The construction of a geometallurgical model for Mineração Maracá – Yamana Gold, Brazil

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ABSTRACT

Mineração Maracá Indústria e Comércio (MMIC) is a Yamana Gold owned Brazilian Cu–Au mining company operating since 2007. The operation and facilities are located 400 km northwest of Brasilia near the town of Alto Horizonte, state of Goias, and produced (as per 2016) 107 koz of gold, 259 koz of silver and 115 Mlb of Cu.

MMIC asked Altair Mineria S.A. for assistance in building a geometallurgical model to estimate the throughput and recoveries for the 2016–2019 period. The objective of this article is to describe the process of generating a geometallurgical model for MMIC, including aspects such as: representative sampling criteria and design, sampling collection and samples preparation, testing program design, testing quality assurance, base case construction, model construction, and model evaluation.

The developed model requires two kinds of inputs to run, MMIC's block model variables: copper head grade, density, drop weight index and Bond's Ball work index; and user inputted operational set–points such as: F80, P80 and grinding power draw. The model´s equations can be used to calculate block by block metallurgical performance of the ore in the grinding and flotation circuits, allowing planning engineers to obtain production rates by block, for a defined mine plan, and visualizing zones of maximum production.

In conclusion, by using the developed model equations MMIC´s planning team optimize the mine plan with less effort and more accuracy than before, and also this team is able to forecast, on a weekly basis, the plant performance by using the information contained on the block model.

INTRODUCTION

Mineração Maracá Indústria e Comércio (MMIC), also known as 'Chapada', is a Yamana Gold owned Brazilian Cu–Au operation operating since 2007. The Chapada deposit is located within the Neoproterozoic's Mara Rosa magmatic arc of approximately 860 million years old; this magmatic arc is part of the Brasilia Belt which hosts major deposits of Au and Cu–Au in the region. The Chapada deposit contains mineral resources (measured + inferred) of 4.1 Moz of gold, 3.8 Moz of silver and 3.2 billion lb of copper. The mining complex is located 400 km northwest of Brasilia near the town of Alto Horizonte, state of Goias, and produces 107 koz of gold, 259 koz of silver and 115 Mlb of Cu (2016).

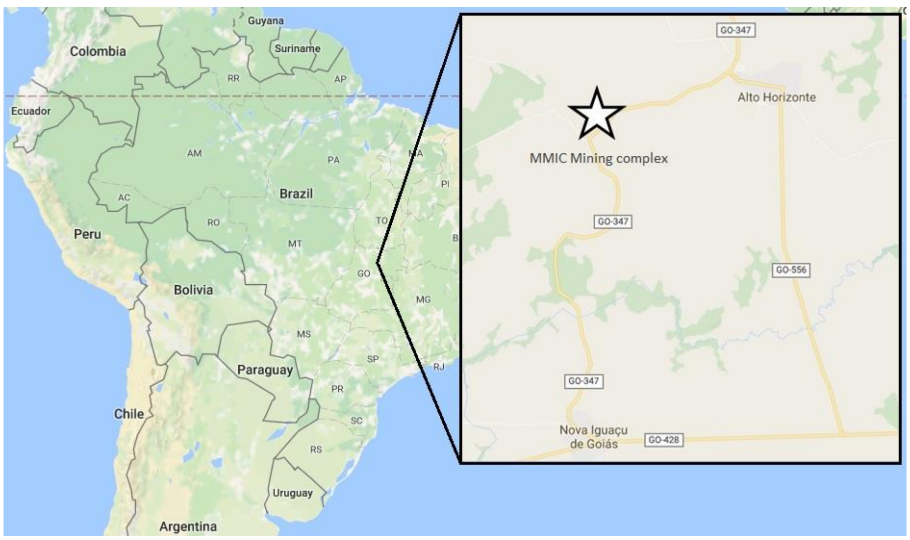

Figure 1 MMIC's Mining complex location

Three operational open pits North, Principal and South feed the concentrator. The ore is sorted by grade and alteration, and then sent to the primary crushing stage or to the stockpiles of high grade, low grade and high altered rock.

