Illusory reconciliation: Compensation of errors by manual sampling

In the mining industry reconciliation can be defined as the practice of comparing the tonnage and average grade of ore predicted by geological models with the tonnage and grade generated by the processing or metallurgical plant. This practice is important because it improves the reliability of short-term planning and optimizes the mining and processing operations. However, the usefulness of reconciliation relies on the quality of the input data generated by different sampling methods. In many cases, errors generated at one stage of the process are offset by errors generated at another stage, resulting in excellent reconciliations. However, this offset can compensate for biases in the system. 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 lower grades or more heterogeneous areas of the deposit. Since good estimation is only possible with correct sampling practices, the reliability of the reconciliation results depends on the representativeness of the samples. This work analyzes the manual sampling practices carried out at a copper and gold mine in Goias and proposes a more reliable sampling method for reconciliation purposes. The results show that the reconciliation between the mine and the plant is superficial, and is a consequence of compensation for many errors due to sampling practices in short-term planning.

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INTRODUCTION

Reconciliation can 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 engineer to evaluate the consistency between actual production and production estimated by the models. 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).
Reconciliation continues to be one of the most convincing method 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 incorrect sampling and reconciliation. The incorrect estimation of the contents, based on incorrect samples, creates serious reconciliation problems which imply in huge financial losses (Pitard, 2008). Thus, the predictability of any mining operation, from resource estimation to metal production, depends on good reconciliation practices which, in turn, depend on adequate sampling practices, capable of generating representative samples.
In order to optimise sampling accuracy and precision, an effective control in sample selection, preparation and analysis must be achieved (Grigorieff et al., 2002). Manual sampling using a shovel leads to poor sampling precision because of the particle variability and size distribution within the pile.
This study addresses the theoretical and, mainly, practical problems of sampling materials containing precious metals. Sampling low-grade ores of high market value requires special attention, in order to avoid future reconciliation problems.

METHODOLOGY

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

Sampling at Maraca mine

The short-term sampling performed at Maraca is manual and uses particulate material (chips) from the Furukawa model HCR1500 drill rig, which generates two products: one of fine material (back discharge) and the other of medium and coarse material (front discharge). From the front pile, 12 increments are taken in radial direction, and from the back pile one increment is taken, generating a 13 increments composite sample. Figure 1 shows the shovel used for sampling.

Figure 1 Shovel used for manual sampling

Sampling campaign and sampling preparation procedures

The main sampling grid (Figure 2) of the sampling campaign had a 10 × 10 m size and all holes in the sampling grid were drilled with 5 m depth, except the central hole with 10 m depth. As presented in the following items, four lithological domains were studied, with a focus in the ANX (amphibole shale), the most complex and diverse in the deposit, i.e. the critical lithological domain.
The sampling campaign was performed with two different drillers, Atlas Copco L8 ROC (Figure 3) and Furukawa HCR 1500, in order to evaluate the sampling performance of each drill rig with different drill diameters. The ROC L8, drilling with 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 2); the other holes (shown in black) were drilled by the Furukawa. The central holes (represented in blue and magenta), drilled by the ROC L8 and the Furukawa, had 10 m depth and were sampled every 2.5 m. In the ANX domain, an extra borehole was diamond drilled next to the other twin holes (and the cores analysed every 2.5 m) in order to evaluate the sampling error related to the two different drillers.

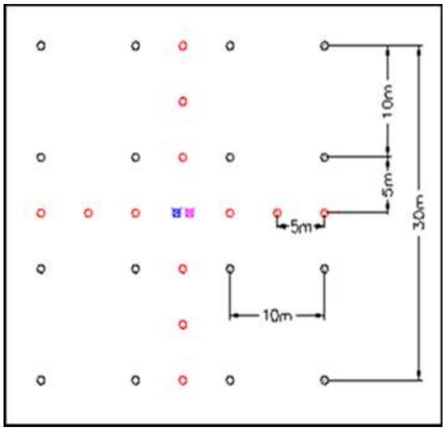

Figure 2 Sampling grid for the campaign

Figure 3 Atlas Copco ROC L8 drill rig

After selecting the area to be sampled, the survey department marked out the hole, and each hole 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 of medium, coarse and fine material) was collected, homogenised and split using a riffle stplitter to form Sample B. All samples were bagged and identified, passing through the same process in the laboratory (Figure 4).

