The challenge of sampling gold

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Introduction

Theoretical and especially practical problems generated by the sampling of materials containing precious metals have been given enormous attention by many specialists for a long time. Since relatively small amounts of material can involve large amounts of money, there are probably no other materials than precious metals for which the achievement of sampling precision and accuracy is so critical. Gold has its peculiarities, especially regarding the segregation effect. Because of its density, a strong segregation phenomenon takes place as soon as gold is liberated. Furthermore, the gold content of an analytical sub sample and the gold content of the sample from which it was selected can be very different. All these problems are amplified as the gold grade becomes lower, as gold deposits become marginal, and as the distribution of gold in rocks becomes erratic. This paper analyses two low grade and erratic gold deposits in Brazil and discusses some sampling problems and the solutions adopted for reconciliation between the mine and the mill. The results show that good estimation of gold content is only possible with proper sampling practices and process control.

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methodologies and equipments, to ensure that the error between estimates and actual data is minimal. Therefore, the estimates become forecasts and can form a basis for decision making, ensuring that what happens in the future corresponds to what was planned at the present.

Another point to consider is that the mine normally will rely upon blasthole samples and some form of interpolation to determine dig lines for the operators. As with the exploration model, the blasthole model is an estimate and is subject to standard estimation problems. Typically, the mill values are perceived to be the most accurate, and are the basis for reconciliation in most cases. However, it does not mean the mills are immune from sampling problems.

Mine reconciliation can be seen as the ultimate test of the quality of grade estimates in resource and grade control models. However, successful reconciliation can be illusory. In many cases, errors at one point of the process are offset by errors at other points in the operation, resulting in an excellent reconciliation. This can hide compensating biases in the system that may surface at some later date3.

An appropriate practice of reconciliation is only possible if there is information about each mining and processing operation, and this information must be based on reliable data. Therefore, the optimization of sampling protocols is a must for the development of a reliable reconciliation system, since only a correct sampling procedure can generate reliable data. Sampling should be understood as a science and technology available for practical industrial use, after all, it is a key element for decision-making, allowing improvements in industrial efficiency and the qualification of products.

Experimental works

The two mining operations studied here were low grade gold deposits, mined in open pits and processed in gravimetric concentration circuits and column or heap leaching. The anomalous gold mineralization is located within highly deformed regions, related to hydrothermal processes. The first deposit presents erratic distribution of gold, with coarse and fine gold associated to the higher and the lower grade ore, respectively. The second deposit presents lateral continuity and a more predictable distribution of grade. Here, the gold occurs mainly as free grains of fine gold.

Over one year, these operations were evaluated with regard to sampling, mine planning and reconciliation practices. The problems identified and the solutions adopted are summarized in the following items. Pitard’s conditions for minimizing sampling errors were the basis for the development of this work. Validation is presented as reconciliation results.

Minimizing sampling errors

According to Pitard4, there are six conditions to fulfill in order to eliminate, or at least minimize, most of the sampling errors when the constituent of interest is a precious metal:

- All the sampling equipment is designed, built and used in such a way that all preparation errors are only relevant to the second order. Special attention needs to be taken to minimize loss and contamination by plating gold on sampling equipment
- The increment delimitation must be correct
- The increment extraction must be correct
- The increments must be numerous enough to minimize the segregation and grouping error until it becomes relevant only to the second order. We shall emphasize that the homogenization of liberated gold is impossible; therefore, the only hope to minimize this error is by minimizing the fundamental error and increasing the number of increments per sample
- For the sampling of one-dimensional lots, the interval between each increment is small enough to render the long range heterogeneity fluctuation error relevant only to the second order
- The sampling selection scheme is chosen with respect to the periodic heterogeneity fluctuation error.

When all the above conditions are fulfilled, the only error left is the fundamental error, which is the smallest error for a sample collected under ideal conditions. The fundamental error is the only error that can never have zero variance, since it is generated by the intrinsic constitution heterogeneity of a particulate solid. Its importance may be secondary for the great majority of the constituents, but, normally it becomes greater for the constituents that occur in smaller concentrations, and much greater for trace constituents in high purity materials and for low grade precious metals. The only way to minimize the fundamental error is by optimizing sampling and preparation protocols.

