Illusory reconciliation: the importance of sample representativeness

Reconciliação ilusória: a importância da representatividade na amostragem

Thammiris Mohamad El Hajj
Universidade de São Paulo
thammiris.poli@usp.br

Ana Carolina Chieregati
Universidade de São Paulo
ana.chieregati@usp.br

Homero Delboni Junior
Universidade de São Paulo
hdelboni@usp.br

Luiz Eduardo Campos Pignatari
Yamana Gold Inc.
lpignatari@yamana.com

Resumo

No contexto da indústria mineral, reconciliação pode ser definida como a prática de comparar a massa e o teor médio de minério previstos pelos modelos geológicos com a massa e teor gerados na usina de beneficiamento. Essa prática tem se mostrado cada vez mais importante, visto que, quando corretamente executada, aumenta a confiabilidade no planejamento de curto prazo e otimiza as operações de lavra e beneficiamento do minério. No entanto, a utilidade da reconciliação depende da qualidade e confiabilidade dos dados de entrada. Uma boa reconciliação pode ser ilusória. Em muitos casos, erros cometidos, em determinado ponto do processo, são compensados por erros cometidos em outros pontos, resultando em uma reconciliação excelente. Entretanto, esse fato mascara os erros do sistema, que, mais cedo ou mais tarde, podem se revelar. Frequentemente, os erros de amostragem podem levar a uma análise errônea do sistema de reconciliação, gerando consequências graves à operação, principalmente quando a lavra alcança regiões mais pobres ou mais heterogêneas do depósito. Como uma boa estimativa só é possível com práticas corretas de amostragem, a confiabilidade dos resultados de reconciliação depende da representatividade das amostras que os geraram. Esse trabalho analisa as práticas de amostragem, em uma mina de cobre e de ouro para fins de reconciliação. Os resultados mostram que a reconciliação aparentemente ótima entre mina e usina, é ilusória, consequência da compensação de diversos erros, na etapa de coleta de amostra, para o planejamento de curto-prazo.

Palavras-chave: Reconciliação, amostragem, representatividade.

Abstract

In the mining industry, reconciliation can be defined as the practice of comparing the tonnage and average grade of ore predicted by the geological model with the tonnage and grade generated by the processing or metallurgical plant. This practice has shown an increasing importance, since, when correctly executed, it increases short-term planning reliability and substantially reduces losses in the operation. However, the usefulness of reconciliation relies on the quality and reliability of the input data. Successful reconciliation can be illusory. In many cases, errors at one point of the process are offset by errors at other points, resulting in excellent reconciliation results. However, this fact can hide compensating errors in the system that may surface someday. Very often sampling errors can be masked and may lead *to erroneous analysis of the reconciliation system, generating serious consequences to the operation, especially when mining reaches poorer or more heterogeneous areas of the deposit. Since good estimation is only possible with correct sampling practices, the reliability in the reconciliation results depends on the representativeness of the samples that generated them. This work analyzes the sampling practices carried out at Maracá Mine for reconciliation purposes. Results show that the apparently good reconciliation between the mine and the plant is in fact illusory, consequence of the compensation of many sampling errors generated by the collection of the primary samples at the mine.*

Keywords: *Reconciliation, sampling, representativeness.*

1. Introduction

The theoretical and, mainly, practical problems of sampling materials containing precious metals have been objects of this study. The sampling of low-grade ores of high market value requires that special attention be given to sampling methods, accuracy and precision in order to avoid future reconciliation problems.

To optimise sampling accuracy and precision, an effective control in sample selection, preparation and analysis must be achieved (Grigorieff et al., 2002). The manual selection of samples using a shovel leads to poor sampling precision because of the existence of particle variability and its distribution within the pile.

In all mining operations, the estimates used for its economic evaluation, mine planning, and performance prediction are based on samples, which then generate the results of reconciliation. When dealing with precious metals, given the difficulty of selecting representative samples, the reliability of the reconciliation results is difficult to determine (Chieregati et al., 2011).

