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Experimental validation of new blast hole sampler for short-term planning

ABSTRACT

Mining operations around the world make extensive use of blast hole sampling for short-term planning, which has two undisputed advantages: (1) blast hole spacing is short range, providing relatively high sampling density per tonne, and (2) there is no additional cost since the blast holes must be drilled anyway. In most cases, however, sample recovery from blast holes is poor and the recovered material very often exhibits severe particulate segregation and transient mixing phenomena. Poor sampling precision is common with blast hole sampling, but the non constant sampling bias caused by particle size and density segregation is an even more serious problem, generally precluding representativeness. One of the main causes of this bias is a highly varying loss of fines, which can lead to both under and overestimation of grade depending of the ore type and the gangue. This study validates a new, modified sectorial sampler, designed to reduce the loss of fines and thereby increase sampling accuracy for narrow-diameter blast hole sampling; this sampler was first presented at WCSB3. The improved sampler has a traditional sectorial sampler layout with a covering semi-spherical cupola, carefully designed to respect the conditions of extraction correctness as laid out by the Theory of Sampling (TOS). The present validation work was performed at a gold mine in Brazil aiming to assist short-term planning and reconciliation practices. First results show a significantly improved estimation of gold grade, as compared to the head samples at the plant, which is very good news for this operation. These results do not mean a blanket recommendation of all types of blast hole sampling however; there are still several unresolved issues in this game, but the fine fraction loss issue would appear to be solved for narrow-diameter blast holes and single-discharge drills, while the wide-diameter holes and double-discharge drills constitute a principally different scenario not addressed in this study.

INTRODUCTION

The increasing complexity of mining operations, with grades increasingly becoming lower, requires more than ever samples as accurate and precise as possible to be able to control and optimise processes. The sampling methods – such as core drilling, blast hole sampling (narrow- and wide-diameters), channel sampling and sampling of particulate materials – are diverse and should be selected according to the type of deposit and purpose of the information. Each method generates a complex total sampling error, which must be quantified in order to assess the suitability of the method involved with respect to the desired quality objectives (accuracy, precision and labour).

In general, a sample is intended reliably to represent a particular mining unit, or volume of material. The sampling methodology is considered correct and unbiased only if all of the particles in the sampling unit have exactly the same probability of being selected for inclusion in a random sample. Studies demonstrate that even little improvements in sampling processes result in significant benefits for mining operations. Thus, correct sampling equipment, correct operating procedures and well-designed processes are of utmost importance to successful sampling, guaranteeing the selection of representative samples. All these issues must be fully in accordance with the principles of the Theory of Sampling.

The constitutional heterogeneity is also an important factor to be considered when planning a sampling campaign, since the heterogeneity by itself, and especially when dealing with precious metals, can generate very large errors even when the sampling procedure is performed correctly.

This paper validates a new narrow-diameter blast hole sampling approach, which presents lower operational costs, lower reduction of productivity and higher accuracy of the estimates if compared to traditional methods used in open pit mines. The sampler developed in this work, first suggested at WCSB3 by Chieregati et al. (2007), is here demonstrated as presenting very satisfactory results for Mine-to-Mill reconciliation purposes. The new approach is also compared with two different blast hole sampling procedures – sampling using a drum and sampling using a canvas – and shows a better recovery of fines, a common problem for blast hole sampling which can ruin grade estimations for block models.

METHODOLOGY

Grade control samples, or samples for short-term planning, are often based on results from blast hole sampling, which usually presents poor recovery due to particulate segregation of the material and, in consequence, is not representative of the total sample (Schofield, 2001; Pitard, 2008; 2009). One of the main causes of this bias is the loss of fines, which can lead to both under as well as overestimation of ore grade, depending on the ore type and the gangue composition (Snowden, 1993).

A sample is said to be correct only when each fragment in the lot to be sampled has the exact same probability of being selected in the sample. Only if a sample is both correct and sufficiently reproducible can it be qualified as representative. A representative sample must unconditionally be unbiased and display a sufficiently small variance. In practice, correct sampling methods are not necessarily simple to carry out on heterogeneous materials, but as the risk of bias is never acceptable, one must reject any sampler or sampling procedure that does not comply, because of the lack of assurance of sample representativeness.

This study was conducted in Mineração Serra Grande, a Kinross/Anglo Gold Ashanti gold mine in Brazil, and consisted of two sampling campaigns in the open pit to verify the representativeness of narrow-diameter blast hole samples and to quantify the loss of fines by three different sampling procedures.

