Dilution, ore grade and blast movement calculation model

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ABSTRACT

This document investigates the dilution control produced by the movement of a bench blasting (i.e. movement created by a rock blast due to the explosive use). A blast dilution calculation and estimation model was developed based on dependent parameters of the blast (hole coordinates, rock contacts, powder factor/hole, amount of explosive/hole, burden, spacing, hole length, stemming length, explosive energy, hole row, sub-drilling, blast sequence, stiffness ratio, blast hole distance to free face, rock density and rock elasticity coefficient). The model was generated from empirical data according to a multi-linear regression and it’s composed of 137 points of surface motion and 6 of internal motion collected in 4 blasts carried out in Cobre Las Cruces Mine (FQM Ltd.) in Gerena (Sevilla, Spain). This is statistically significant with a coefficient of determination of 0.803 for surface motion (validated with 31 additional points) and 0.97 for the internal motion (validated with XX additional points). The main objective of the study was to corroborate the minimization of dilution using a blast selective sequence, resorting to the use of electronic detonators.

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1. Introduction

In large majority of open pit mines, bench blasting method is used to allow the removal of a determined volume of a given rock mass. These mine deposits are highly heterogeneous with the ore disseminated in pockets of varying grade with an economic cut-off grade determined for the mine operation and as such, any material with less mineralization is designated as waste. The ore is excavated and hauled to the mineral processing plant while the waste is transported to a suitable dumping location. Blasting of these rocks involves drilling a series of holes with a calculated spacing-burden ratio necessary to fragment and loosen the rock mass. However, the movement of the rock caused by blasting has an unfavorable effect on the separation of the ore and waste region in the muck pile, causing either ore loss (the ore is wrongly categorized as waste and sent to the waste dump) and/or ore dilution (waste is wrongly categorized as ore and sent to the processing plant). The dilution or loss of mineral are two important factors in grade control of a mine. For example, in a blast zone with 7678m$^3$ of mineral with a grade of 2.06%, when diluted with 504.7 m$^3$ of sterile waste(mejor??) at 0.81%, it decreases the initial grade by 24%. This, for a long period of production, represents a reduction of the processing plant productivity, transportation of unwanted material and consequently lower profits. The starting point for a dilution control study is to estimate the amount of material that is mixed during blast movement, so that, this document presents a new formula for predicting the surface and internal motion as well as the dilution produced by them. This formula was empirically deduced from the study of 100 data from different blasts and validated with 31.

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2. Objective

The objective of the study is to develop a tool that enables estimation, control and minimize dilution in metal mining. The use of electronic detonating technology and selective sequencing were considered in order to decrease the mineral mixture (decreasing the risk area in contact - [Fig. 1]) to facilitate the process of zoning and muckpile loading.

Fig. 1 – Risk area
3. Background

Essentially, in a blast, the dilution or loss of mineral are associated with:
- Blasting location (existence of contacts between different materials).
- Blast design (hole position, charge distribution, stemming).
- Sequence and blast movement.

The two types of dilution that may occur are: internal dilution (produced by inclusion of waste existing inside the ore block); dilution or external contact (produced by the unfavorable movement of the boundary between two types of material, and some of the sterile mixes with mineral). The external dilution is pretended to be studied and estimated by monitoring the blast parameters. Dilution in a blast can be calculated from the percentage of waste (or material below a certain cut-off) that is mixed with the ore body during operation.

\[
\% \text{ Dilution} = \frac{V_{\text{ext}}}{V_e} \quad \text{Ec. 1}
\]

Where:
\( V_{\text{ext}} \): Waste Volume (m³)
\( V_e \): Blast total volume (m³)

The importance of dilution control or ore loss, mainly in metal mining, is associated with the construction of blending to standardize the grade of mineral entry into the treatment plant.

4. Problem identification

The grade control is based on the drill cuttings of each hole and, with the mean of it, different zone types are delimited.

These zones are marked after the blast process over the muck pile without considering the movement produced by the work of the explosive in the detonation moment.

The theoretical blending construction is based in the initial grades of each blast zone, so that, the grade changes produced by the movement of the mass were not considered in the calculus. This situation can mean a significance grade change when entering the plant.