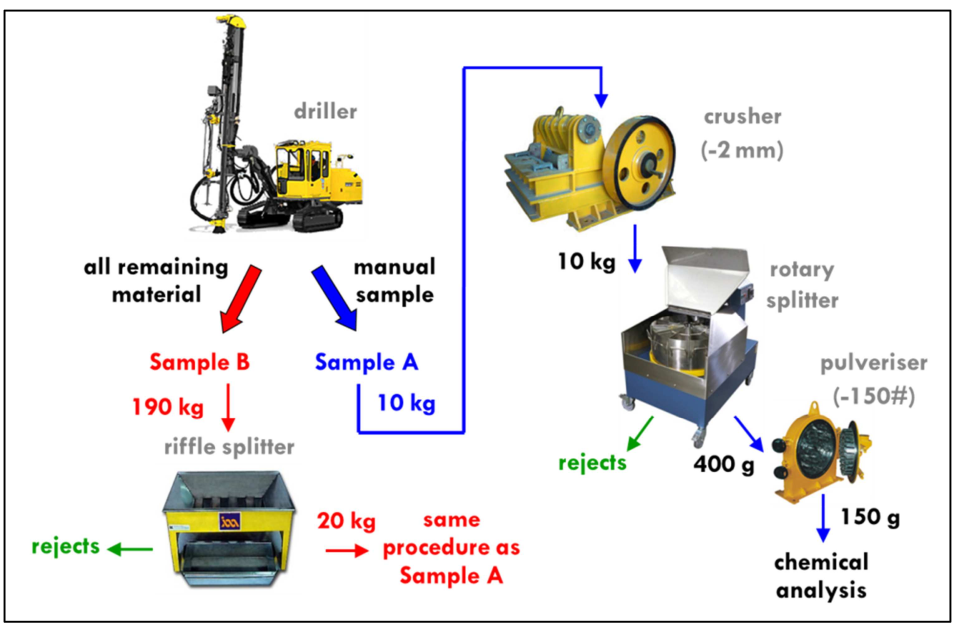

Figure 4 Sample preparation flowchart.

The sample preparation consisted in crushing the 10-20 kg samples at 95% passing 2 mm, then splitting and pulverising the 400 g subsamples at 95% passing 150 # (or 105 µm). Next, 150 g of the pulverised material was selected and sent to the chemical laboratory for gold, copper, sulphur and iron analysis. To determine the gold content, standard fire assay technique was performed.
It's important to emphasise that, in order to prevent contamination and to optimise the material recovery, 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 problem is the loss of fines. To minimise that problem, the area around each hole was covered with a canvas big enough to collect all the material recovered.

RESULTS AND DISCUSSION

The four lithological domains studied were:

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 presents a summary of all data, showing the average results. The relative errors refer to the errors generated by collecting the 13 increment composite sample (Sample A) in relation to the more representative Sample B (referece sample).

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

Lithology		Sample A Grade (g/t)	Sample B Grade (g/t)	Absolute Error (%)	Relative Error (%)
GNS	Mean	0.482	0.473	0.009	-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
QSRT/GNS		0.087	0.071	0.045	18.76
ANX		0.256	0.307	0.074	10.07

Based on the results, the following comments can be made: (1) with the exception of the ANX domain, there is no significant systematic error (bias) 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 to the Sample B; (2) in the case of ANX domain, there is a significant bias (-7.69%) between Sample A and Sample B; this result means that, for this domain, the 13 increment manual samples are not accurate, presenting values 7.69% lower than the values of the reference samples; and (3) 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 material recovered by the drill rig.

The ANX domain

The ANX geological domain 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 deposit and this reason led the authors to select this domain for a special experiment using diamond drill.

Tables 2 and 3 show the results of the 2.5 m samples collected by the Furukawa, the ROC L8 and the diamond drill rig on the ANX domain. Rejects were collected as per Sample B above. For the Furukawa and the ROC L8, Samples B and B' refer to duplicates generated by riffle splitting the total sample (coarse, medium and fine). For the diamond drill rig, Samples B and B' refer to the results of the two core halfs, which were separately analysed.

The 8th and the 10th columns of Tables 2 and 3 show, respectively, the estimate errors of the samples collected every 2.5 m (Furukawa and ROC L8 compared to the diamond drill rig), as well as the mean value of the total depth (10 m).