Stationary sectorial sampler with cupola

Aiming to minimise the associated sampling errors, especially the increment delimitation error (IDE) and the increment extraction error (IEE), Chieregati (2007) proposed a new sampling equipment design called the 'stationary sectorial sampler with cupola' adapted from the stationary sectorial sampler proposed by Pitard (1993). Figure 1 illustrates the modified sectorial sampler, which should be positioned around the blast hole to be drilled.

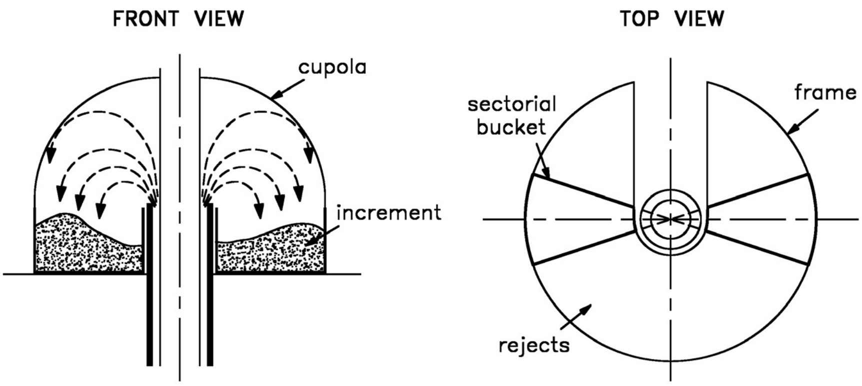


Figure 1 Basic design of stationary sectorial sampler with covering cupola (Chieregati, 2007)

The sectorial cutters are pie-shaped buckets easily removed from the frame; for the cutter to operate correctly the sides should be radial with respect to the centre of the blast hole. The bucket must at all times be deep enough not to overflow before the end of the drilling (Pitard, 1993). The new semi-spherical cupola is made of acrylic material and respects the conditions of extraction correctness. A rubber sealing is placed on the top of the cupola (Figure 3) in a way to minimise sample biases caused by the loss of fines. This modification also minimises the risk of contamination and the errors introduced by manual sampling. The sectorial sampler is fitted to the drill and generates two samples, one per bucket, weighting between 2 kg and 3 kg each. As shown in Figure 2, the sectorial buckets are positioned in two quadrants of the sampler, each one collecting an increment represented by a sector of the total sample.

To verify the suitability of the modified sampler in estimating the average grade of a mining block, a sampling campaign was performed in block I5A of Mineração Serra Grande. A total of 48 blast holes, between 1 m and 3.5 m deep, were sampled using the new sectorial sampler and a Pro-Eletro single-discharge drill model PWH-5000 with a 7.6 cm bit diameter. In this study each bucket generated one increment, called Sample A and Sample B, which were analysed separately.

The validation consisted of calculating the reconciliation factor MCF ('mine call factor'), which expresses the difference, a ratio or percentage, between the grade predicted by the short-term model based on blast hole sampling and the grade reported by the plant ('reference grade'). This is the second step of reconciliation, also called Mine-to-Mill reconciliation.

After the mining and crushing stages, the whole block alone was sampled at the plant feed, generating the reference grade for Mine-to-Mill reconciliation. A total of 25 samples, weighing approximately 20 kg each, were taken from the discharge of the conveyor belt that fed the secondary crushers, with an interval of ten minutes between cuts. All of the 25 samples were prepared in the same laboratory and followed the same procedures of drying, splitting, crushing, pulverising and gold analysis.

Figure 2 New modified sectorial sampler fitted to the PWH drill (right) and detail of the buckets/frame (left)

Comparison between three different procedures for blast hole sampling

A concomitant sampling campaign was conducted in order to specifically quantify the fines recovery of the sectorial sampler compared with two previous sampling procedures employed at the mine: blast hole sampling with a canvas and blast hole sampling with a drum. Two holes were sampled by each of these alternative procedures (Figure 3) and the comparison between them was based on the average particle size distribution of the samples obtained.

To optimise the procedures, minimising the loss of fines and the sample contamination as well, the following steps were taken: (1) sampling with the canvas was conducted by four people, who held its extremities high, minimising the effect of the wind; (2) the drum was wrapped with canvas and sampling was conducted by three people; (3) the cupola was covered by a rubber seal and sampling was conducted by two people. Each sampling cycle with the canvas took on average seven minutes, the drum took eight minutes and the sectorial sampler took four minutes.