The ore from North and Principal Pits are fed into a gyratory crusher & MMD Sizer primary crushing circuit while the South pit's material is fed into a Jaw Crusher. Both primary crushing circuit products are sent to a general crushed ore stockpile which feeds the SABC–AB circuit followed by a flotation circuit with two cleaner stages.

In order to estimate the throughput and metallurgical recoveries for the 2016–2019 period, MMIC contacted Altair Mineria S.A. (ALTAIR) for assistance in building a geometallurgical model. The geometallurgical model involves a set of equations that predict the instantaneous throughput and recovery using two set of data. First, the estimated ore metallurgical parameters that are part of the block model, such as: grades, densities and hardness parameters, and second some user–entered operational variables or set–points, such as ROM's F80, feasible power draw in main grinding equipment and flotation target P80.

Since the throughput and recoveries can be parameterized as a function of operational set–points in each block of the block model, the mine planning team can use these equations in order to find optimal income scenarios based on a given plant operational variable.

METHODOLOGY

Altair´s methodology for building geometallurgical models is based on previous work done by Alruiz (Alruiz et al., 2009) and Suazo (Suazo et al., 2010) developed and tested at Doña Inés de Collahuasi SCM, Chile.

The method comprises the selection of representative samples under technical consideration such as: mine plan, geological/geometallurgical units, tonnage, and grades. Once the samples are in place a series of laboratory metallurgical test are executed in order to obtain comminution and flotation parameters, steady-state simulations for each variability sample, model equations development and display in Mining software. In the case of MMIC, lithological unit classification was used as the main criteria for selecting representative samples, since at that time, alteration and mineralization models were still in progress.

The main feature of this methodology is that the outcomes for TPH and Recovery are industrial results. The comminution and flotation parameters from laboratory test are only used to generate different feasible industrial production scenarios through JKSimMet and FLOTSOFT software. These industrial steady state simulations are used to generate the industrial models.

Mine plan review and sample selection

MMIC lithological information, contained in the block model, was intersected with the mine plan volumes to quantifying the tonnage contribution by each lithology in the mine plan and design the sampling program.

Table 1 Percentage of each lithology in the 2016-2019 mine plan.

Lithology	2016	2017	2018	2019	TOTAL
Northern Pit					
ANX	0%	1%	1%	4%	2%
BTO-CRT	12%	27%	62%	25%	32%
GNS	0%	1%	1%	0%	0%
Central Pit					
ANX	4%	0%	0%	0%	1%
BTO	7%	0%	0%	0%	2%
GNS	26%	22%	14%	0%	15%
MIX	1%	0%	0%	0%	0%
Southern Pit					
ANX	1%	1%	0%	2%	1%
BTO	43%	31%	19%	38%	33%
MIX	1%	1%	0%	1%	1%
QDPB	4%	16%	3%	30%	13%

Only lithologies representing over 5% of the total plant feed were considered in this study. Therefore, the main lithologies were BTO-CRT from North pit (32%), GNS from Central pit (15%) and BTO (33%) and QDPB (13%) from South pit. Additionally, as MMIC requested, the ANX lithology was tested as well.

Two types of samples were used in this study: composite and variability samples. The composite samples represented the global metallurgical response of each lithology in the selected mine plan period. The variability samples represented the local metallurgical response of within each lithology to the process. In this case, variability samples were selected to represent a month period response.

Representative samples were prepared using pieces of drill core and the samples selection and composing process was based on the following criteria:

- The sample must be located inside the ore volume defined by the mine plan.
- The drill core piece must be traceable, physically in existence in the core shed and in good condition.
- The composites samples are built following the same grade distribution of the grades defined found in the mine plan.
- Uniform spatial distribution should be considered when selecting samples.
- The number of variability samples is proportional to the tonnage percentage of each lithology in the mine plan. The more tonnage participation of a lithology in the mine plan the more samples are required for that lithology

Figure 2 shows the spatial location of the samples taken from the South Pit and Figure 3 shows the statistical distribution of the Cu grade in the BTO composite sample matching the 2016–2019 mine plan. The actual composite distribution was verified at the laboratory with actual weight and grades.