Reconciliation components

Reconciliation is a common activity carried out at most mining operations around the world and can be defined as a comparison between the grade reported by the plant and the grade predicted by models. Of course these values rarely match, due to the different variables involved.

The mine/mill reconciliation problem often has multiple causes. But the problem can be solved, or at least minimized, if a good strategy is undertaken. Pitard4 suggests dividing the complex problem into its basic components, and then solving them one at a time. These components are presented in Table I.

The following items discuss some problems observed on both gold deposits under study, and suggest a solution for each component analyzed. Of course, in such an approach, priorities must come into account, therefore, we decided to analyse two components per stage.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Causes</th>
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| Geological models | • true, in situ nugget effect  
• sampling and sub-sampling errors  
• analytical errors  
• interpolation errors  
• excessive rejection of outliers  
• ore density  
• definition of ore boundaries |
| Mining and grade control | • in situ nugget effect  
• drift of mineralized boundaries upon blast  
• loss of fines in stockpiles or during sampling  
• sampling and sub-sampling errors  
• analytical errors  
• dilution  
• blastholes parallel to mineralization  
• ore grade contouring |
| Mill and flotation plant | • material balance based on non-probabilistic sampling  
• process cycles either unknown or misunderstood  
• calibration of weightometers and flowmeters  
• inappropriate sampling equipments  
• analytical accuracy  
• poor laboratory sub-sampling |

Table I

The causes of mine/mill reconciliation problems (after Pitard4)
Geological Models

In situ nugget effect

The nugget effect describes how well sampling results can be reproduced by repeated sampling at the same location. The higher the sample reproducibility the smaller the nugget effect. It’s important to consider that the nugget effect incorporates both the natural inherent variability of the deposit and the variability due to all sampling, preparation and analysis stages. Heterogeneous mineralization is sensitive to the method of sampling and could give variable results from a single location. Recognition of the nugget effect is vital to resource estimation. The higher the nugget effect, the higher the degree of smoothing required in the estimation where the estimate is a weighted average of samples within the range of influence of the block being evaluated.

In a high nugget effect environment, which is the case of gold deposits and heterogeneous mineralization, the difficulty of deciding whether a block is ore or waste is considerable, due to the low reproducibility of the samples. Therefore, the precisions of sampling for these types of mineralization are very sensitive to the sampling method, which should be as accurate as possible. Care must be taken to ensure that correct values of nugget effect are considered in reserve and grade control models.

Excessive rejection of outliers

Even knowing the principles of a correct sampling practice and using correct sampling equipment, errors will always be there due to the sample extraction and handling stages and also due to the material heterogeneity. Isaaks and Srivastava say that one of the most tedious and time consuming tasks in a geostatistical study is error checking. Therefore, the authors suggest some steps to eliminate gross errors before statistical analysis proceeds: (1) sort the data and examine the extreme values. If they appear excessive, investigate their origin and try to establish their authenticity; (2) locate the extreme values on a map. Note their location with respect to anomalous areas and analyze if they are located along trends of similar data values or if they are isolated. Be suspicious of isolated extremes (outliers); and (3) check coordinate errors by sorting and examining coordinate extremes.

Figure 1 shows the gold grade distribution for two blocks in a gold mine, where the values at unobserved locations were estimated by kriging. The values plotted on the maps refer to the gold grade (g/t) of the samples collected for short term planning.

Figure 1 shows an isolated value (outlier) for Block 1, but for Block 2 the extreme values only suggest a trend, or a richer portion of the deposit. In the specific case of precious metals, the individual analysis of outliers is a must, assuring that correct data will not be rejected as outliers before the statistical analysis.

Mining and grade control

Loss of fines during sampling

Even though reverse circulation (RC) drillers are considered the most appropriate for sampling operations, because of their higher recovery, a significant amount of fines can be lost through overflow of the cyclone (Figure 2a). In some cases, these amounts reach up to 20% of the total weight. The blasthole drillers, in turn, are generally inadequate for sampling, since a large amount of fines can be lost by the action of the wind (Figure 2b) or can be retained in the filters of the drillers. Furthermore, manual sampling of blasthole piles using a shovel is not an equiprobabilistic process and should be rejected. A solution would be the use of a stationary sectorial sampler with cupola for minimizing the loss of fines, the delimitation error and the extraction error.