Table 2 Gold content and estimate errors for the ANX block

Central Hole	Sample B Au grade (g/t)	Sample B'Au grade (g/t)	Au mean (g/t)	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	-0.3	Furukawa	52.3	0.486	75.5
20-F2	0.68	0.6	0.64	0.08	13.25		72.4		
20-F3	0.59	0.6	0.6	-0.01	-1.49		109.6		
20-F4	0.37	0.36	0.37	0.00	1.1		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		24.1		
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	Diamond 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 content and estimate errors for 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	0.3	0.3	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	Diamond Drill Rig		0.381	
20-S2	0.43	0.5	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				

Results show that both the Furukawa and the ROC L8 overestimate the gold and copper grades considering the diamond drill samples as the reference values. The Furukawa overestimates the gold grade at 75.5% and the copper grade at 32.4%; the ROC L8 overestimates the gold grade at 34.8% and the copper grade at 14.2%.

Next, the samples were 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 were collected from three 5 m holes in the ANX domain, using the Furukawa. Tables 4 and 5 show the obtained results, where:

- Sample 20-1 represents all the material of the hole (coarse, medium and fine) collected using plastic bags placed in the discharges of the driller. 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 of the hole (coarse, medium and fine) collected by the canvas placed on the floor under the discharges of the driller. Samples 20-2-A and 20-2-B were obtained splitting the original sample 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.

Table 4 Gold and copper contents of 7 size fractions for ANX

Opening #	mm	20-1-A Au g/t	20-1-A Cu %	20-1-B Au g/t	20-1-B Cu %	20-2-A Au g/t	20-2-A Cu %	20-2-B Au g/t	20-2-B Cu %	20-3 Au g/t	20-3 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 5 Particle size distributions for ANX samples

Opening #	mm	% Retained 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

Figure 5 shows the percentage retained for each sample and the variation of gold and copper contents by size fraction for each individual sample. It is important to emphasise that among the three sampling methods, the one of sample 20-1 was the most reliable, therefore, sample 20-1 was considered the reference for this comparative study.

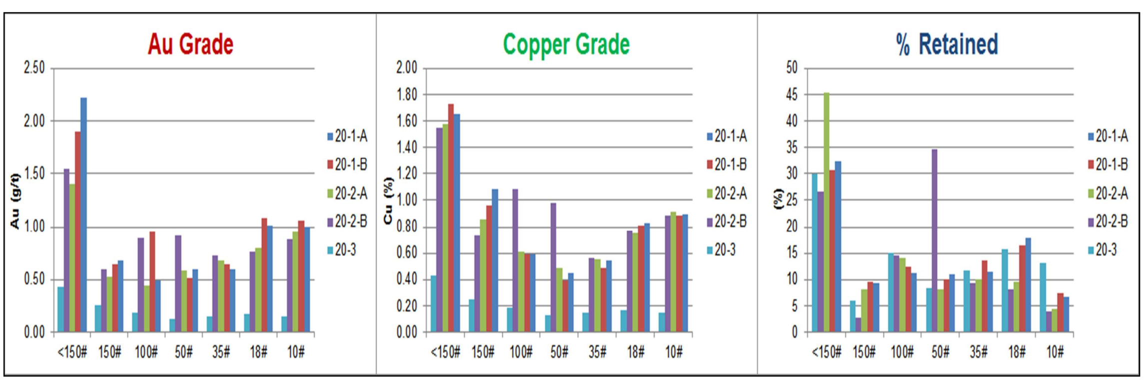

Figure 5 Gold and copper content by particle size fraction and percentage retained by particle size fraction

The results allow the authors to make the following observations:

1. All samples showed similar variation in the contents of the various particle size fractions, with higher concentrations of copper and gold in the finest fraction.
2. The 13 increments composite sample showed a higher percentage of coarse fragments, 13.1% versus 7.1% (mean of Sample 20-1-A and 20-1-B), and a similar percentage of fine fragments, 29.9% versus 31.5% (mean of Sample 20-1-A and 20-1-B). This means that the composite sample tends to present a relatively lower content of copper and gold when compared to the total sample recovered by the Furukawa. Therefore, the 13 increments composite sample tends to underestimate the total sample.
3. Taking into consideration that the Furukawa tends to overestimate the content of gold at 75.5% and the content of copper at 34.8% (Tables 2 and 3), the results of particle size distribution and chemical analyses indicate the compensation of errors, leading to satisfactory, but illusory, reconciliation results.

Sampling precision

Even after eliminating sampling biases, there are still serious pitfalls in the reconciliation regimen: According to Pitard (2010), "you don't need a bias to have a reconciliation problem; precision can cause huge reconciliation problems as well." Sampling reproducibility for gold ores is usually poor. It's not rare to misclassify ore and waste due to sampling precision. Thus, sampling optimization is always necessary, aiming to ensure that the primary samples are representative, i.e. sufficiently precise and accurate. If one cannot guarantee an adequate sampling accuracy and precision, one cannot rely on the reconciliation results.

