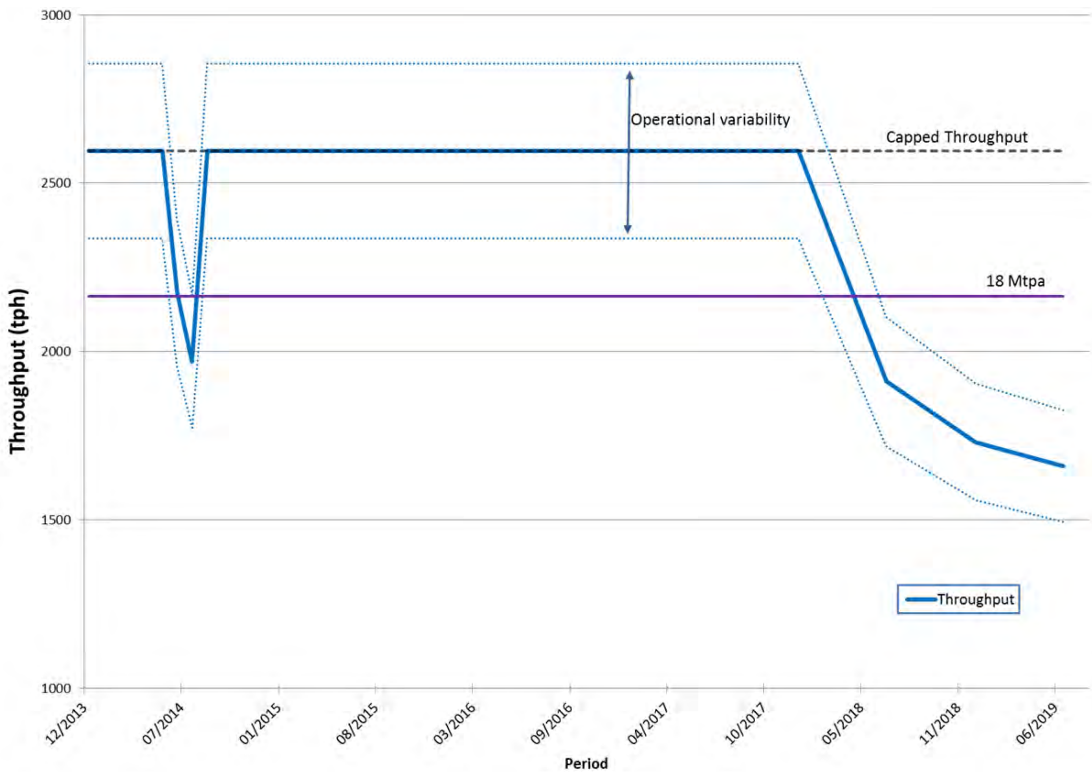

FIG 10 – Phu Kham throughput forecast.

The predictive models rely on ore characterisation data. The collection of ore characterisation data is labour intensive and expensive, and therefore often sparsely distributed across the ore deposit. Additionally, in most mining operations it is difficult to keep track of a 1000 m³ block of ore (and its geotechnical characteristics) from a blast, through ROM pads, stockpiles, crushing and grinding circuits. The resulting uncertainty in feed characteristics makes any empirical approach to geometallurgical modelling difficult.

The SmartTag™ system allows the ore (and its characteristics) to be tracked through the process precisely. An extension of this system, GeoMetso™, provides a link between the ore source (and characteristics) with plant performance data from the process control system and automatically updates the predictive models and block model in real time. It is described in more detail by Lynch-Watson *et al* (2013).