In the context of the mining industry, reconciliation may be defined as a comparison between the model estimates and the plant's production. It is a powerful tool to detect problems in all stages of the operation. It also enables the engineers to evaluate the consistency between actual production and production estimated by the models. In such a way, reconciliation may be seen as a quality test of the models mass and grade estimate.

Reconciliation continues to be one of the most convincing methods to demonstrate the accuracy of the resource model, good operating practices and, consequently, the operation's financial health (Crawford, 2004). However, the mining companies have underestimated the economic impact of the incorrect sampling and reconciliation. The incorrect estimation of the contents, based on incorrect sampling, creates serious problems of reconciliation which imply in huge financial losses (Pitard, 2008). Thus, the predictability of any mining operation, from the estimation of the resources up to the metal production, depends on good practices of reconciliation, which, in turn, depend on adequate sampling practices, capable of generating representative samples.

2. Methodology

The data required to perform this work was collected during an extensive sampling campaign conducted on February of 2011 at Maraca Mine in Goiás, central-west of Brazil.

Sampling at Maraca Mine

The short-term sampling performed at Maraca is manual and uses the particulate material from the Furukawa model HCR1500 drill rig, which generates two products: one of fine material and the other of medium and coarse material. From the front pile, with medium and coarse material, 12 increments were taken in radial direction of the cone installed and from the pile of fine material one increment was taken, generating a sample composed of 13 increments. Figure 1 shows a shovel used to sample the piles and Figure 2 shows the drill model used for sampling.

Sampling Campaign

The main sampling grid had a 10 × 10 m size and all holes in the sampling grid were executed with a 5 m depth, while the central hole had a 10 m depth. As presented in the following items, four lithological domains were studied, focusing in the ANX (Amphibole Shale), the most complex and diverse of the deposit, i.e. the critical lithological domain.

The sampling campaign was performed with two different drills, Atlas Copco L8 ROC (Figure 4) and Furukawa HCR 1500 (Figure 2), in order to evaluate the sampling performance for each drill rig with different drill diameters. The ROC L8, having a larger diameter and, consequently, resulting in larger sample masses, was expected to generate more representative samples.

The ROC L8 was used to drill the central cross (shown in red in Figure 3); the other holes (shown in black) were executed by the Furukawa HCR 1500. The central holes (represented in blue and magenta) were performed with a 10 m depth and sampled every 2.5 m, with the ROC L8 and the Furukawa. For the ANX domain, a borehole was drilled as a twin hole of the central hole (and the core analysed every 2.5 m) in order to evaluate the sampling error related to the drill depth and the two different drill rigs.

After selecting the area to be sampled, the geology team passed the information to the survey department, which marked out each hole. The locations of the holes were pegged ready for drilling.

Each hole shown in Figure 3 (sampling grid) generated two samples (A and B). The first sample (Sample A) was collected using the standard procedure of manual sampling with a shovel. After collecting sample A (about 10 kg), all the remaining material (approximately 190 kg) - coarse and fine - was collected. To prevent contamination and to optimise the recovery of the material, before starting the drill hole, the area around each hole was cleaned, removing coarse material with a hoe. In this type of sampling, the most significant loss is in the fine material. To minimise loss of fines, the area around each hole was covered with a canvas big enough to collect the material from the holes.

The remaining collected material was homogenised and split, in order to generate sample B (20 to 25 kg). All samples were bagged and identified. Both samples passed through the same process in the laboratory, with subsequent analysis for gold, copper, sulphur and iron.

Figure 1
Shovel used to sample the piles.

Figure 2
Furukawa Drill Rig Model HCR1500.

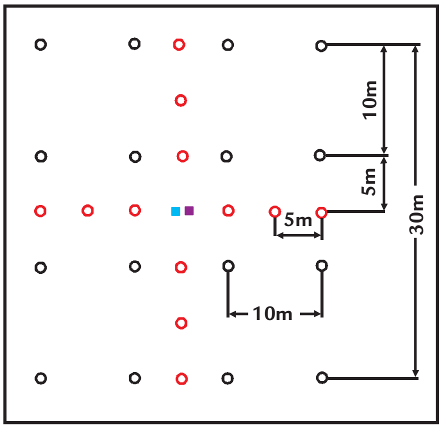

Figure 3
Sampling grid scheme used in the campaign.