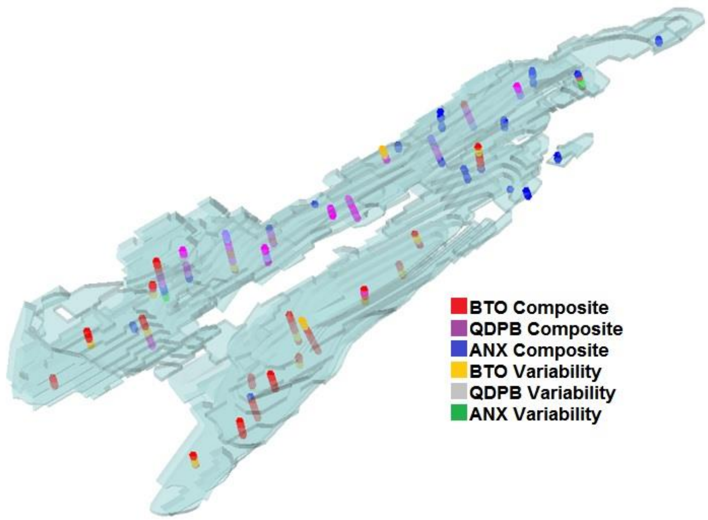

Figure 2 Spatial location of samples within the South Pit taken for composite and variability

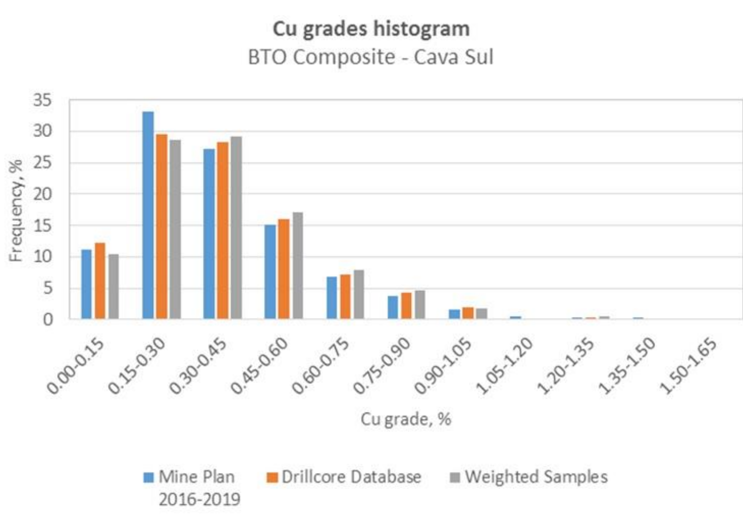

Figure 3 Copper grade histograms, for the BTO lithological unit, calculated from: blocks contained in the mine plan, data from the drill core database and from drill core samples

The calculated and measured average copper grades for the composites were similar within a 5% deviation. The match between actual and designed composites was considered the proof of a correct samples selection methodology.

Laboratory testing program and results

Six composite samples of 300 kg each and 41 variability samples of 16 kg each were sent to SGS Mineral Services laboratory in Santiago–Chile in order to obtain general metallurgical parameters for each lithology. The summary of the laboratory testing program and results are shown in the next tables.

Table 2 Laboratory testing program performed for the composite and variability samples

Tests	Composite Samples	Variability Samples
Number	6	60
Mass required, kg	300	18
Chemical analysis	Cu, CuS, Au, Ag, Fe, S, As, Pb, Zn	Cu, Au
ICP	Yes	No
QEMSCAN	Yes	Some
Eh and pH vs lime addition	Yes	No
Grinding Tests		
SMC Test	Yes	Yes
Bond Ball Work Index	Yes	Yes
Bond Abrasion Index	Yes	No
Grinding kinetics	Yes	No
Flotation Tests		
Rougher kinetics	Yes	P80
Regrinding kinetics	Yes	No
First cleaner flotation (open)	Yes	No
Second cleaner flotation (open)	Yes	No
Locked cycle tests	Yes	No

Table 3 Summary of comminution tests performed over composite and variability samples

