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Mine-to-mill reconciliation—variability study of blast hole sampling in Serra Grande gold mine

ABSTRACT

A significant amount of apparent mining losses are due to estimates being based on erroneous data. To minimise such losses, so-called reconciliation practices are applied. These involve comparing grades estimated on the basis of a geological model with product based grades and computing an adjustment factor. They have assumed an increasing importance for the mining industry. Historically, reconciliation has been performed improperly by the use of the Mine Call Factor (MCF), which expresses the ratio of production predicted by the models and production recorded at the plant. However, the application of adjustment factors may disguise the errors associated with incorrect grade estimation as well as propagating such errors to mine planning and grade control. The Theory of Sampling is a powerful tool which includes procedures for carrying out representative sampling, i.e., for obtaining accurate samples and minimising sampling errors. This paper aims to assess the sampling from blast holes at the open pit of the Serra Grande gold mine in Brazil, for short-term planning and decision making within its Mine-to-Mill (MTM) program.

INTRODUCTION

Ideally, every mining enterprise should have its unit operations controlled by an integrated system for evaluating each processing step. Reconciliation is an important tool for such evaluation, especially for mine planning. It provides quality assurance in both long and short terms. Reconciliation aims to compare the grades obtained by the processing plant with those estimated by geological models of the deposit. The synergy between mining and processing (Mine-to-Mill or MTM) allows the operation to achieve better use of natural resources and higher economic performance.

Over many years, the practice of reconciliation has been used incorrectly by using a Mine Call Factor (MCF) which adjusts models in an attempt to improve the forecasting performance of the operation. Such a practice generally attempts to estimate discrepancies between actual grades (plant) and grades estimated by the geological models. According to Morley (2003), this is not the best industrial practice of reconciliation. Correct practice of reconciliation should assess the causes of discrepancies and make changes to sampling methodology in order to reduce these variances to an acceptable level.

Correct sampling methodology should result in representative and unbiased samples. This objective is achieved when proper equipment operation and sampling techniques based on theories that minimise sampling errors are used. In this context, statistics and geostatistics provide powerful tools for assessing errors associated with sampling and for minimising them.

This paper presents a study of blast hole sampling methodology that was conducted at Mineração Serra Grande, a Kinross/Anglo Gold Ashanti's gold mine in Brazil.

METHODOLOGY

Blast hole sampling

Body I5A (carbonaceous schist) was chosen for this study because it was considered representative of the lower zone of open pit, which is typical of the next year's lifespan of the mine. During the drilling work, material from all blast holes between 1 m and 2.5 m deep was collected using a special canvas (Figure 1). These accounted a total of 130 samples weighing approximately 10 kg each. The drilling work was carried out with a hydraulic drill model DC550.

Figure 1 The selected blast hole sampling procedure for MTM reconciliation

Processing plant sampling

So that the average grade estimated in the mine could be compared with the processing plant feed, the plant was run for a time using only the block sampled on Body 15A, thus resulting in a reference grade for MTM reconciliation. 50 samples weighing approximately 2 kg each were obtained at 15-minute intervals from the crushing plant product conveyor belt.

Sampling was carried out using a shovel, endeavouring to cut the entire flow at a constant speed to simulate the rectilinear motion of a cross-flow sampler.

Sampling for particle size and grade distribution analysis

A successful reconciliation can be deceptive. In many cases, errors generated at some point of the process compensate the errors generated elsewhere, resulting in excellent reconciliations (Crawford, 2004). In order to quantify the loss of fine material during blast hole sampling, particle size and grade distribution analysis were carried out at the material obtained from two different sampling procedures.

For this purpose a new sampling campaign was conducted in Body I5A, collecting twin samples using two different methods. The first (A) sample was collected following the same procedure as the previous blast hole sampling. The second (B) sample used a cut drum fitted to the drill, enabling the recovery of fine material that would not have been collected during the first sampling procedure. A pneumatic drill PWH-5000 was used, with a cut drum which was adapted for collecting the fine material.

The opening sizes of the sieves used in screening for particle size and chemical distribution were: 5.66; 3.66; 2.00; 1.00; 0.59; 0,297; 0.149; 0.105 and -0.105 mm.

Figure 2 shows the procedure for the new sampling campaign.