Figure 4
Atlas Copco ROC L8 drill rig.

Sample Preparation Procedures

Figure 5 shows the sample flowchart from drilling to analysis. The chemical analyses were performed for gold using the standard fire assay technique that consists in submitting the pulverized sample along with the flux mixture to fusion. Silver nitrate is added to each sample in order to shield the platinum metal league that contains gold; hence the adsorption in the cupellation step is avoided. The lead oxide of the flux is reduced to metallic lead by the action of carbon contained in the starch, and when the temperature becomes sufficiently high to melt the flux, the metallic lead is precipitated by mass and it joins the button at the bottom of the crucible, leaving molten glass on top that is called slag.

Thus, all noble metals are collected on the button. The lead is subjected to the cupellation process which is the oxidation of the lead and subsequent adsorption of lead oxide to the cupel at a temperature of about 960° C. At the end of this process a bead of metallic silver is formed by the silver-gold alloy. Then, the removal of the silver is performed by putting acid on the silver-gold alloy. The gold sponge is then solubilized and read by Atomic Absorption Spectrometry.

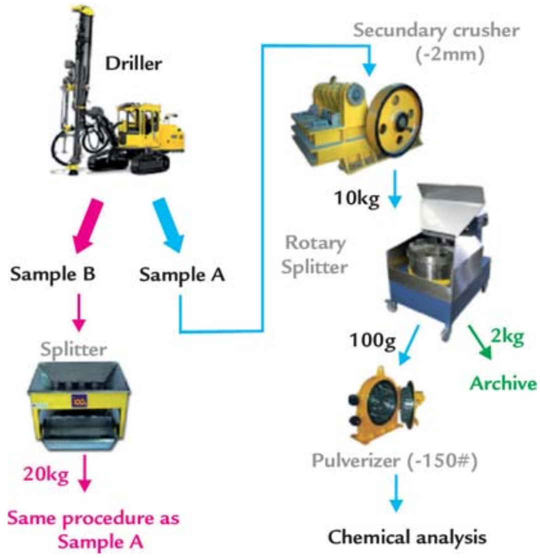

Figure 5
Flow chart of sample processing in the physical laboratory.

3. Presentation, analysis and discussion of results

The four lithological domains studied are shown below.

1. GNS (gneiss): stone gray, brittle, coarse grained, schist, composed mainly of biotite and feldspar.
2. BTO (biotite schist) rock dark gray, medium to coarse, with pronounced foliation, composed of biotite, feldspar and quartz.
3. QSRT / GNS (quartz sericite schist / gneiss): rock of grayish white, medium to coarse, schist, with quartz, sericite, biotite and feldspar;
4. ANX (amphibole shale): grained rock with schistosity undeveloped comprising amphibole crystals (60%) of green, oriented in the matrix formed by quartz and feldspar.

Table 1 contains a summary of this data, showing the average results. The relative errors refer to errors generated by collecting Sample A with the 13 increments related to the sample represented by all the material from the hole (Sample B).

Based on the results, the following comments can be made: with the exception of the ANX domain, there is no significant systematic error between Sample A and Sample B, since the average error varies from -0.29% to -4.71%. This means that the Samples A are accurate in comparison with the Sample B. In the case of ANX domain, there is a significant systematic error (-7.7%) between Sample A and Sample B. This result means that, for this domain, the manual samples of 13 increments present values 7.7% lower than the values of the total sample.

Therefore, the manual samples are not accurate for the gold content of ANX. Nevertheless, it can be noted that, for all domains, the average sampling error is negative, which means that the sample collected by the manual shovel tends to underestimate the real gold content of the block.

Lithology		Sample A Grade (g/t)	Sample B Grade (g/t)	Absolute Error (%)	Relative Error (%)
GNS	Mean	0.482	0.473	.009	-0.29
BTO		0.295	0.306	-0.010	-4.71
QSRT/GNS		0.222	0.231	-0.009	-3.59
ANX		0.419	0.463	-0.044	-7.69
GNS	Standard Deviation	0.286	0.190	0.205	43.36
BTO		0.197	0.182	0.098	20.33
QRST/GNS		0.087	0.071	0.045	18.76
ANX		0.256	0.307	0.074	10.07

Table 1
Gold contents, in g/t, and relative errors for each lithological domain.

