Analysis of the Impact of the Dilution on the Planning of Open-Pit Mines for Highly Structural Veined-Shaped Bodies

R. Amirá, N. Morales and A. Cáceres

1 Introduction

For the vein-shaped bodies, the dilution of the mineral resource causes greater economic impact than for the porphyry copper due to the higher amount of surface ore contact with waste that can be diluted during the operation.

According to Bertinshaw and Lipton [1], there exist four types of dilution:

1. By geometry: related to the size of shovel, bank. and shape of the mineral.
2. Due to uncertainty in the in situ contact: given by the lack of geological information.
3. By blasting: result of overbreak where it is also reduced waste.
4. Due to mining errors: due to errors in the operation, marking, and perforation.

Ebrahimi [2] defined two main types of dilution: internal dilution, which is difficult if not impossible to avoid, where lithology and the distribution of grades are important factors and external dilution, also called contact dilution, which refers to the waste outside of the mineralized body. The fundamental factors in the external dilution are the shape of the body, the techniques of drilling and blasting, and the scale of the operation and the size of the equipment.

The contact surface impacts mine planning as the material previously considered ore may become waste depending on the definition of the cut-off grade. Therefore, the quantification of this contact surface is essential to determine the possible dilution and to incorporate it in the mine planning. The study of the contact surface is intrinsically

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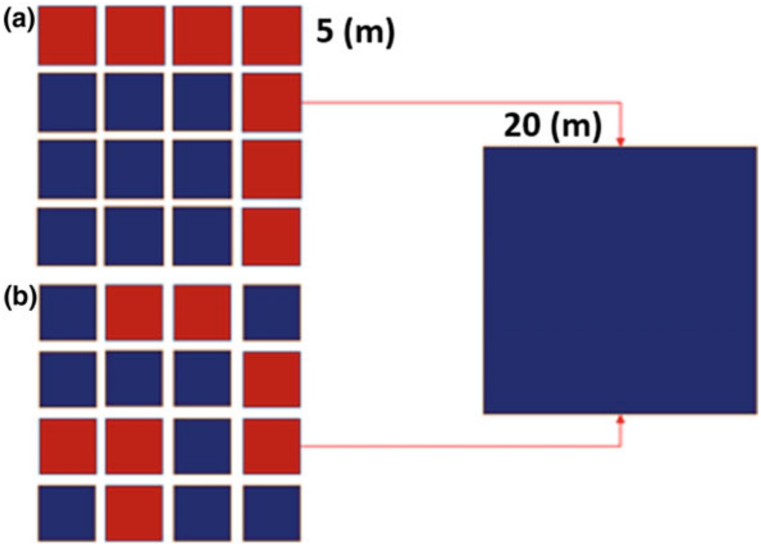

Fig. 1 Scheme of the internal dilution given by the two kinds of internal disposition of grades, ore blocks in blue and waste blocks in red: **a** regular distribution of ore, where the contact with waste is minimal and **b** irregular distribution of ore where the contact with waste is maximum

related to the size of the support used; the smaller it is, the larger the contact surface. Therefore, the size of the blocks must be considered in the analysis.

Vargas [3] defined planning as the ordering and scheduling of activities and resources of the mining operation to obtain the best possible result of the objective sought such as NPV, reserve, and life of the mine and operational continuity. In the planning, the geometric dilution is reflected in the change to a larger support unit, which results in the loss of selectivity of the extraction together with the incorporation of unwanted geological sections. In addition, the re-blocking decreases the recovery of the metal content as the size of blocks increase. Figure 1 shows an example of the change of support, where case (b) has a higher contact dilution income than case (a), with the same number of blocks in both cases.

Rossi and Deutsch [4] stated that a block size change brings with it several consequences; it is possible to reduce the block size to have the option to choose the blocks to be exploited better, increase the selectivity, or change to a larger support to reduce the number of blocks exploited. With the increase in block size, the softening of the grades implies a reduction of the variance, while the average does not vary.

This paper presents the outcome of the investigation to characterize and incorporate dilution in open-pit mining planning in structurally controlled high-grade deposits. A long-term strategic evaluation was carried out, using fixed economic parameters and considering the internal and contact dilution but not the operational dilution. The evaluation was made based on a block model of the copper deposit,

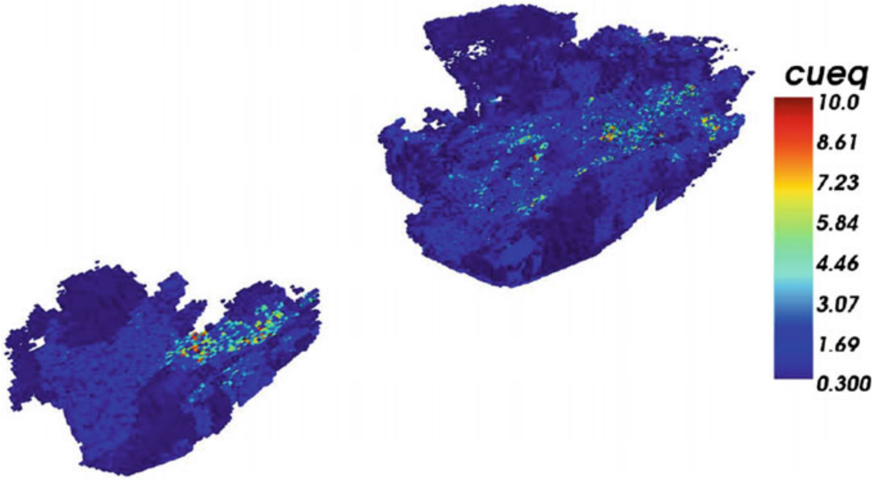

Fig. 2 Isometric view of the block model grades with a cut-off grade of 0.3 (%)

which consisted of a highly stratified vein-like body with 25,026,301 blocks, measuring 7.5 m × 5 m × 2.5 m each block.