Figure 2 The two sampling procedures for particle size and grade distribution analysis

It's worth emphasising that this campaign was carried out simply to quantify the loss of fines generated by the blast hole sampling procedure using the canvas and, thus, to analyse the reliability of the sampling method selected for this study.

PRESENTATION, ANALYSIS AND DISCUSSIONS OF RESULTS

Chemical analysis results

Table 1 shows the average results of chemical analysis from the first blast hole sampling campaign, performed using the canvas. These results were compared with the results of the sampling campaign at the processing plant which, according to Crawford (2004), are much more accurate than the results of sampling at the mine. Therefore, these results were considered the reference for calculating the estimate error of blast hole sampling.

Table 1 Results of chemical analysis

Sampling	Average grade (g/t)	Variance	Error mean	Error variance	Estimate error
Blast hole	1.58	4.2	-0.09	0.18	1.25%
Plant	1.60	0.53	0.06	0.24	

Blast hole sampling analysis

The blast hole sampling showed acceptable results in that the average estimated error was only 1.25%.

However, following the aim of this study, it is important to examine the sampling methodology. The design of a sampling system should always aim at the elimination of errors in order to obtain the most representative samples at an acceptable cost (Grigorieff, Costa & Koppe, 2002).

It was noted that the main problem of blast hole sampling was the loss of fine material, mainly due to wind. The impact of loss of fines was assessed by both particle size and grade distribution.

Table 2 Results of particle size and grade distribution analysis

		A sample (using canvas)			B sample (using cut drum)		
Mass (g)		8650			9470		
Grade (g/t)		0.73			0.74		
		Mass (g)	Relativy mass (%)	Grade (g/t)	Mass (g)	Relativy mass (%)	Grade (g/t)
Opening (mm)	5.66	1180.9	14.14	0.60	973.4	10.28	0.59
	3.66	1016.9	12.17	0.56	852.5	9.00	0.55
	2.00	1958.4	23.45	0.57	1766.6	18.65	0.79
	1.00	1370.7	16.41	0.58	1390.6	14.68	0.62
	0.59	468.3	5.61	0.59	533.5	5.63	0.56
	0.297	691.8	8.28	0.63	884.6	9.34	0.60
	0.149	431.2	5.16	0.79	683.3	7.21	0.71
	0.105	123.4	1.48	1.63	322.5	3.40	0.91
	- 0.105	1111.2	13.30	1.47	2065.0	21.80	1.01

Discussion of results

The A and B samples were expected to show similar grades as they were closely spaced with the same depth. However, the B samples had a significantly greater mass (8.7%) than the A samples. Moreover, percent passing in the finest size fraction was even greater for B samples than for A samples, indicating that the cut drum worked properly.

Even though there is much heterogeneity, Table 2 indicates that grades associated with coarser fractions were similar for A and B samples. However, for the two finest size fractions (0.105 mm and -0.105 mm) the grades varied substantially, with the A samples having a higher grade than the B samples in these fractions.

The total mass associated with the two finest fractions in sample A is halved compared to sample B. Such a trend was not observed for the coarser fractions. An intuitive explanation is that the coarser and heavier particles are less influenced by the wind dragging effect. The fine material was preferentially dragged by the wind as compared to the coarser fractions which were properly recovered. Moreover, in this case the high density of gold played a role in concentrating it in the fine fractions, as the relatively light grains of silica were preferentially dragged by the wind.

Processing plant sampling analysis

Variogram analysis

Sampling accuracy is measured by assessing the variability around the average for a specific set of samples. This measure is usually expressed as the variance of sampling error.

The variogram was used in this study for carrying out the analysis of regionalised analysis. If increments show variation smaller than 20% it can be assumed that the variogram of grades (*tq*) is practically the same variogram of heterogeneities *Q* (Gy, 1998).

There are several methods for estimating the 'nugget effect' $v(0)$ associated to a variogram. The most appropriate method here considered was to calculate the variance based on duplicated samples, in this case calculated by the difference between grades of duplicates. According to Gy (1998), the variance of this population of differences is an excellent estimator of $2v(0)$.

Semi-variogram

Semi-variogram is better than variograms for comparisons with classical statistics. The variogram is calculated by the variance referred to the difference between two values (one pair of samples separated by distance or period *j* between them). When comparing the value obtained by the variogram with that obtained by classical statistical, it is thus necessary to divide this variance by two (Pitard, 1993), $2v(0)$ representing the variogram and $v(0)$ represents the semi-variogram.