The ANX Domain

The ANX Domain (Amphibole-Shale) is comprised of weak schistose, and medium grained green amphibole-quartz-feldspar rock. As previously mentioned, the domain is considered the most complex and heterogeneous of the mine and this reason led the authors to select this domain for a special test using a borehole rotating drill rig.

Tables 2 and 3 show the results of the 2.5 m samples collected by the Furukawa, the ROC L8 and the rotating borehole drill rigs at the ANX domain. Residue material was collected as per Sample B above. The samples B and B' for this domain are related to the quartering of the total sample (coarse, medium and fine) generated by the Furukawa and by the ROC L8 rigs. In the case of the borehole drill rig, Samples B and B' refer to the results of the two splits from the core, which were analysed separately.

The last three columns of the Tables 2 and 3 show the estimation errors of the samples collected by the Furukawa and by the ROC L8 rigs with respect to each sample (2.5 m) from the borehole drill rig, as well as the mean value of the total depth (10 m).

The results show that for the ANX domain, both the Furukawa and the L8 samples overestimate the gold and copper grade relative to the rotating drill rig. The estimate errors of the Furukawa were 75.5% for gold and 32.4% for copper. The estimate errors of the ROC L8 were 34.8% for gold and 14.2% for copper.

The samples were further tested for particle size distribution and chemical analysis, in order to evaluate the influence of the composite samples with non-proportional masses of medium, coarse and fine fragments on the resulting content.

Samples of an ANX block were collected from three 5 m holes, using the Furukawa. Tables 4 and 5 show the obtained results, where:

- Sample 20-1 represents all the material from the hole (coarse, medium and fine) collected using plastic bags placed in the discharges of the drill. The Samples 20-1-A and 20-1-B were obtained splitting the original sample using a riffle splitter and presented masses of 2,982 g and 2,583 g respectively.
- Sample 20-2 represents all the material from the hole (coarse, medium and fine) collected by the canvas placed on the discharges of the drill. Samples 20-2-A and 20-2-B were obtained splitting the original sample using a riffle splitter and presented masses of 2,929 g and 2,972 g respectively.
- Sample 20-3 represents the company's standard sampling method with 13 increments, presenting a mass of 5,642 g.

Figure 6 shows the mass percentage retained curves for each sample and the variation of gold and copper contents by range of size for each individual sample.

It is important to emphasise that among the three samples collected, the selecting method of sample 20-1 was the most appropriate and, therefore, sample 20-1 was considered as the reference for this comparative study.

The results allow us to make the following observations:

1. All samples showed similar variation in the contents of the various particle

Table 2
Gold contents and estimation errors of the samples collected from the central point of the ANX block.

Central Hole	Sample B Cu grade (%)	Sample B'Cu grade (%)	Cu mean (%)	Absolute Error (B – B')	Relative Error (%)	Driller	Estimate Error (%)	Grade g/t all hole (mean)	Estimate Error (%)
20-F1	0.33	0.33	0.33	0.00	-0.30	Furukawa	52.3	0.486	75.5
20-F2	0.68	0.60	0.64	0.08	13.25		72.4		
20-F3	0.59	0.60	0.60	-0.01	-1.49		109.6		
20-F4	0.37	0.36	0.37	0.00	1.10		60.2		
20-L1	0.16	0.17	0.17	-0.01	-4.65	ROC L8	-23.3	0.366	32.4
20-L2	0.34	0.59	0.46	-0.26	-43.15		24.2		
20-L3	0.48	0.47	0.47	0.02	4.09		66.2		
20-L4	0.35	0.37	0.36	-0.02	-5.16		56.9		
20-S1	0.26	0.18	0.22	0.07	40.66	Borehole Drill Rig		0.277	
20-S2	0.34	0.41	0.37	-0.07	-17.36				
20-S3	0.31	0.26	0.29	0.05	18.77				
20-S4	0.22	0.23	0.23	-0.01	-3.86				

Table 3
Copper contents and estimation errors of the samples collected from the central point of the ANX block.