Lithology	DWI, kWh/m3		Axb		BWI, kWh/t	
	Composite	Variability	Composite	Variability	Composite	Variability
BTO	4.59	7.26 ± 5.40	57.3	52.9 ± 37.0	12.2	12.5 ± 1.5
QDPB	1.88	3.24 ± 1.70	140.2	104.5 ± 58.3	11.4	11.7 ± 1.5
ANX	3.24	3.91 ± 1.54	81.4	87.3 ± 61.3	12.7	13.5 ± 2.4
BTO-CRT	3.27	5.54	84.3	52.9	15.7	17.0 ± 2.1
GNS	6.3	5.29 ± 1.26	42.9	55.5 ± 15.6	15.9	13.6 ± 3.5

Table 4 Summary of flotation tests performed over composite and variability samples

Lithology	Cu Recovery		Au recovery		Mass Pull	
	Composite	Variability	Composite	Variability	Composite	Variability
BTO	91.2	89.4 ± 3.6	75.4	68.9 ± 5.9	8.3	7.6 ± 1.1
QDPB	88.6	84.8 ± 5.4	60.3	60.9 ± 5.9	7.4	7.1 ± 0.8
ANX	81.1	73.2 ± 9.7	52.2	28.6	6.5	4.8 ± 0.1
BTO-CRT	91.2	92.2 ± 3.4	67.1	60.1 ± 15.9	8.1	8.2 ± 1.9
GNS	86.8	86.4 ± 4.2	63.2	64.4 ± 11.6	9.1	11.5 ± 2.9

Steady state simulations

The first step in the construction of the geometallurgical model is to develop the Base Cases. ALTAIR analysed MMIC´s historical operational data from January 2014 until February 2015 to collect the required comminution data. The Base Case intends to represent an average actual operating condition which includes favourable and unfavourable conditions caused both by ore and by equipment. The grinding Base Case circuit simulation includes from primary crushing up to overflow of hidrociclones. The flotation base case circuit starts in rougher and ends in final concentrate. These base cases were built using the steady-state simulators JK SimMet for grinding and CONASAS' FlotSoft® for flotation. The base cases are considered a well–known concentrator operational condition, and from that point is possible to simulate outcomes when different ores and grades are processed. In order to run the Base Case simulation, both software require the following information:

- Circuit flowsheet.
- Equipment information obtained from the original/actual equipment blueprints and manufacturer's data sheets.
- ROM particle size distribution estimated from image analysis software's measurements.
- Ore comminution/flotation parameters, obtained by weighted average of laboratory results with the tonnage of each lithology fed into the plant during the period.

Using all this data, JKSimMet and FlotSoft® were run to generate a database of simulations for each variability sample at different operating scenarios. For instance: different tonnages, different grades, different P80 to flotation, and different ROM particle size distributions.

In the case of grinding model, Figure 4 shows the relation between specific energy consumption and P_{80} to flotation. Each point represents a simulation in JKSimMet. Note that for a given P80, several values of specific energy appear. This "broad band" phenomenon can be explained by other important variables that affects the specific energy, such as the ore hardness (DWI or BWI) and the particle size in the feed (F_{80}).