The [Table 2] compares the estimated blending without taking in account the movement of the blasted mass (Theoretical) with the ones considering that situation (Real). In this part of the study 7 blast data were used, and as it can be verified, the mixture during rock blasting may provide a reduction of the final blending grade from about 3.5 up to 3.03% or 4.2 to 3.79%. This phenomenon can be understood by regarding the difference of the metallic Cu between forecasts and reality (*), where the negative sign represents the tonnage not entered into its final destination.

To understand the importance of this situation, analyzing in economic terms, we have three points:

### Table 2
Blending construction study

<table>
<thead>
<tr>
<th>Blending</th>
<th>Blast nr.</th>
<th>Density</th>
<th>Volume</th>
<th>Ton.</th>
<th>Theoretical Density</th>
<th>Volume</th>
<th>Ton.</th>
<th>Real Cu Ton.</th>
<th>Difference (%)</th>
<th>%Cu Theoretical</th>
<th>%Cu Real</th>
<th>Difference</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4</td>
<td>3.84</td>
<td>5984.15</td>
<td>23254.19</td>
<td>3.83</td>
<td>5131.56</td>
<td>20079.52</td>
<td>-213.43</td>
<td>3.5%</td>
<td>3.03%</td>
<td>0.50%</td>
<td>-14%</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>3.85</td>
<td>3611.77</td>
<td>13908.77</td>
<td>3.87</td>
<td>3779.51</td>
<td>14642.97</td>
<td>24.45</td>
<td>2.7%</td>
<td>2.73%</td>
<td>0.03%</td>
<td>1%</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>4</td>
<td>3.61</td>
<td>5114.04</td>
<td>19312.50</td>
<td>3.61</td>
<td>4982.95</td>
<td>18071.40</td>
<td>-134.37</td>
<td>4.2%</td>
<td>3.79%</td>
<td>0.45%</td>
<td>-11%</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>5</td>
<td>3.94</td>
<td>4166.62</td>
<td>23709.02</td>
<td>3.90</td>
<td>4825.21</td>
<td>25067.90</td>
<td>8.26</td>
<td>5.9%</td>
<td>5.66%</td>
<td>0.29%</td>
<td>-5%</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>4</td>
<td>3.73</td>
<td>4786.09</td>
<td>18283.96</td>
<td>3.73</td>
<td>5321.06</td>
<td>20245.69</td>
<td>44.57</td>
<td>3.9%</td>
<td>3.73%</td>
<td>0.16%</td>
<td>-4%</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>4</td>
<td>3.88</td>
<td>7252.99</td>
<td>27903.49</td>
<td>3.85</td>
<td>8249.28</td>
<td>31631.08</td>
<td>145.35</td>
<td>6.6%</td>
<td>6.32%</td>
<td>0.32%</td>
<td>-5%</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>2</td>
<td>3.70</td>
<td>1567.75</td>
<td>5837.34</td>
<td>3.67</td>
<td>1562.03</td>
<td>5593.65</td>
<td>-11.23</td>
<td>2.9%</td>
<td>2.78%</td>
<td>0.08%</td>
<td>-3%</td>
<td></td>
</tr>
<tr>
<td>IEM</td>
<td>3</td>
<td>3.29</td>
<td>5969.16</td>
<td>5837.34</td>
<td>3.28</td>
<td>5048.46</td>
<td>17438.99</td>
<td>57.08</td>
<td>0.8%</td>
<td>0.58%</td>
<td>0.17%</td>
<td>-23%</td>
<td></td>
</tr>
<tr>
<td>SBL</td>
<td>4</td>
<td>3.45</td>
<td>7714.20</td>
<td>5837.34</td>
<td>3.45</td>
<td>6990.40</td>
<td>24313.37</td>
<td>261.77</td>
<td>1.6%</td>
<td>1.46%</td>
<td>0.14%</td>
<td>-9%</td>
<td></td>
</tr>
<tr>
<td>SM</td>
<td>2</td>
<td>3.70</td>
<td>2868.77</td>
<td>5837.34</td>
<td>3.71</td>
<td>3444.94</td>
<td>12929.15</td>
<td>125.49</td>
<td>2.5%</td>
<td>1.87%</td>
<td>0.12%</td>
<td>-6%</td>
<td></td>
</tr>
<tr>
<td>GA</td>
<td>2</td>
<td>2.82</td>
<td>1471.61</td>
<td>5837.34</td>
<td>2.82</td>
<td>1165.03</td>
<td>3383.12</td>
<td>-14.34</td>
<td>0.3%</td>
<td>0.12%</td>
<td>0.19%</td>
<td>-61%</td>
<td></td>
</tr>
<tr>
<td>SGE</td>
<td>1</td>
<td>2.98</td>
<td>474.57</td>
<td>5837.34</td>
<td>2.98</td>
<td>410.46</td>
<td>1221.72</td>
<td>-1.17</td>
<td>0.02%</td>
<td>0.00%</td>
<td>0.02%</td>
<td>-100%</td>
<td></td>
</tr>
</tbody>
</table>