The semi-variogram function results in correlation between samples separated by a period *j* allowing setting a minimum interval j_{min} between samples. This is used to achieve the best representative of the studied set. From the point where the curve of the semi-variogram reaches the threshold or statistical variance, there is no further correlation between samples, indicating that these can be treated as uncorrelated random variables.

The grades of duplicate samples obtained in the plant were used to calculate an experimental semi-variogram. The estimate of $v(0)$ was based on the variance of duplicates. The calculations of variance and the experimental semi-variogram are shown in Table 3 and Figure 3 that follows.

Table 3 Results of the plant sampling

Interval *j*	*v(0)* 'nugget effect'	Statistical variance 'sill'
15 min	0.242	0.521

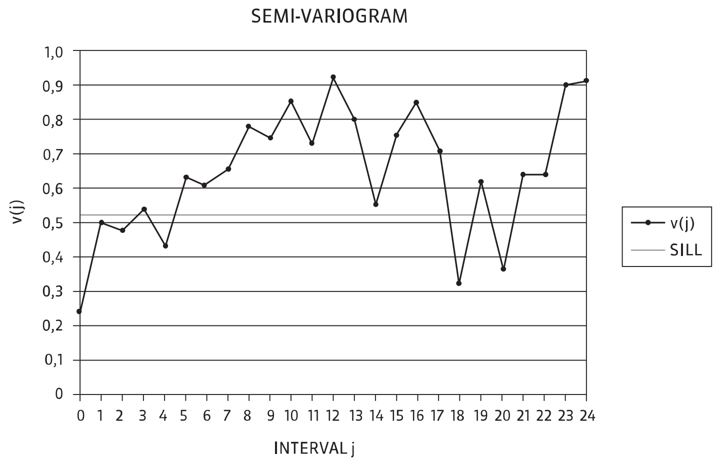

Figure 3 Semi-variogram of processing plant sampling

The analysis of the experimental semi-variogram shows that from the third interval (*j*=3), the curve surpasses the threshold starting to vary around the threshold. It was thus concluded that there were correlation between samples collected only for intervals equal to or less than 30 min (*j*=2).

Integration error analysis

The study of the integration error (IE) associated with the collection of samples from a one-dimensional flow (conveyor belt) allows the calculation of sampling error generated for each *j* interval between collected samples.

The integration error variances were here calculated for each interval *j* considered. The time interval value considered for the calculation of variance was obtained by multiplying the *j* value by the minimum interval between collected samples (in this case, 15 minutes). It was also calculated for the 95% confidence – represented by ±2s(IE), – assuming that the errors follow a normal distribution. The calculated values are shown in Table 4.

Table 4 Calculation of integration error variance

j	v(*j*)	*s2*(*IE*)*sy*	*s*(*IE*)*sy*	*Sst* 95%	*Sst* 95%
0	0.242	-	-	-	-
1	0.498	0.0076	0.0869	0.1738	10.9%
2	0.481	0.0110	0.1047	0.2094	13.1%
3	0.544	0.0132	0.1149	0.2299	14.4%
4	0.435	0.0140	0.1200	0.2400	15.0%
5	0.637	0.0155	0.1244	0.2488	15.5%
6	0.614	0.0167	0.1290	0.2580	16.1%

Table 4 shows that the integration error variance increases with increasing the interval between collected samples and with decreasing the number of increments.

According to Pitard (1993), in case of gold ore, the maximum acceptable deviation for the sampling error is 16%. The analysis of experimental semi-variogram indicated that only for intervals equal to or lower than 30 minutes (*j*=2) there was correlation between collected samples. However, the integration error is not the only one that includes the global error estimation. Table 4 shows that in any interval smaller than six errors are smaller than 16%. As it starts with 10.9% error (associated with the interval *j*=1) any of them may be considered adequate.

CONCLUSIONS

Within a Mine-to-Mill programme, sampling campaigns carried out on the mine and on the plant were considered as reference values for reconciliation analysis.

Based on sampling theory, the best sampling procedure was carried out for collecting material from all blast holes associated with the studied block. The achieved reconciliation was here considered excellent as it showed 1.25% error.

According to Schofield (2001) for many professionals the reconciliation is the final mass and grade reconciliation quality test resulted from resources and cut grade models. However, a diagnostic of the entire process sampling is required for estimations. Therefore an additional sampling campaign was carried out for assessing particle size and gold grade distribution. Such an analysis indicated that losses might bias the sample, by overestimating the grade of finer fractions.