Central Hole	Sample B Cu grade (%)	Sample B'Cu grade (%)	Cu mean (%)	Absolute Error (B – B')	Relative Error (%)	Driller	Estimate Error (%)	Grade g/t all hole (mean)	Estimate Error (%)
20-F1	0.31	0.30	0.30	0.01	3.02	Furukawa	-9.2	0.513	34.8
20-F2	0.64	0.65	0.64	-0.01	-1.54		38.7		
20-F3	0.66	0.67	0.67	-0.01	-2.08		82.5		
20-F4	0.47	0.41	0.44	0.06	13.32		22.2		
20-L1	0.19	0.19	0.19	0.00	0.53	ROC L8	-42.8	0.435	14.2
20-L2	0.43	0.43	0.43	0.00	-0.93		-7.9		
20-L3	0.66	0.69	0.67	-0.03	-3.94		84.0		
20-L4	0.42	0.48	0.45	-0.05	-11.13		24.7		
20-S1	0.39	0.27	0.33	0.12	44.85	Borehole Drill Rig		0.381	
20-S2	0.43	0.50	0.46	-0.08	-14.97				
20-S3	0.37	0.36	0.37	0.02	4.48				
20-S4	0.36	0.36	0.36	0.01	-1.96				

size fractions, with higher concentrations of copper and gold in the finer fraction.

2. The sample composed by 13 increments showed a higher percentage of coarse fragments (13.1% versus 7.1% of the total sample) and a similar percentage of fine fragments (29.9% versus 31.5% of the total sample). This means that the composite sample tends to present a relatively lower content of copper and gold, when compared with the total sample collected by the Furukawa drill. Therefore, the composite sample tends to underestimate the total sample.

3. Taking into consideration that the Furukawa tends to overestimate the content of the block in 75.5% for gold and 34.8% for copper (Tables 2 and 3), the results of particle size and chemical analyses indicate the compensation of the estimates, leading to satisfactory, but illusory, reconciliation results.

Opening		20-1-A		20-1-B		20-2-A		20-2-B		20-3	
#	mm	Au (g/t)	Cu (%)	Au (g/t)	Cu (%)	Au (g/t)	Cu (%)	Au (g/t)	Cu (%)	Au (g/t)	Cu (%)
10#	2.000	1.002	0.897	1.056	0.889	0.954	0.918	0.881	0.884	0.119	0.147
18#	1.000	1.017	0.825	1.080	0.806	0.795	0.755	0.760	0.767	0.148	0.169
35#	0.500	0.596	0.542	0.645	0.488	0.686	0.554	0.724	0.561	0.142	0.148
50#	0.297	0.600	0.448	0.518	0.392	0.586	0.490	0.917	0.977	0.135	0.128
100#	0.149	0.494	0.593	0.953	0.592	0.447	0.608	0.896	1.087	0.142	0.185
150#	0.100	0.684	1.086	0.641	0.963	0.526	0.857	0.599	0.731	0.144	0.251
< 150#	0	2.214	1.652	1.905	1.727	1.403	1.572	1.550	1.544	0.355	0.429
Average Grade		1.219	1.021	1.158	0.998	0.978	1.077	1.041	1.077	0.203	0.245

Table 4
Gold and copper contents resulting from the particle size distribution and chemical analysis in the ANX domain.

Opening		% retained				
#	mm	20-1-A	20-1-B	20-2-A	20-2-B	20-3
10#	2.000	6.7	7.5	4.3	3.8	13.1
18#	1.000	18.0	16.5	9.7	8.2	15.7
35#	0.500	11.5	13.5	10.1	9.4	11.8
50#	0.297	11.1	10.0	8.2	34.8	8.3
100#	0.149	11.1	12.4	14.2	14.6	15.0
150#	0.100	9.3	9.5	8.2	2.7	6.1
< 150#	0	32.3	30.6	45.3	26.6	29.9
Total		100	100	100	100	100

Table 5
Particle size distributions resulting from the particle size and chemical analysis in the ANX domain.