4.1. Copper tones lost to waste

8.4 Cu tons equivalent to 50,984.78 USD [Table 1] were determined as mineral loss in just three blasts (waste/mineral contact)

| Table 1 |
| Blast mineral loss |

| Blasting | 3 |
| Loss Cu (ton.) | 8.4 |
| $/ton (12-May-14 - InfoMine.com) | 6939.0 |
| Copper processing price/ton | 888.89 |
| Loss (USD) with production cost | 50,984.78 |

4.2. Copper tons transported to the wrong blending

If the diluted mineral is not moved to sterile, then it is transported to another blending, in which affects the theoretical grade through is being built. Indeed, we cannot refer to the concept of loss of mineral, however, depending on the grade of the mixing material, the severity can be equal or greater than the loss of it. The estimated tons moved to the wrong destiny in the 7 studied blasts, reach the amount of 565.25 tons of copper.

4.3. Blending under the theoretical building grade

The preceding points could lead to a lower grade blending construction. When analyzing the [Fig. 2], based on [Table 2], it is possible to affirm that, in the time window of the study, the blending that are being built were using material with lower grade previously predicted.

![Fig. 2 - Blending control grade](image-url)
5. Description of the database

The database of the model is composed by measurements made in Cobre Las Cruces Mine (First Quantum Minerals, Ltd.). General blasts characteristics of the study will be described in the following points.

5.1. Blasts characteristics

Fig. 3 represents the general scheme of Cobre Las Cruces blast and its geometrical parameters. The most influential parameter in dilution is the rock displacement during a blast and this can depend on holes coordinates, rock contacts, powder factor/hole, kg explosive/hole, burden, spacing, hole length, stemming, explosive energy, rows of holes, sub-drilling, ms/burden, ms/spacing, stiffness ratio, blast hole distance to free face, rock density and rock elasticity. Blast parameters are related to each other depending on the rock type, as shown in [Table 3].

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Mineral (kg/cm$^3$)</th>
<th>Waste (kg/cm$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>3 – 4.2</td>
<td>1 – 4.12</td>
</tr>
<tr>
<td>Rock Elasticity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drill diameter (mm)</td>
<td>140</td>
<td>152</td>
</tr>
<tr>
<td>Production holes BxS (m)</td>
<td>4x4</td>
<td>5x5</td>
</tr>
<tr>
<td>Cut holes BxS (m)</td>
<td>3x3.5</td>
<td>4x3</td>
</tr>
<tr>
<td>Bench high (m)</td>
<td>4.5 – 5</td>
<td>4.5 – 5</td>
</tr>
<tr>
<td>Free face angle (º)</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>Stemming (m)</td>
<td>2.5 - 3</td>
<td>2.5 - 3</td>
</tr>
<tr>
<td>Powder factor (kg/m$^3$)</td>
<td>0.34-0.45</td>
<td>0.5-0.7</td>
</tr>
<tr>
<td>Delay between rows (ms)</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Delay within rows (ms)</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Explosive type</td>
<td>Emunex 8000</td>
<td>Emunex 8000</td>
</tr>
<tr>
<td>In-hole and surface initiation systems</td>
<td>Non electric</td>
<td>Non electric</td>
</tr>
</tbody>
</table>

Fig. 3 – Sketch of a typical blast (RIOBLAST – MAXAM ®)
6. Methodology

6.1. KPI’s measurements

KPI’s represented in [ Table 4] were collected from each hole of all the studied blasts.