The GeoMetso™ concept is shown schematically in Figure 11. Initial ore domains are defined based on preliminary ore characterisation tests, and predictive models are developed for each unit operation as per the previous methodology. SmartTags™ are then used to continuously track ores from the mine through the process, and when linked with process data from the plant DCS, provide actual plant performance data (throughput, recovery, grade, etc) for each ore type and blast conditions. These data are automatically compared with model predictions and updated in the block model using the SmartTag™ software in real time. Thus, the block model is continuously updated and refined with actual plant data. This eliminates the need for further expensive ore characterisation

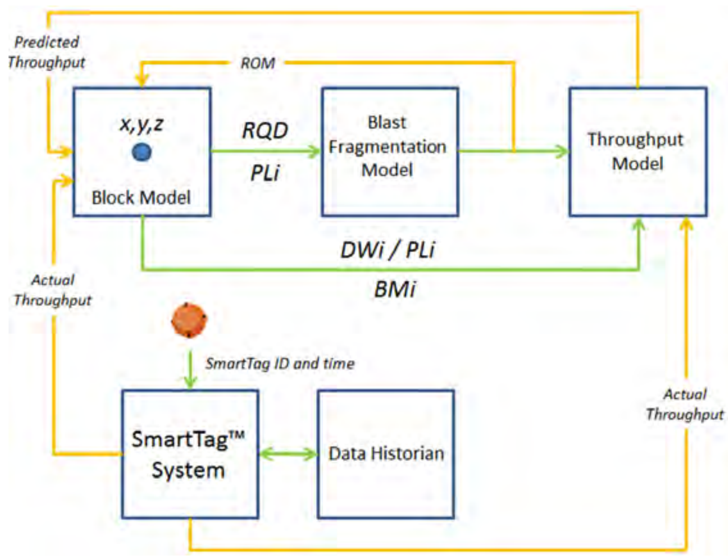

FIG 11 – Schematic of the GeoMetso™ methodology.

tests and improves the accuracy and predictive abilities of geometallurgical modelling.

More accurate geometallurgical modelling and throughput forecasting can improve long-term mine planning, and capital equipment purchases can be predicted well in advance of their requirement. In the short-term, the plant receives advance notice of the ore type(s) about to be processed and adjustments made to operating conditions to optimise plant performance.

The GeoMetso™ system is currently being implemented at Phu Kham. Due to mining operational constraints, the mining activity has predominantly been in heavily weathered areas with soft ore that were not included in the current system. Therefore, only limited data is available to date, but is sufficient to demonstrate the sort of information the system will be able to automatically generate.

A typical screen capture of the system software is shown in Figure 12. In this example, a blast and ore blocks are shown on the right (cooler colours indicate softer ore, and warmer colours harder ore). The mill feed trend is shown on the left and suggests a correlation between the ore hardness and feed rate, with higher feed rates achieved for the softer ores.

More detailed analysis of the data already generated by the GeoMetso™ system indicated several interesting correlations, as shown in Figure 13. The blast design was relatively constant over data collection period, so changes in ROM size distribution would be a result of intrinsic ore characteristics.

The data demonstrates that crusher throughput increases with coarser feed (a result of higher RQD), which seems counter intuitive. However, Phu Kham is located in a tropical zone, and the data was collected during the wet season when fine clay material is known to cause problems with crusher throughput. Therefore, this correlation may not hold true over an entire year. This operational issue may have implications if the powder factor is increased to produce more fines, and will need to be considered in the definition of blasting domains.

