Homogenization piles are largely used in the mining industry for variability reduction in the head grades from the ores feeding the processing plants. Variability reduction in large piles is based on the principle volume-variance relationship, i.e. the larger is the support the smaller is the variability. The methodology proposed combines chevron type piles and geostatistical simulation to emulate the in situ and the pile reclaimed grade variability. Based on a pre-defined mining sequence to select the blocks that will form each pile for each simulated block model, the statistical fluctuation of the grades derived from real piles can be simulated, at different pile sizes and number of layers used in pile construction. Using this methodology, one can evaluate within a certain time period the expected grade variability for various pile size and, also, the internal grade variability when a given pile is reclaimed. The results forecasted by the method were compared against the real grades obtained by the grade control system used at a large iron mine operated by Vale during 2004.

Keywords: piles, homogenization, variability reduction, iron ore.

Introduction

Ore recovery at mineral processing plants can be affected by head grade variability. Generally, ore recovery is maximized when head grades, from the ore feeding the plant, are kept within narrow intervals of variation. The reduction in this interval of grade feed variability can be reached via adequate mining scheduling, finding the most feasible stationary mining route and/or homogenizing ore using large blending piles.

Ore heterogeneity can be evaluated on several scales. The types of heterogeneities found during ore preparation are related, essentially, with the geological processes involved in the mineral deposit genesis and with the equipment and methods used in mining, handling and transporting this ore. According to Schofield (1980), shipment, transportation, comminution, storage and handling contribute in some way to the variability found in the grades, since they introduce certain amount of reverse structuring on the space distribution of the natural mineralization.

Parker (1979) shows the intrinsic relation between support (volume) of a lot and grade variability. The quantification of volume variance relationship demands the knowledge of mineralization methods and the use of proper geostatistical methods.

Most estimation techniques provide a block model with grades assigned to each block using the methods of kriging. (Matheron, 1963). This block model is inappropriate for accessing the uncertainty associated with the estimated grades. Consequently, this procedure fails in predicting grade fluctuations correctly. Geostatistical simulations aim rather, at reproducing in situ variability, provided that the spatial continuity of the input data set is respected. The simulated model is said to be conditionally simulated, if it honors the values that are obtained at sampled points while reproducing the same dispersion characteristics of the original data set, (i.e. the mean, variance and covariance or variogram functions). In a conditionally simulated model, the dispersion of the grades during mining or processing can be addressed, since the dispersion characteristics of the original data are maintained. As the spatial continuity and variability of the real deposit is properly determined, quality reliability in the numerically simulated model is obtained, helping to assess potential risks during the decision making process.

Some previous studies involving blending and homogenization piles and geostatistical simulations are described by Schofield (1980), Costa et al. (2007), Ribeiro et al. (2008).

This paper presents a study developed at two iron ore deposit, in southeast Brazil. It investigates the in situ grade variability obtained during mining and the influence of pile dimension to attenuate this variability. SiO2 was chosen as the main variable for this analysis as it constitutes the most critical and variable contaminant present in the ore.

Methodology

Before starting the analysis on the variability reduction with the increase of the pile mass, it is necessary to understand all variability sources influencing the system, namely:

- Intrinsic variability of the ore grades from Mine 1
- Intrinsic variability of the ore grades from Mine 2
- Variability of the grades, which feed the homogenization system (pre-pile combining ore from several mining benches from the two mines)
- Variability among grades coming from different homogenization piles (variability inter-piles depending on pile mass).

Figure 1 displays a schematic representation of the
analyzed system. The black dots in this figure highlight the sampling locations along the circuit, also the variability plots at those locations are also depicted. These plots will be further discussed.

The sampling is carried out along the conveyor belt at every 600 t interval. These materials are homogenized at the end of the shift and sent for laboratory analysis.

Each block mined has a different grade. These grades differ among them and they are also different from the global mean grade mined along the first production year. By grouping various blocks and forming a pile, the average grade of this pile is closer to the global annual mean if compared to the grades of each individual block which comprise the pile. This phenomenon of variance reduction (Figure 2) is well known among geostatisticians and it is referred to as the volume-variance relationship (Parker, 1979).2

The data collected at the mine site includes production information at every stage along the homogenization system within the year of 2004. The smallest scale of available information corresponds to a production shift, including the tonnes produced and their grades. The analysed variable is silica (SiO2), an erratic component in this type of mineral deposit.

The data and information acquired, made it possible to proceed with a comparative analysis on the variability in the grades derived from the two mines and the effect along each blending stage.