According to Pitard, conventional blasthole sampling for grade control has acquired an extremely bad reputation for the last 50 years because of the many sources of bias introduced by this operation and the consequent difficulty of getting a representative sample. Attempts to automate blasthole sampling at the drilling site have failed, not because it cannot be done, but mainly because it interferes with drilling productivity. It’s clear that too many problems are unsolvable, but this scenario can be greatly improved if we take into account the delimitation, extraction and weighting errors, as well as the segregation phenomenon, and use a correctly designed sampler, correctly positioned around the hole. Certainly this solution will reduce productivity, but can lead to reasonably representative sampling.

Table II presents, for both gold deposits, errors of estimate due to the loss of fines during blasthole and short term sampling and due to improper sampling and preparation protocols. Note that the grade reported by the plant is also an estimate calculated based on samples. However, the estimates from the plant are considered more accurate for the reasons explained on item Mine-to-mill and reconciliation concepts, and that’s why they were considered the basis for the error calculations.

Figure 1. Gold grade distribution for two different blocks
Table II shows that the gold grade estimates based on the samples taken by the drillers presented on Figure 2 overestimated the real block grade, most probably because of the loss of fines and, consequently, the concentration of denser and richer material in the samples sent to the chemical analysis.

**Dilution**

When ore and waste are mined and dispatched to the stockpiles and dumps, some waste ends up on the ore stockpile (dilution) and some ore ends up on the waste dumps (loss). Misclassification of waste as ore and of ore as waste, both cause a lowering of the production grade and loss of earnings for the operation. However, because the grade of the material assigned to waste is never measured by the milling process, the metal loss caused by misclassification of ore as waste does not enter into the reconciliation equation. Therefore, it is possible to achieve good reconciliation between the predicted ore grade and plant production grade and at the same time dispatch substantial amounts of profitable ore to waste dumps.

**Mill and flotation plant**

**Improper sampling equipments**

Cross stream samplers are usually correct provided that certain limiting conditions of use are met. These conditions, established by Pierre Gy’s theory of sampling, aim at controlling the effects that the complex mechanisms of the fragments bouncing on the moving sampler cutting blades may have on sample correctness. First, the cutter opening must be at least three times the diameter of the largest fragment, with a minimum opening of 10 mm when the diameter of the largest fragment is smaller than 3 mm, and second, a maximum speed allowed must be calculated from the retained opening.

A correctly designed cross stream cutter may slowly degenerate into an incorrect cutter for various reasons: (1) the cutter is built with fragile material and, consequently, damaged by the violent impact of large fragments; and (2) the cutter becomes obstructed by sticky materials. This can be observed in flotation plants where samplers are not regularly cleaned. Figure 3 shows two cutters totally or partially obstructed. Furthermore, the cutter opening of Figure 3a is smaller than 10 mm, making this selection incorrect.

A strategy for avoiding sampling errors in industrial plants is the design of processes and sampling equipment which ensure correct delimitation of sampling increments, by assuring that the entire section of the stream is intercepted by the cutter, (i.e., when we meet some basic conditions such as geometry, speed of installation and sampling). Assuming that all other correctness conditions are respected, the probability of a fragment being part of the increment is uniform all across the stream.

**Poor laboratory sub-sampling**

Due to the high density of gold and the strong segregation between the particles of a lot, it is possible that a laboratory sub sample may present a much higher grade than the original sample. The segregation, also known as the distributional heterogeneity of a particulate material, reduces sample reproducibility and multiplies its variance by a larger factor. It is, therefore, essential to develop sampling, preparation and subdivision protocols that can minimize the segregation effect. It’s equally essential to optimize the sampling and preparation protocol, in a way that the fundamental error is minimized.
Results

Following Pitard\(^1\), a good sampling strategy should provide the following chronology: (1) study of the heterogeneity of the material of a given lot; (2) optimization of the sampling protocols to minimize the fundamental error, the grouping and segregation error and the heterogeneity fluctuation errors; and (3) control of sampling correction (i.e., choice of the sampling equipment) in order to eliminate the delimitation error, the extraction error and the preparation error.

The six components presented on the previous chapter were analysed and optimized for further sampling campaigns. The following adjustments/changes to sampling methodologies were applied to the mining operations, in order to minimize sampling errors:

*In situ* nugget effect
Reduction of the sampling grid and collection of two samples per hole (for calculating the variance of the fundamental error). In a high nugget effect environment, individual sample results are not representative of the block grades and can’t define correctly the ore/waste limits.