The precision ellipse is a way to analyze if the estimates are into acceptable limits. Figure 6 illustrates a precision ellipse for Maraca mine. The abscissa axis values (estimated grades) represent samples collected by manual sampling; the ordinate axis values (real grades) represent the rejects of the material, and thus can be considered the best estimate for the actual content of the hole (assumig no delimitation and extraction errors).

Considering that the cut-off grade of gold is 0.18 g/t, the area #1of the ellipse represents the ore that wrongly goes to the waste (underestimation or loss) while area #2 represents the waste that wrongly goes to the plant (overestimation or dilution). The samples in the upper part of the ellipse represent the ore that goes to the plant, and the samples in the lower part of the ellipse represent the waste that goes to the waste dump.

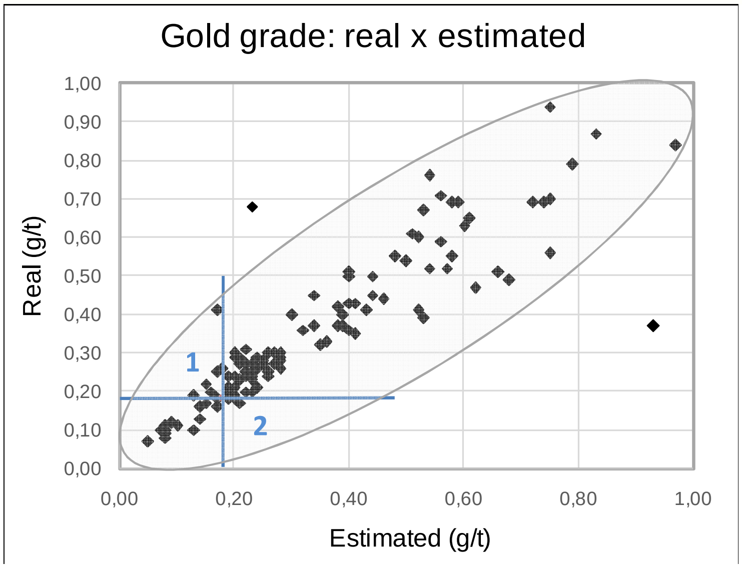

Figure 6 Precision ellipse for Maraca mine

The ellipse in Figure 6 is only an indicator showing the way a precision problem can interfere with reconciliation; this restricted example is not appropriate to quantify losses in an accurate way, but it highlights potential problems in the operation. In this case, manual sampling misclassified 10.3% of the grades (12 of 117 samples) and showed a tendency of underestimation, or ore loss, which is a serious problem, since losses are very difficult to measure or estimate.

CONCLUSIONS

The results demonstrates that a successful reconciliation can be illusory. In this case study, errors introduced by manual sampling using a shovel were compensated by errors introduced by drill rigs used for sampling. The 13 increments composite samples tend to <u>underestimate</u> the grades of the hole, especially in the case of gold; and the drill rigs tend to <u>overestimate</u> the grades of the hole, resulting in satisfactory but artificial reconciliations. Therefore, the manual sampling procedure in Maraca mine is unsuitable for reconciliation purposes. The economic impacts of this incorrect procedure cannot be underestimated, because the errors inherent to the sampling process are, in this case, masked, and may result in erroneous analysis of the operation performance, especially when mining reaches poorer or more heterogeneous regions of the deposit. It was, therefore, demonstrated the importance of sample representativeness in the reconciliation results.

It was observed that the estimate errors due to the composite sample are not as significant as the errors due to the type of drill rig used for sampling. To minimise this problem, it's recommended to work with an automatic sampling system and reverse circulation, which has several advantages that can far outweigh the cost of acquiring it. According to Pitard (2008), some of these advantages are: (1) absense of sub-drill, avoiding the delimitation error; (2) possibility to drill several benches at the same time; (3) possibility to drill at a chosen angle; (4) minimization of contamination and losses; (5) ability to drill into benches away from blasting; (6) sampling does not interfere in the production; (7) more precise and accurate grade control. Among the disadvantages of introducing the mentioned system, the extra cost can be mentioned, as well as the increase in traffic in the mine. 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 up the old practices that can lead to big reconciliation problems in the future" (Pitard, 2008). This system was recently implemented in Maraca mine and promptly proved to generate more precise, more accurate, and, therefore, more representative samples, ensuring the reliability on the reconciliation results.

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