In situ grade variability is obtained using diamond drill hole core assays from mine 1 and 2 and also with the following steps:

- generation of multiple equally probable 3D models via sequential Gaussian simulation (sGsim)
- determination of optimal scheduling for the 3D block model input
- calculation of the variability in each stage for every 3D simulated block model,

The simulated block models are required to be validated prior to their use in defining uncertainty limits. Validation of stochastic models comprises visual checking to verify the correct reproduction of the spatial continuity and data conditioning, and histogram and variogram reproduction and their ergodic fluctuations.

A 3D grade block model was built using sequential Gaussian simulation (sGsim) (Isaaks, 1990). This algorithm generates multiple and equally probable scenarios for the grade spatial distribution, reproducing statistically, its spatial continuity and histogram. Simulated grades at various supports provide the means to forecast pile grade fluctuations. These fluctuations can be plotted as confidence intervals. If the process is valid the real grades determined by the sampling system should fall within the interval predicted by the simulations.

Figure 1. Diagram showing a typical blending system used at some Brazilian iron mines. Black dots represent the locations where samples were obtained

Figure 2. Volume-variance relationship. As the mass of the lot analyzed increases (mass of the pile) (a), the variance among the grades reduces (b)
Results and discussion

Assessing block grade uncertainty

Data available include vertical drill holes, comprising 5,928 composites from mine 1 and 3,585 composites from mine 2, which have their support regularized at 10 m intervals.

Conditional geostatistical simulations (sGsim) were used to obtain 50 equi-probable scenarios for the attribute of interest at the block size associated to the mining selectivity to be adopted (10 m \times 10 m \times 10 m).

Mine sequence

Reconciliation results for grade blocks were not available at a block by block basis. The mines, during each month were mined in polygons and these polygons include all blocks extracted in a given period without any specific order. Basically, the sequence of blocks extracted along a month is not available. Consequently, we sorted out the blocks within each given month (polygon) by x, y and z coordinates.

Pre-product variability

The material analyzed before arriving at the processing plant is the so-called ‘Pre product’, which is basically ROM from mine 1 and 2. This material is sampled at the conveyor belt which transports ore from each mine.

Mine 1

The average mass of the lots analysed during a shift is 8.6 ktonnes with a standard deviation of 2 ktonnes (Figure 3a). The SiO$_2$ average grade mined along the year was 2.21% with a standard deviation of 1.07%. Figure 3b presents the time series for all grades from ore lots produced at mine 1 along 2004.

Figure 4 shows three series with SiO$_2$ grades. Note, the lower and upper bounds obtained by the 50 simulations and also the measured (real) grades. Each point plotted corresponds to approximately 8.7 ktonnes mass which refers to three blocks.

It can be verified that practically all the sampled values fall in the upper lower uncertainty limits predicted by the 50 simulations.

Mine 2

The lots analyzed at each shift weights 8.2 ktonnes on average with a 3.2 ktonnes standard deviation, (Figure 5a). The SiO$_2$ average grade mined along 2004 is 2.64% with a standard deviation of 1.42%. Grades from mine 2 are more erratic than the ones from mine 1. Figure 4b presents the time series for all grades from ore lots produced at mine 2 along 2004.

It can be noticed at Figure 3b and 5b, the large variability from SiO$_2$ produced along each shift at each mine. This variability would lead to a yield reduction at the processing plant with obvious operational problems.

It can be verified that practically all the sampled values fall in the upper-lower uncertainty limits predicted by the 50 simulations. Note, that there is not a direct block to block (block grades predicted by simulation and the block sampled at the blending system) correspondence at plot 5 and 6. As it is not possible to identify within a given month the exact sequence of blocks mined, probably the sequence of blocks (scheduled) used for the simulations do not match the real one adopted at the mine. This leads to a few readings (real grades) plotting outside the predicted limits.

Pre pile variability

The pre pile material includes ROM from the two mines. It is the combination of the ore from mine 1 and 2. The lots

Figure 3. (a) Histogram for the mass of the lots (b) SiO$_2$ grades at each 8.6 ktonnes lot along 2004

Figure 4. SiO$_2$ grades at each 8.6 ktonnes lot along 2004 (red dots), upper (green line) and lower (blue) bound for simulated SiO$_2$ grades
analyzed along each shift weighs approximately 19 ktonnes. Figure 7 presents the masses of lots at the pre-pile stage and their SiO₂ grades.

Note in figure 7b, there is a significant reduction in variability, if compared against the ones obtained from the grades at each mine individually (Figure 3b and 5b).