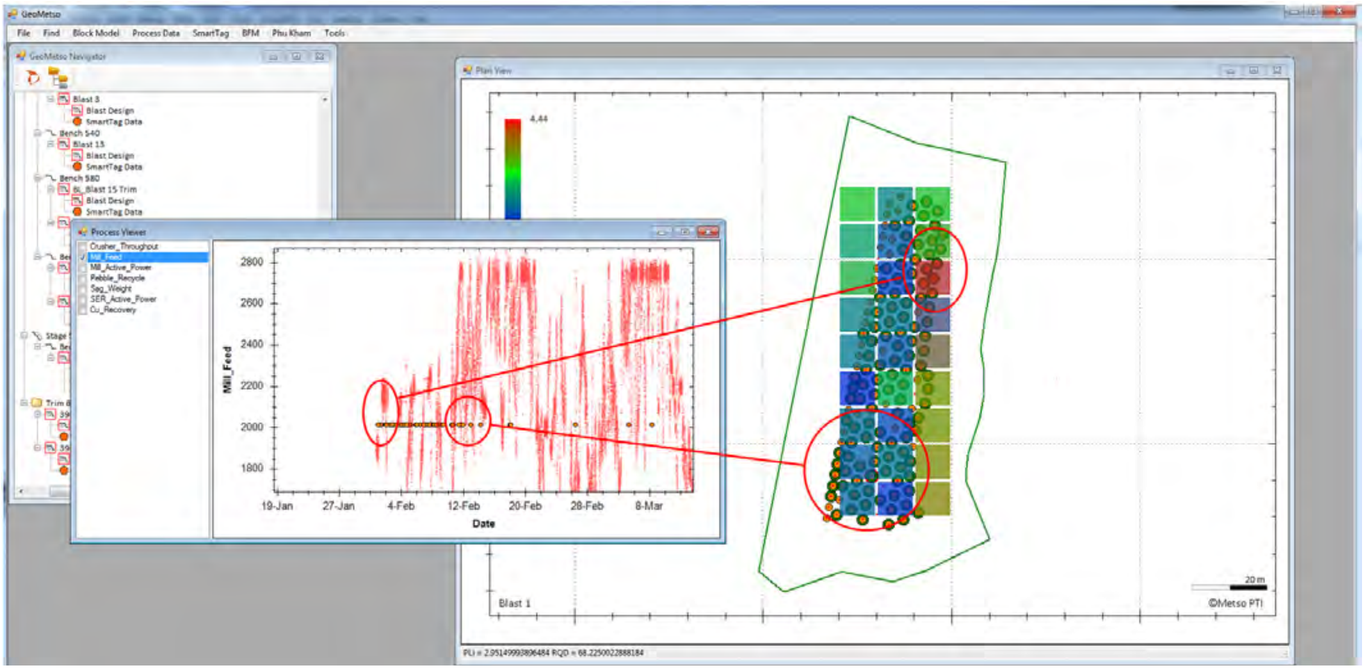

FIG 12 – Example of GeoMetso™ system interface.

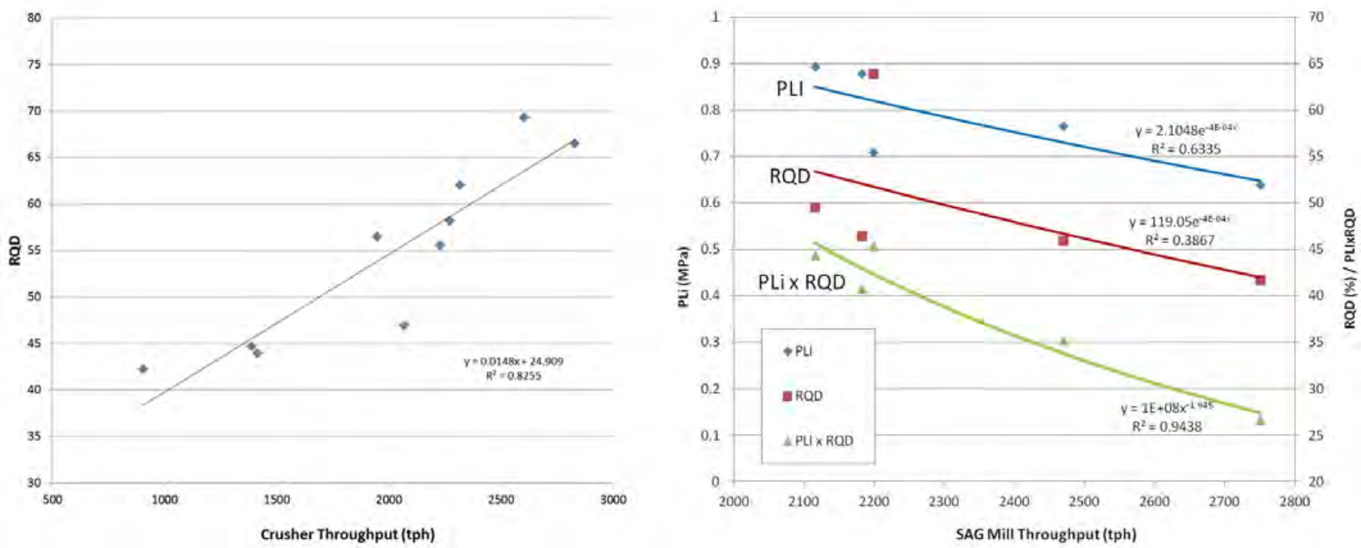

FIG 13 – Examples of correlations established from GeoMetso™ data.