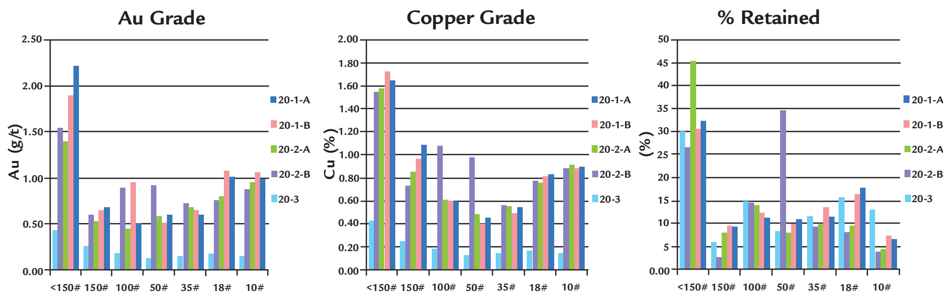

Figure 6
Single Percentage Retained by particle size fraction, gold content by particle size fraction and copper content by particle size fraction.

4. Conclusions

The analysis of the results demonstrates that a successful reconciliation can be misleading. In the case studied, errors introduced during the sampling process using the Furukawa drill rig were compensated by the errors derived from the type of drill used for sampling, resulting in satisfactory reconciliations.

Sample A, composed of 13 increments, tends to *underestimate* the mineral content of the hole, especially in the case of the gold. The results of the study executed with the borehole drill rig show a tendency of both Furukawa and ROC L8 drill rigs to *overestimate* the mineral content of the hole compared to the core samples.

The sampling procedure executed in Maraca Mine, therefore, demonstrates to be unsuitable for reconciliation purposes. The tendency of overestimation of the Furukawa drill rig is compensated by the tendency of underestimation by the manual sampling method consisting of 13 increments, which leads to satisfactory reconciliation results. The economic impact of this deficiency cannot be underestimated, because the errors inherent to the sampling process are, in this case, masked, and can eventually result in erroneous analysis of the performance of mining operations, especially when the production reaches poorer or more heterogeneous regions of the deposit. It was, therefore, demonstrated the importance of the sampling representativeness on the reconciliation results of a copper and gold mine.

It was observed that the estimation errors due to the sample composition of the 13 increments are not as significant as the errors due to the type of drill rig; therefore, more attention should be given to the drill used for the short term sampling. In this case, the authors recommend the use of a reverse circulation driller with an automatic system of sampling and splitting.

The option to work with the automatic sampling system and reverse circulation has several advantages that can far outweigh the cost of acquiring it. According to Pitard (2008), some of these advantages are:

1. Absence of sub-drill: the absence of sub-drill material avoids the delimitation error. The elimination of this sampling error is an economic advantage which may represent 5 to 15% of total revenues of the operation.
2. Possibility to drill several benches at the same time: the control of the contents in the multiple quarters can be done at the same time, which results in better short-term and mid-term mine planning.
3. Possibility to drill at a chosen angle: the possibility of drill at an angle allows better sampling of sub-vertical veins. The reverse circulation system has such flexibility, leading to a better evaluation of the block.
4. Minimization of contamination and losses: the rocks are protected within the drill by the cyclone, minimising ascending contamination, reflux and loss of material within the fractures.
5. Ability to drill into benches away from blasting: with the system of reverse circulation, blocks not being prepared for blasting may be sampled. With a good sampling planning, this measure is a way to save time.
6. Sampling does not interfere in the production: the increase in traffic from the mine equipment can be minimised with proper planning. Sampling by reverse circulation should not interfere with the production of the mine.
7. More precise and accurate grade control.

Among the disadvantages of introducing the mentioned system, we can mention the extra cost, and increase in traffic in the mine, which, depending on the access to the benches, can be a major inconvenience. However, "it is highly recommended that mining companies closely examine the feasibility of implementing an automatic sampling system with reverse circulation for content control, rather than hold on to the old practices that can lead to big reconciliation problems in the future" (Pitard, 2008).

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