Figure 3 Blast hole sampling with three alternative approaches: canvas, drum and new sectorial sampler

RESULTS AND DISCUSSION

According to Pitard (2008; 2009), conventional blast hole sampling for grade control has acquired an extremely bad reputation over the last 50 years, because of the many sources of bias introduced by this operation and the consequent difficulty of documenting representative sampling. This scenario can be greatly improved only if we take into account the delimitation, extraction and weighting errors (IDE, IEE and IWE) as well as the segregation phenomenon, and if we use a correctly designed sampler. It is often claimed that this 'very likely' will reduce drilling productivity, but if it can be shown to lead to representative sampling, the final evaluation can be based on a much more relevant basis than before. Balancing this issue should not be difficult: representativeness must be priority number one in any reconciliation work.

The results show significant improvements in sample representativeness, as manifested by an excellent Mine-to-Mill reconciliation and a very successful minimisation of the loss of fines.

Validation of sectorial sampler with cupola

Table 1 shows the values of gold grade for Sample A and Sample B, as well as their absolute and relative errors. Note that Sample A and Sample B refer to the two opposite sectorial buckets of the stationary sampler, testing the A vs B correctness of the sectorial sampler operation.

The results show that the internal accuracy of the sampling procedure is good (m=0.067) and thus there is no significant bias between Sample A and Sample B (mean of the relative error=2.45%). This suggests that the sectorial sampler generates two equally good samples in the opposite sectors. On the other hand, the reproducibility (precision) is poor (±32.6% relative). This low precision is a well-known manifestation of gold ores and environments with high nugget effects.

When sampling gold, it's not rare to misclassify ore and waste due to a poor sampling precision. There are methods for analysis if the estimates are within acceptable limits, however, notably the 'precision ellipse' approach. A discussion of the nugget effect and the precision ellipse is not included in this paper (for more information see Pitard, 2009), but these issues must be taken into account when analysing the precision of any sampling campaign, as this provides an excellent internal consistency check without which this salient aspect cannot be said to be properly characterised.

Table 1 Results of the blast hole sampling with the new stationary sectorial sampler

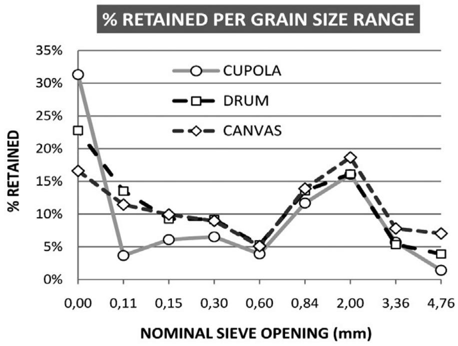
Blast hole number	Grade sample A (g/t)	Grade sample B (g/t)	Absolute error	Relative error (%)	Blast hole number	Grade sample A (g/t)	Grade sample B (g/t)	Absolute error	Relative error (%)
1	0.73	2.27	-1.54	-67.84%	25	5.03	5.10	-0.07	-1.37%
2	0.03	0.03	0.00	0.00%	26	2.33	2.50	-0.17	-6.80%
3	1.33	1.07	0.26	24.30%	27	1.17	1.33	-0.16	-12.03%
4	3.13	4.77	-1.64	-34.38%	28	5.43	3.83	1.60	41.78%
5	1.10	2.37	-1.27	-53.59%	29	7.20	6.60	0.60	9.09%
6	3.83	2.17	1.66	76.50%	30	1.13	1.23	-0.10	-8.13%
7	7.80	7.97	-0.17	-2.13%	31	1.10	8.83	-7.73	-87.54%
8	1.43	2.57	-1.14	-44.36%	32	3.87	4.40	-0.53	-12.05%
9	14.67	14.03	0.64	4.56%	33	13.90	16.67	-2.77	-16.62%
10	6.90	5.17	1.73	33.46%	34	7.60	7.87	-0.27	-3.43%
11	5.80	6.00	-0.20	-3.33%	35	8.43	8.30	0.13	1.57%
12	1.50	1.57	-0.07	-4.46%	36	8.07	7.00	1.07	15.29%
13	3.33	2.93	0.40	13.65%	37	5.37	5.60	-0.23	-4.11%
14	5.33	4.43	0.90	20.32%	38	11.77	7.07	4.70	66.48%
15	9.47	8.30	1.17	14.10%	39	5.07	5.93	-0.86	-14.50%
16	9.77	11.90	-2.13	-17.90%	40	3.57	2.77	0.80	28.88%
17	0.67	1.27	-0.60	-47.24%	41	0.93	0.83	0.10	12.05%
18*	*sample was lost				42	12.30	7.27	5.03	69.19%
19	6.50	5.80	0.70	12.07%	43	4.20	3.23	0.97	30.03%
20	7.67	9.17	-1.50	-16.36%	44	1.53	1.27	0.26	20.47%
21	9.50	5.93	3.57	60.20%	45	2.67	2.40	0.27	11.25%
22	5.90	6.37	-0.47	-7.38%	46	7.50	6.47	1.03	15.92%
23	8.83	9.50	-0.67	-7.05%	47	5.00	3.97	1.03	25.94%
24	6.17	7.03	-0.86	-12.23%	48	3.83	4.13	-0.30	-7.26%
					mean	**5.327**	**5.260**	**0.067**	**2.45%**
					standard deviation	**3.677**	**3.500**	**1.878**	**32.6%**