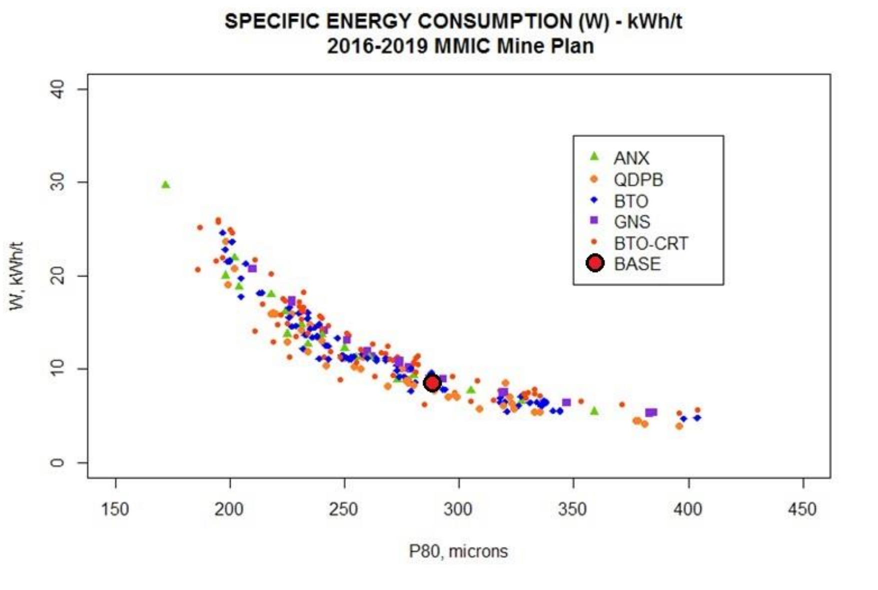

Figure 4 Summary of JKSimMet simulations (W vs P_{80}) for each variability sample

Development of model equations

To find the grinding model structure a predefined searching routine is applied, trying different variables and combination of these. The candidate variables are chosen based on well-known empirical grinding relations and equations, also using Altair´s experience from previous work. Once the structure of the model is defined, the most statistically significant variables become part of the model. The other variables are discarded. This statistical methodology for variable selection is known as stepwise regression.

Throughput Model

The throughput model is based on the relation $P = W \times TPH$; where P is the available power draw and W is the specific energy consumption for a given circuit, ore and operational parameters. The Chapada grinding model is comprised of two equations, one for specific energy and another for throughput. The global prediction error (between simulation database and grinding model) for the specific energy consumption and throughput are 2.7% and 2.9% respectively. The equations are the following:

$$W = 3.05 + 4365.28 \times \frac{F_{80}}{P_{80}^{2.3}} - 0.65 \times \frac{SG}{DWI} + 28.23 \times 10^{6} \frac{BWI}{P_{80}^{2.3}} \quad (1)$$

$$TPH = -12.0582 + 1.0403 \times \frac{P_{SAG} + P_{BM}}{3.0415 + 4365.2790 \times \frac{F_{80}}{P_{80}^{2.3}} - 0.6476 \times \frac{SG}{DWI} + 28234950 \times \frac{BWI}{P_{80}^{3.2}}} \quad (2)$$

The model input variables and parameters come from two sources, the block model and circuits design or historical data. For Equations (1) and (2), values of *SG*, *DWI* and *BWI* are acquired from the block model estimation done by geologists and the rest: F_{80}, P_{80} P_{SAG} and P_{BM} are submitted by the planning team. For instance, the grinding power draw P_{BM} and P_{SAG} depends on the programmed power draw strategy and maintenance plan, and the P80 is fixed by the metallurgist based on a given operational strategy.

Recovery Model

A similar approach to grinding structure is used to find the recovery model structure. In Chapada case, the copper recovery model equation the statistical meaningful variables were copper grade, Bond Ball Work Index and the P_{80}. The global prediction error (between database simulation and model) for the copper recovery is 4.5% and the model equation is shown next.

$$RCu = \begin{cases} 32.3912 + 105.9598 \times Cu + 3.1713 \times BWI - 0.02296 \times Cu \times BWI \times P80 & RCu < 90 \\ 90 & RCu \geq 90 \end{cases} \quad (3)$$

RESULTS AND DISCUSSION

The hardness parameters obtained from the laboratory testing program were used by the geology team to estimate DWI and BWI for all blocks in the period of analysis.

The geometallurgical model equations were programmed in a script using the MineSight 3D® mining software and then displayed in colours to identify the higher throughputs and recoveries zones at a P_{80} of 250 µm. Since throughput and recovery can be calculated using the models, and grades are part of the block model; the planning engineers can estimate the total copper output and visualize the results in the block model itself. The visualization of the copper production by block using colours, allows the planning team to optimize the production plan.