<table>
<thead>
<tr>
<th>KPI’s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powder factor (Kg explosive/hole)</td>
</tr>
<tr>
<td>Burden</td>
</tr>
<tr>
<td>Spacing</td>
</tr>
<tr>
<td>Hole length</td>
</tr>
<tr>
<td>Stemming</td>
</tr>
<tr>
<td>Explosive energy</td>
</tr>
<tr>
<td>Row</td>
</tr>
<tr>
<td>Sub-drilling</td>
</tr>
<tr>
<td>ms/burden</td>
</tr>
<tr>
<td>ms/spacing</td>
</tr>
<tr>
<td>Stiffness ratio</td>
</tr>
<tr>
<td>Powder factor</td>
</tr>
<tr>
<td>Distance to free face</td>
</tr>
<tr>
<td>Rock density</td>
</tr>
<tr>
<td>Rock elasticity</td>
</tr>
</tbody>
</table>

Table 4: Superficial and internal movement analyzed KPI’s

Every data was compared with the superficial and internal displacement.

6.2. Superficial movement

The study of the superficial movement is based on control units (10/blast) introduced in the stemming of determined holes. Its initial position (before the blast) and the final one (after the blast) were calculated, so the blast maps were built with that data movement [Fig. 8]. With the control unit movement vectors [I] associated to the zone contacts, it was possible to predict their movement [III]. With the coordinates of the initial and final contact, it was possible to calculate the mixing area of each contact, and therefore, predict dilution, loss or gain, was possible. A 3D Laser (it measures distances and horizontal angles) was used to carry out the measurement of the points before and after a blast thereby generating their coordinates.

6.3. Movement direction

To corroborate the blast direction perpendicular to the isolines, a visual comparison of the real displacement vectors with the blast isolines was made.

Fig. 7 - Real blast direction vectors vs. time iso-lines

Fig. 8 - Superficial blast movement control
6.4. Internal movement

To understand the internal movement of a blast, the displacement of some blast zones were studied in 6 blasts. For this purpose, spring rubber and synthetic reinforced hoses with high tenacity yarn in nitrile rubber coating were used. These materials were introduced into empty holes drilled between the production ones and as the fragmented rocks were loaded the initial position of the rubber was changed. In order to register the final shape of these control objects, GPS coordinates were taken with respect to depth.

The internal movement can be understood analyzing the typical profile of the objects in [Fig. 9]. It is possible to affirm that the bench movement displaces the rock in a convex/membrane curvature shape reaching its maximum point at half of the bench height. For this reason, it was decided to use a mathematical equation (Membrane Equation) to represent the bench internal movement phenomena.

![Fig. 9 - Typical shape of internal movement control](image)

6.5. Bench movement and membrane equation

The function that defines the membrane behavior is given by the wave equation

$$ T \Delta u = \rho \frac{\partial^2 u}{\partial t^2} \quad \text{Ec. 2} $$

Where:
- $T \Delta u$ = Dilation of membrane surface
- $\rho$ = Membrane density

Solving the equation we obtain,

$$ \sin \frac{n \pi}{a} x \sin \frac{m \pi}{b} y \cos \left( t - t^* \right) = \frac{T \pi}{\rho} \frac{n^2}{a^2} + \frac{m^2}{b^2} \quad \text{Ec. 3} $$

Where:
- $t^*$ = Elapsed time of the membrane movement from this resting position to the maximum dilation.

Nevertheless, in the maximum dilation point where $t = t^*$,

$$ \cos \left( t - t^* \right) = 1 \quad \text{Ec. 4} $$

so that,

$$ T = \sin \frac{x \pi}{a} \sin \frac{y \pi}{b} \quad \text{Ec. 5} $$

Where:
- $a$ = Horizontal dimension of the membrane
- $b$ = Vertical dimension of the membrane
- $x$ = Horizontal variation of the membrane
- $y$ = Vertical variation of the membrane

Based on this equation, the bench movement phenomena has been represented in [Fig. 10] so as to better understand the phenomena: I – Perpendicular contacts to the typical bench movement; II y III – Expansion of the membrane shape; IV – Final contact deformed in the form of a membrane shape.

![Fig. 10 - Bench movement based on Membrane Equation](image)

As it can be observed, the initial contacts are modified by the blast and the next step, as represented in [Fig. 11] is to define the maximum displacement point ($K$).

![Fig. 11 - Membrane's maximum displacement point](image)

7. Model description

The model description is separated in 2 phases: superficial and internal movement: data treatment; and dilution calculation: grade control and mixed volume estimation.