The reference sampling procedure for the present study was carried out at the plant feed, which generated 25 TOS-correct samples from 10 min cuts. The resulting average grade at the plant is used here as the 'true' reference grade for the calculation of the MCF, since it's the most reliable value obtainable for the block's average grade. The MCF is calculated by dividing the average gold content generated by the sectorial sampler ($mean_{SampleA/SampleB}$=5.294 g/t) by the reference gold content at the plant (5.172 g/t). In the present case, MCF=97.7%, which is very good indeed. This result provides the ultimate testing basis for the cupola method.

The MCF shows an estimate error of 2.3% only, validating the modified sectorial sampler as a suitable sampling procedure for short-term estimation. The authors recommend the implementation of further work both at this mine and in similar mining contexts to monitor the new sectorial sampler's efficiency across a broader field of mineralisation types and for different mining operations.

Estimation of fines recovery by each sampling procedure

Figure 4 shows the average particle size distribution of the three investigated sampling procedures.



Opening	% Retained		
mm	CUPOLA	DRUM	CANVAS
4.760	1.4%	3.9%	7.0%
3.360	5.7%	5.3%	7.8%
2.000	16.0%	16.1%	18.7%
0.841	11.7%	13.6%	13.9%
0.595	3.9%	5.3%	5.1%
0.297	6.5%	9.2%	9.0%
0.149	6.1%	9.3%	9.9%
0.105	3.7%	13.5%	11.5%
-0.105	31.3%	22.8%	16.6%

Figure 4 Average size distribution for three alternative sampling procedures

Figure 4 shows a significantly higher recovery of fine material by the cupola sectorial sampler (31.3%), followed by the drum (22.8%) and finally by the canvas (16.6%) sampling procedures. An opposite trend occurred for the largest fragments. The intermediate grain size ranges display a much more similar percentage of retained material. The results suggest that, between the three sampling procedures analysed, the sectorial sampler with cupola is the one with the smallest loss of fines and, consequently, the most reliable procedure for this type of blast hole sampling.

CONCLUSIONS

Reconciliation problems due to serious sampling errors are not rare in the gold industry, especially because of high mineralisation heterogeneity and the high values of the nugget effect, which are the prime characteristics of these environments. Therefore, minimisation of the total sampling error is a must when a company intends to use reconciliation results to control and optimise its mining processes. From the results of this work the following can be concluded:

- The low value of the mean of the selection error, m(SE), shows that the opposite sectors of the new blast hole sampler are unbiased. The associated reproducibility is poor however (±32.6% relative). This result needs further substantiation from parallel studies covering other gold mineralisation types before clear generalisations can be made.
- The high value of the MCF suggests good predictability of the short-term model, based on the improved blast hole sampling approach. This does not hold for standard sectorial samplers, which generally produce non-representative samples. The MCF value is the ultimate test for reconciliation purposes.
- The significantly higher recovery of fine material by the new sectorial sampler is a manifestation of successful minimisation of the sampling error due to loss of fines.
- The new sectorial sampler does not cause significantly lower productivity relative to the current standard work routines.

Even with poor precision, improvements in Mine-to-Mill reconciliation were demonstrated in Mineração Serra Grande, showing that the new modified sampling equipment can bring impressive benefits to the mining industry with extremely low investment and without significant reduction of productivity. The sampling procedure with the cupola stationary sectorial sampler was validated in a realistic mining context and can be seen as a useful tool to assist short-term planning, since it generates more reliable grade estimates. It is possible that these results could be the result of a specific mineralisation/mining operation combination, so additional studies are needed before meaningful generalisations can be considered justified.

Caveat: The present results do not mean a blanket recommendation of all types of blast hole sampling! There are still many unresolved issues in this game, primarily regarding the previous and current sub drill; these issues will always create significant IDEs, the magnitude of which may very easily offset the advantages claimed from close-spaced drilling; see Pitard (2008; 2009) for in-depth treatments. Double-discharge drills with dust collectors and wide-diameter blast hole options constitute a completely different scenario, which cannot be directly compared to its single-discharge drill and narrow-diameter counterparts.

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