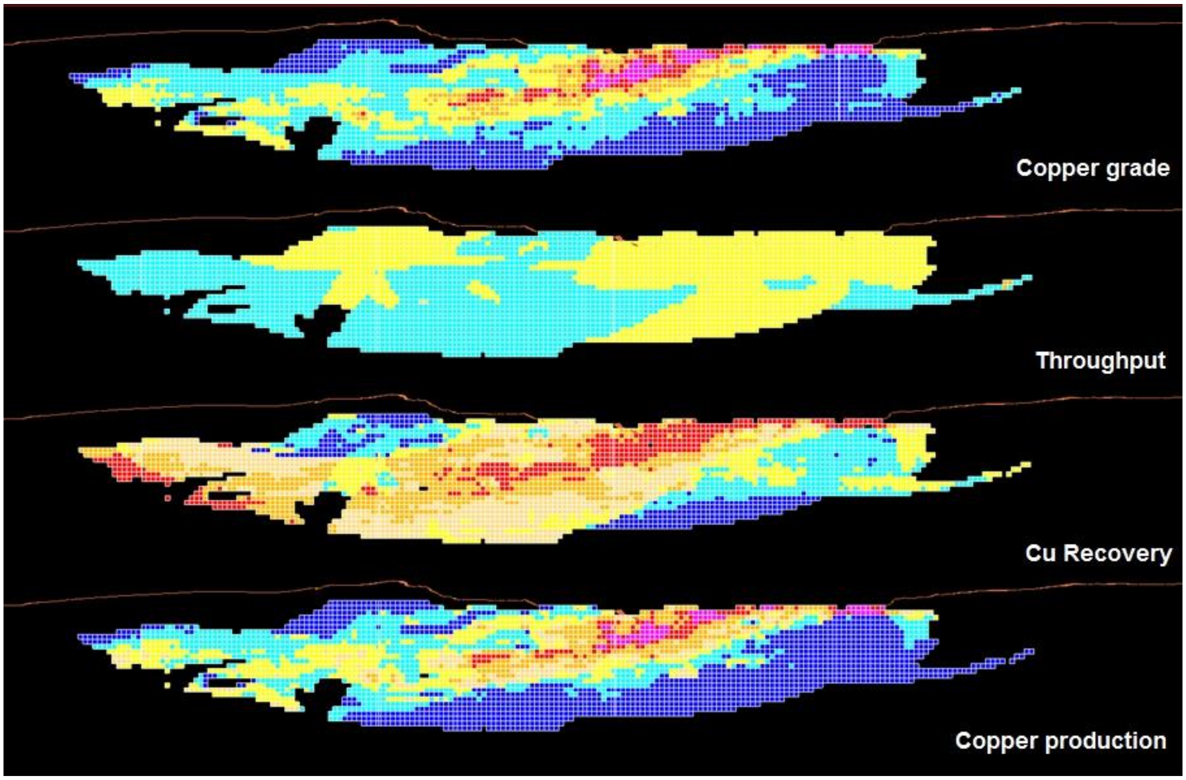

Figure 5 From top to bottom: Sections of MMIC pit showing copper grades, throughput, copper recovery, and total copper production at a fixed P80 (250 µm)

CONCLUSION

MMIC´s Geometallurgical Model shows to be a very useful tool allowing planning engineers to obtain different production rates by block and visualizing maximum production zones. Therefore, by using this model the planning team can optimize mine plan with much less effort and much more accuracy than before. Also, with this model is possible to forecast in a weekly basis the plant performance by using the information contained on the block model for the short-term production polygons.

Also, the model gives an adequate platform for future calculations. For instance, for a specific mine plan, it would be possible to calculate the operational income and the operational cost associated to this process. The income could be calculated by multiplying the copper production by the copper price; whereas the variable cost function can be estimated using the specific energy consumption (W) to estimate the energy and steel consumptions. All these expressions could be linked to calculate a 'plant operational profit' for each block in the block model. Since these functions depend on operational variables such as P_{80} or F_{80}, mine plan could be optimized by moving these variables to find an optimal production scenario based on the ore characteristics.

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NOMENCLATURE

BWI	Bond Ball Work Index, kWh/t
Cu	Copper head grade
DWI	Drop Weight Index, kWh/m³
F80	80% passing of the primary crusher product or SAG Mill feed, mm.
P80	80% passing of the primary crusher product or SAG Mill feed, mm.
PBM	Average Ball Mill power, kW.
PSAG	Average SAG Mill power, kW.
SG	Specific gravity
TPH	Throughput, t/h
W	Specific energy consumption of the grinding circuit, kWh/t.

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