The work developed by Chieregati et al. (2011) enhanced the performance of sampling at Serra Grande by minimising losses of fines during blast holes sampling. The use of a sectorial sampler with a cupola (see Appendix A) thus reduced the fine losses and increased the sample's representativity. The practice resulted in more reliable data for reconciliation and thus for the entire mining chain.

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APPENDIX A

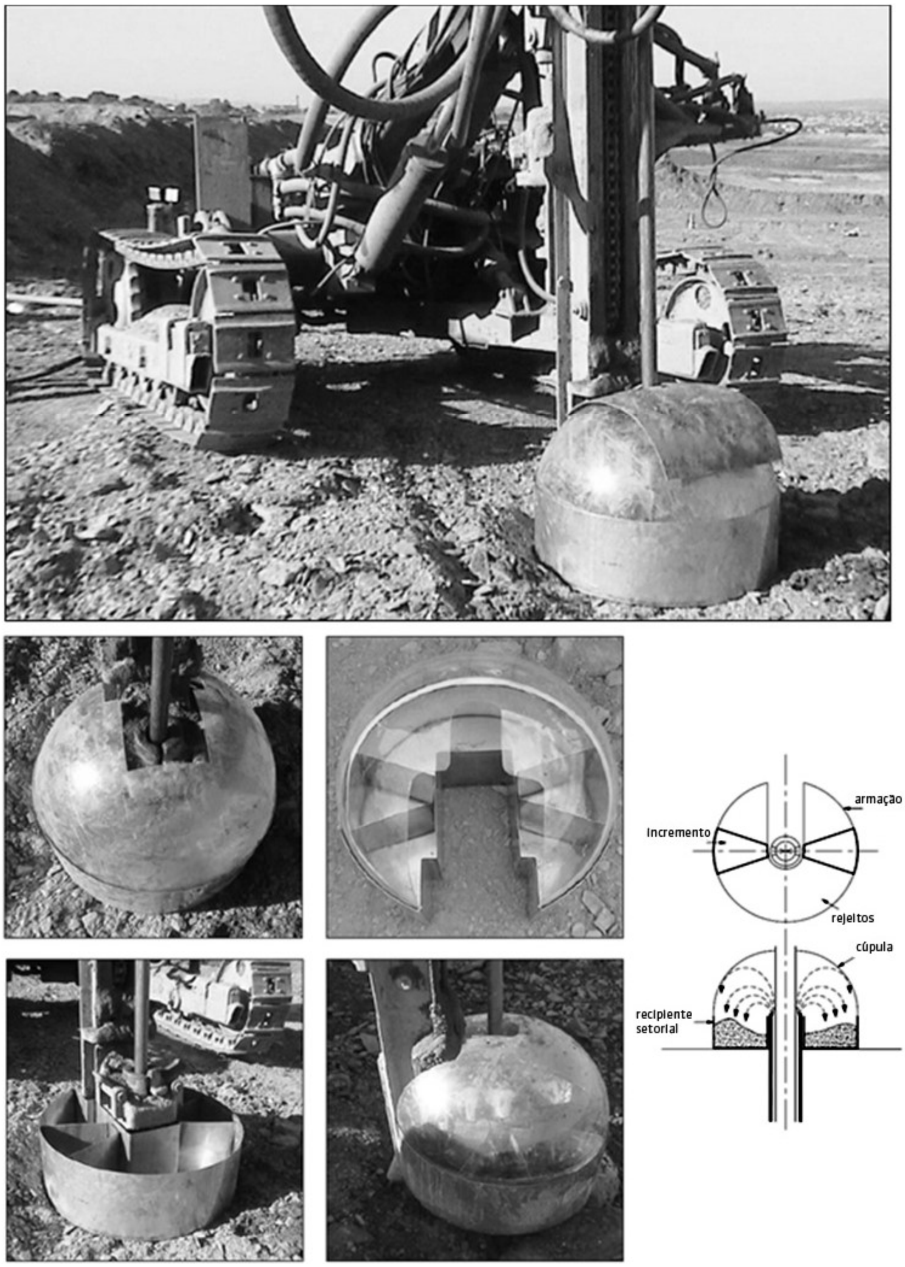

Figure A1 Stationary sectorial sampler (Chieregati, 2007)