For each data combination (superficial and internal movement) a multilinear regression was made (using forward method), where the insignificant variables were identified and dismissed. To confirm and characterize the regression as a model, the residual was analyzed and proved that zero was contained within the confidence interval for the average at 95%. The residual points follow a normal distribution because, according to Kolmogorov-Smirnov and Shapiro-Wilk, their significance level is superior to 0.05.
7.1. Superficial movement

From all the controls used in the study, 131 were selected for the whole development and model validation (100 for the formalization and 31 for the validation). For a coefficient of determination representing 80.3% of the data with a significance level of 0.069 (Kolmogorov-Smirnov) and 0.128 (Shapiro-Wilk) the superficial movement equation was obtained as shown.

\[ D = \frac{6.089}{\ln \left( \frac{kg}{B \times S \times L} \right)} + 0.121 \times B^2 - 0.944 \times \ln S + 0.256 \times R^2 - 0.067 \times \ln \left( \frac{SR}{3^2} \right) + 0.579 \times \frac{H}{B} \times 3.117 \]

Where:
- \( D \) = Superficial displacement (m)
- \( PF \) = Powder factor/hole (kg/m³) = \( \frac{kg}{B \times S \times L} \)
- \( L \) = Hole length (m)
- \( B \) = Burden (m)
- \( S \) = Spacing (m)
- \( R \) = Stemming length (m)
- \( SB= \) Sub-drill (m)
- \( \frac{SR}{3^2} \) = Delay/spacing (ms)
- \( SR = \) Stiffness Ratio (HB/B)
- \( HB = \) Bench height (m)
- \( Row = \) Hole row

7.2. Internal movement

For the membrane dilation calculation a new parameter appears to define its maximum value – \( K \)

Using the same methodology with a coefficient of determination representing 97.6% of the data, with a significance level of 1.79 (Kolmogorov-Smirnov) the maximum dilation of the membrane was obtained as follows:

\[ K = -0.304 \times \rho_{roca} + 5.038 \times PF - 0.008 \times \Delta_{CZ} \]

Where:
- \( K \) = Maximum dilation of the membrane (m)
- \( PF \) = Powder factor/hole (kg/m³) = \( \frac{kg}{B \times S \times L} \)
- \( \rho_{roca} \) = Rock density (g/cm³)
- \( \Delta_{CZ} \) = Distance to free face (m)

In this manner, combining [Ec. 5] with [Ec. 7] the final equation which defines the membrane is obtained as shown below:

\[ T = \sin \left( \frac{x_{pi}}{a} \right) \sin \left( \frac{y_{pi}}{b} \right) \times K \]

Taking into account the described \( K \), the membrane volume is:

\[ V_T = \frac{4 \times ab}{\pi} \times K \]

Ec. 8

Ec. 9

7.3. Dilation and final grade calculation

7.3.1. Dilation

As dilution is directly associated with the mixed volume, it is important to firstly define that volume. A determined volume of a blasted zone is characterized by the superficial movement and the entrance and exit of internal movement of this zone [Fig. 13]

The final mixed zone (by superficial movement) is defined:

\[ V_i = A_i \times H \]

Ec. 10

Where:
- \( V_i = \) Zone i mixed volume considering superficial movement (m³)
- \( A_i = \) Initial and final contact coordinates defined area (m²)
- \( H = \) Bench height (m)

However, the zone volume considering the internal movement is described by

\[ V_c = V_i + V_{ke} - V_{es} \]

Ec. 11

Where,
- \( V_c = \) Final zone mixed volume considering the superficial and internal movement (m³)
- \( V_i = \) Zone i mixed volume considering superficial movement - Ec. 10
- \( V_{ke} = \) Entrance membrane volume (m³)
- \( V_{es} = \) Exit membrane volume (m³)

Knowing very well which volumes represent ore or waste, the dilution or loss can be calculated by:

\[ \text{Dilution} \% = \frac{V_c - (V_{ke} + V_{es})}{V_c} \]

Ec. 12
Where:
\[ V_{ec.13} = \text{Entrance waste volume (m}^3\) \]
\[ V_{cor.13} = \text{Exit ore volume (m}^3\) \]
\[ V_{Ec} = \text{Final zone volume (m}^3\) \]

In this manner, the final zone volume is,
\[ V_{Ec} = V_{Total} - V_{cor} + V_{Zm} \]

7.3.2. Grade’s zone

The final grade zone calculation is based on a mass balance between zones, after the mixture among them. In this way, the final percentage of each element can be calculated with the formula below.
\[ P_z = \frac{P_{z1} \times V_{z1} \times \rho_{z1} + P_{z2} \times V_{z2} \times \rho_{z2} - P_{z1} \times V_{z1} \times \rho_{z1} + P_{z2} \times V_{z2} \times \rho_{z2}}{V_{z1} \times \rho_{z1} + V_{z2} \times \rho_{z2} - V_{z1} \times \rho_{z1} + V_{z2} \times \rho_{z2}} \]

8. Results and discussion

Resorting to the dilution control model developed, different types of sequencing would be compared for a given blast with the aim of testing the best design to prevent dilution. The blast analysed consist of two zones of low grade and medium grade and the main objective is to separate the former amongst itself and as well as the latter. In the following sections, the results obtained by the use of each type of the referred initiation system are described.