In Figure 8, each value plotted corresponds to every three re-blocked grades from mine 1 and 2, (i.e. approximately 17.4 ktonnes).

The average silica grade for the combined lots from the two mines is 2.28%, and the standard deviation is 0.66%. The variability of the initial grades was reduced by 40% blending the ores from the two mines.

Inter piles variability

There are various constructive methods for pile homogenization and among them the most common is the chevron type. The chevron system at Vale’s iron mines contains two or a multiple of two long, rectangular beds. While a pile is being built on a bed, the pile on the other bed is being reclaimed (Figure 9). The company can set up piles of up to 200 ktonnes each (max two piles).

Along the year 2004, 135 piles with different masses were mounted (Figure 10a). These differences in pile masses were caused by high market demands for iron ore; this didn’t allowing the company to stock material at piles. The consequence was less mass at the piles than planned. Figure 10b presents grades from each pile following the order they were mounted (time series). The variability of grade values on this plot (Figure 10b) is less than the variability at the previous stage (Figure 7b).

As the 137 piles have different masses they were divided into 27 classes of similar size with at least five piles in each class. Within each class (which include piles of similar size), the variability of the piles average grade was calculated in relation to the average grade of the year 2004. The process was applied to the 27 classes and the variability for each of them calculated. The results obtained are plotted at Figure 11, (i.e. the mass of the class versus the variability for each pile size). Variability is expressed through the...
coefficient of variation. It is demonstrated (Figure 11) that there is a general trend in decreasing the variability as the pile size increases. This plot also illustrates the principle embedded in the volume variance relationship and explains why the reclaimed grades after the blending piles have a lower variability than the grades from the blocks leaving the mine.

Figure 12 depicts the upper and lower bounds for the expected grades for each pile mass obtained by sGsim and the chevron pile emulator. Each 3D simulated block model was used to construct multiple piles which will be formed along a scheduled mining period (month). There are 50 simulated models each with different grade values for a given block, leading to different grades for the same pile. The piles analyzed are equivalent to 50, 75, 100, 125, 150, 175, 200, 225 and 250 ktonnes. As the block grade variability is incorporated, the uncertainty limits can be evaluated and compared against the real pile grades along the year.

Note that the larger the pile, the better will be the blending process; however, from an operational perspective the problems and costs tend to increase as the size of the equipment involved increases. The adequate pile size is the minimum size which will deliver ore to the plant with grades varying within a pre determined and acceptable grade interval.

Composition of the variability of the homogenization system

Variability was measured along different stages within the production chain (Table I). It started by measuring ore grades variability from the ore leaving each mine which is basically the variability from ROM ore grades. The combination of ROM from the two mines leads to the so-called pre pile variability. The last stage is the variability after the blending piles which were tested for various pile sizes. All these readings were combined in a single plot (Figure 12a) depicting the amount of variability as a function of pile mass or support (volume) of the sample. A model was adjusted for the experimental results leading to a volume variability curve. It can be read along this model the expected coefficient of variation for SiO2 for any pile size or support.
Conclusions

Silica variability was reduced to 40% of the initial grade's variability by mining multiple benches and operating two mines simultaneously. After the homogenization piles, it was verified that it is possible to reduce in up to 75% on the initial silica grades variability. The decay on grades variability follows an exponential law as a function of the mass of the pile. This corroborates the volume-variance relationship.

The uncertainty limits can be properly forecast using geostatistical simulation. The limits predicted included the

Table I
Comparative among SiO₂ grades at different sampling stages

<table>
<thead>
<tr>
<th>Sampling point</th>
<th>Average mass (ktonnes)</th>
<th>SiO₂ CV (%)</th>
<th>Mean (%)</th>
<th>Min(%)</th>
<th>Max(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mine 1</td>
<td>8.6</td>
<td>0.49</td>
<td>2.21</td>
<td>0.66</td>
<td>12.08</td>
</tr>
<tr>
<td>Mine 2</td>
<td>8.2</td>
<td>0.54</td>
<td>2.64</td>
<td>0.63</td>
<td>18.74</td>
</tr>
<tr>
<td>Pre-pile</td>
<td>19</td>
<td>0.29</td>
<td>2.28</td>
<td>0.84</td>
<td>7.35</td>
</tr>
<tr>
<td>Piles</td>
<td>150</td>
<td>0.20</td>
<td>2.31</td>
<td>1.40</td>
<td>4.04</td>
</tr>
</tbody>
</table>
real grades obtained by sampling along various stages from the blending system.

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References


Diego Machado Marques
Graduate student, LPM - UFRGS