The SAG mill throughput is inversely proportional to feed strength and structure characteristics, with the mill throughput increasing with decreasing strength (PLI) and structure (RQD) indicators as expected. Combination of the parameters into a single 'grindability' index demonstrated an even stronger correlation with an R^2 value of 94 per cent.

CONCLUSIONS

The PanAust – Phu Kham copper-gold operation is expecting harder ore types which have the potential to limit throughput as mining progresses deeper into the pit. To evaluate how to maintain the target throughputs over the LOM, Metso PTI was engaged to conduct a throughput forecasting and optimisation project. The objectives of the project were to identify opportunities to increase throughput when treating hard ore types, develop a throughput forecasting model, and determine if and when secondary crushing or other process changes would be required to maintain the target throughput over the LOM.

The project involved ore characterisation, detailed audits of blasting and comminution practices linked with ore characterisation data using SmartTag™ ore tracking, and development of site-specific models for blasting and comminution processes. These models were integrated to provide an optimisation tool for the overall operation, and for throughput forecast modelling.

Opportunities to increase throughput for hard ores were identified using the modelling tools. These included increasing blasthole diameter, tightening the blast pattern to increase powder factor, and reducing the primary crusher closed side setting. Combining these changes could increase throughput by more than eight per cent.

Throughput forecasting indicates these changes may not be sufficient to maintain the target throughput for 2019 when the hardest and blockiest material is scheduled in the mine plan. The modelling indicates that a secondary crushing circuit would be required to meet the 2019 production target.

The models developed in this project are a useful tool for short and long-term optimisation and planning, as demonstrated by the outcomes of this project. The GeoMetso™ system, which is currently being implemented at Phu Kham, will improve the accuracy of these models by automatically updating the predictive models and block model with measured plant data in real time.

ACKNOWLEDGEMENTS

The authors acknowledge Phu Bia Mining Limited and PanAust Limited for allowing this paper to be published.

REFERENCES

Bennett, D, Crnkovic, I and Walker, P, 2012. Recent process developments at the Phu Kham copper-gold concentrator, Laos, in *Proceedings 11th AusIMM Mill Operators' Conference 2012*, pp 257–272 (The Australasian Institute of Mining and Metallurgy: Melbourne).

Burger, B, McCaffery, K, Jankovic, A, Valery, W and McGaffin, I, 2006. Batu Hijau model for throughput forecast [online], in *Mining and Milling Optimisation and Expansion Studies*, pp 1–21 (SME). Available from: <http://www.metso.com/miningandconstruction/mct_service.nsf/WebWID/WTB-120117-22576-2A79C/$File/107.pdf>.

La Rosa, D, Valery, W, Wortley, M, Ozkocak, T and Pike, M, 2007. The use of radio frequency ID tags to track ore in mining operations, in *Proceedings Symposium on Computer Applications and Operations Research in the Minerals Industries (APCOM),* pp 601–606 (Gecamin: Santiago).

Lynch-Watson, S, Valle, R, Duffy, K, La Rosa, D and Valery, W, 2013. GeoMetso™: a site-specific methodology to optimise production and efficiency over the life-of-mine, in *Proceedings ProceMin 2013*, p 507 (Gecamin: Santiago).

Rybinski, E, Ghersi, J, Davila, F, Linares, J, Valery, W, Jankovic, A, Valle, R and Dikmen, S, 2011. Optimisation and continuous improvement of the Antamina comminution circuit, in *Proceedings Fifth International Conference on Autogenous and Semi-Autogenous Grinding Technology*.