*Excessive rejection of outliers*
Individual analysis of each outlier and the data from which it was generated. Original sample diaries or sampling logs were useful sources of information. The rejection of an outlier took place only when the sample that generated it was proved to be unreliable.

*Loss of fines during sampling*
Replacement of the manual shovel by a stationary sectorial sampler with cupola\(^4\) for the PW blasthole driller (Figure 4a) and replacement of the RC driller by the Atlas Copco driller with only one point of discharge (Figure 4b). For the RC driller an alternative would be the use of a secondary cyclone to recover the fines.

*Dilution*
Reduction of the sampling grid, especially in the direction of maximum variability, in a way to define more precisely the limits between high grade ore, low grade ore and waste. The sampling grid of the first mining operation was reduced from $15 \times 10$ m to $5.0 \times 3.5$ m and the sampling grid of the second operation was reduced from $5 \times 20$ m to $5 \times 10$ m.

*Improper sampling equipments*
Adjustment of the cutter openings and cleaning of sampling equipments. Sticky materials accumulate around the cutter edges, partially closing the cutter opening. Preventive maintenance and periodic cleaning should be done frequently.

*Poor laboratory sub sampling*
Adjustment of sample preparation equipment and execution of the heterogeneity test to optimize sampling and preparation protocols. The results of this work demonstrated the necessity of pulverizing a greater mass of material as a step in preparing the analytical sub samples.

Table III shows the errors of estimate for some blocks after adjusting the six reconciliation components and following Pitard’s chronology and strategy to minimize the sampling errors for precious metals.

![Cross-stream samplers with cutters totally or partially obstructed](image1)

![Changes to sampling equipments to reduce the loss of fines](image2)
significant improvements in reconciliation and process control. The only thing we can do is to identify their causes and try to minimize their effects. This work showed the advantages of a proactive reconciliation practice, dividing the reconciliation problem into its basic components and resolving one at a time. Changes to sampling equipments and protocols reduced estimate errors to as little as one tenth. It’s evident that eliminating sampling errors when dealing with precious metals is impossible, but the first step is to control them. Sampling and analytical biases can be eliminated by taking preventive actions. But sampling imprecision can never be completely eliminated. Therefore, reconciliation problems will always exist in a mining operation and the only thing we can do is to identify their causes and try to minimize their effects. This work showed that small improvements in sampling practices result in significant improvements in reconciliation and process control.

## References


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Mining Engineer from the University of Sao Paulo (1998), master's degree in Mineral Engineering (2001) and Ph.D. in Mineral Engineering (2007) from the University of Sao Paulo, Brazil. Currently is a lecturer in the Mining and Petroleum Department of the Polytechnic School of the University of Sao Paulo and responsible for the disciplines of Mineral Exploration and Geophysics. Has professional experience in the following areas: mineral processing design, mineral exploration, sampling and reconciliation in the mining industry. Teaches the Theory of Sampling and Reconciliation Practices for several mining companies - especially gold companies - and technical training institutions.

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### Table III

<table>
<thead>
<tr>
<th>Block number</th>
<th>Gold grade at mine (g/t)</th>
<th>Gold grade at plant (g/t)</th>
<th>MCF</th>
<th>Estimate error</th>
</tr>
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<tr>
<td>1</td>
<td>0.640</td>
<td>0.601</td>
<td>1.037</td>
<td>1.57 %</td>
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<tr>
<td>2</td>
<td>0.548</td>
<td>0.524</td>
<td>0.956</td>
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<tr>
<td>3</td>
<td>0.583</td>
<td>0.503</td>
<td>0.863</td>
<td>15.9 %</td>
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<tr>
<td>4</td>
<td>0.386</td>
<td>0.363</td>
<td>0.940</td>
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<tr>
<td>5</td>
<td>0.685</td>
<td>0.680</td>
<td>0.993</td>
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<tr>
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<td>0.540</td>
<td>0.470</td>
<td>0.870</td>
<td>14.9 %</td>
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<tr>
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<td>0.470</td>
<td>0.539</td>
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<td>8</td>
<td>0.720</td>
<td>0.760</td>
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