8.1. Non electric Initiation System

Using the non-electric sequencing system, the sequencing was designed as shown in [Fig. 14]. Introducing the data in the control tool as previously described and applying the surface and internal displacement models, the results presented in [Fig. 15] were obtained. According to the grade control in [Fig. 18] a decrease in the grade in three of the four zones: -9.60% (Z2), -3.85% (Z2) y -1.01% (Z3) respectively, was obtained. The grade in Zone 1 was increased (as expected) since material in Zone 2 (higher grade) had admixed with the former. As already discussed, these differences, on a large scale, can jeopardize the blend construction. In terms of dilution, this blast presents a 13.6% caused by the volume blend in Zones 2, 3 and 4.
With this type of sequencing, the isolines are characterized as seen in Fig. 17. The same figure shows the application of the displacement model and represents the surface and internal blast movement. In a preliminary analysis, a blast movement quite favourable to the material separation was verified and with the mixture of this material being considerably reduced. To corroborate this situation, in Fig. 19 it was found that indeed there was only a decrease of grade of: \(-0.044\%\) (Z2), \(-0.06\%\) (Z3) y \(-0.4\%\) (Z4). As expected, Zone 1 had a slight rise in grade of only \(0.105\%\). Respecting to dilution, a reduction of 5.7% was obtained; a value extremely low as compared to the value registered for non-electric detonators. This data reflects a clear optimization in the grade control using electronic detonators for the blast design; therefore they are vehemently advisable for these situations.

![Fig. 18 - Grade control of the displacement model – Non Electric Initiation](image1)

![Fig. 19 – Grade control of the displacement model – Electronic Initiation](image2)
Taking into practice the last blast example and using electronic detonators, the effect is clear taking into consideration the muck pile shape. The visual result has been clearly satisfactory in employing this methodology. As observed in [Fig. 20], three muck piles were formed from the detonation of the central holes of each zone and its consequent valleys in the boarders of the zone.

After marking the contacts topographically as seen in [Fig. 21], it is possible to verify that they are located in the valleys generated by the designed sequence employed.

Fig. 20 – Valleys produced by the blast movement

Fig. 21 – Final appearance of the example of the application of an electronic blasting with selective sequencing
9. Conclusions

To develop a prediction model for dilution, measurement techniques for superficial and internal blast movement were unwrapped and showed an extremely useful application for the mentioned model. The model has been validated, passing all the normality tests which it was subjected to. This confirmed the uncertainty of the blend construction based on materials separated in blasts designed with non-electric detonators (up to a 14% difference of the proposed grade) and achieved ascertainably the improvements in blend construction with electronic detonator initiation system.

A loss of about 60,000.00 USD was estimated in only 3 blasts. These values are alarming when analysed at the end of a year of work, hence clearly justifying that investment in such studies can cause a reduction of more than 50% of the estimated loss. This reduction is based on the difference in the volume of mineral lost in a blast using a non-electric initiation system and an electronic initiation system with values of 1234.37 m$^3$ and 545.93 m$^3$ respectively.

To carry out these studies, the definition of each blasting area before designing a sequence is of great importance and this requirement has been achieved by Cobre Las Cruces.

The use of electronic detonators corroborated an expected reduction in dilution from 14% to 5.7%. The design of a selective sequence involves a more detailed study of the blast. Nevertheless, the obtained results from the study were highly satisfactory.

A decrease in the dilution enables the construction of a more reliable blending and an optimized exploitation of the grade present in the deposit under study.

In terms of blast design for short and long time detonations within isolines surrounding contacts, it was concluded that the former allows a better separation between zones.

The separation of zones of equal grade for the construction of two distinct blendings is of equal importance as the others. Avoiding the mixture between zones, and the danger of grade reduction curtail the risk of uncertainties in the blending control data.

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11. References