2 Methodology

2.1 Characterization of Geological Dilution by Contact

A study of the neighborhood of each block was carried out identifying the blocks according to a cut-off grade threshold of 0.3 (%).

The categories shown in Fig. 2 defined in this study were as follows:

- ore in contact with ore (O-O): an ore block whose neighborhood consists only of blocks of ore (blue)
- ore in contact with waste (O-W): an ore block whose neighborhood consists of at least one block of waste (celestial)
- waste in contact with ore (W-O): a waste block whose neighborhood consists of at least one block of ore (yellow)
- waste in contact with waste (W-W): a waste block whose neighborhood consists only of waste blocks (red).

2.2 Characterization of Internal Geological Dilution

To study the internal dilution, four changes of support size were made with respect to the original model (C5), which had block dimensions of $7.5 \times 5 \times 2.5$ m, generating cases C10, C15, C20, and C30, where the dimensions of each block was multiplied by 2, 3, 4, and 6, respectively.

2.3 Strategic Planning

Valuation of the blocks using the grades was carried out according to fixed economic parameters, however, different sizes of the block have different costs. With this, a determined envelope was obtained with nested pits used to define the phases of the mine and a production plan with a corresponding NPV. For the mine planning, plans with different capacities of mine and plant were generated and fixed for the reminder of the study.

2.4 Incorporation of CV in Mine Planning Due to Mixing Restrictions

To study the impact of the internal distributions of the small blocks which make up the large blocks in a larger support, a calculation of the coefficient of variation (CV) was performed for each large block. This coefficient represents the variability of grades present within each large block; the higher it is, the greater the risk of dilution exists. Therefore, mixing restrictions were applied for the plans of each case studied consisting of each period sending blocks with CV average not exceed the maximum established to the plant.

3 Case Study

A cut-off grade of 0.3 (%) was established as a threshold between ore and waste. Figure 2 shows the grades present in the reserve of mineral.

The final pit had 4,688,153 blocks. The total ore tonnage was 180 (Mton), a 40 (%) of the reserve, with an average grade of 0.194 (%). Figure 3 shows the final pit for two different block sizes of 5 and 10 (m).

When considering the larger block sizes, the contact boundary between ore and waste was undoubtedly affected by the loss of information. To minimize this loss of information, the coefficient of variation (CV) of the grades for large blocks was calculated as follows:

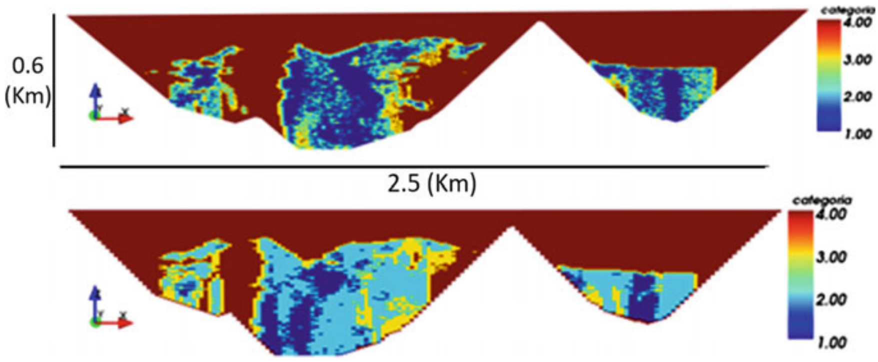

Fig. 3 View of the X–Z plane of the deposit categorized for the block size of 5 and 10 (m)

$$\mathrm{CV} = \sigma / G \tag{1}$$

$$\sigma^2 = \frac{\sum (G - g_i)^2}{N - 1} \tag{2}$$

where G is the grade of the big block and σ is the variance applied to a large ore block, g_i is the grade of the small blocks i and N the number of small blocks.

4 Results

4.1 Categorization of Block Size

Table 1 shows the amount of ore and waste for each block size with their respective average grades. The considerable increase of the total ore by 44 (MTon) from C5 to C30 is explained by the incorporation of a large quantity of small waste blocks within the large ore block as observed directly from the reduction of total waste as the block size increases.

Table 1 indicates a 0.2 (%) reduction in the mean grade of the total ore verify by the addition of small waste blocks to the large ore blocks. Figure 4 shows the selectivity curve for the different block models, which compares the amount of fines obtained between the block sizes for different amounts of ore according to its cut-off grade. It can be noted that the amount of metal content is considerably reduced by the increase in block sizes, reaching 100 MTon, where the amount of metal content of C30 represents two-thirds of the amount of metal of C5. The magnitude of this difference between the curves is greater for the smaller blocks as seen in cases C5 and C10. This effect decreases with the increase in block size. The comparison between cases C15 and C20 can be observed, where the effect is smaller.

Table 1 Summary table of the amount of ore and waste with its average grade for each block size

	Tonnage (MTon)	Average grade (%)	Metal content (KTon)
C5			
Ore	180.33	1.01	1828.54
Waste	962.41	0.04	375.34
Strip ratio	5.34		
C10			
Ore	193.98	0.94	1827.26
Waste	948.760	0.04	370.02
Strip ratio	4.89		
C15			
Ore	211.77	0.86	1827.55
Waste	930.97	0.04	353.77
Strip ratio	4.40		
C20			
Ore	212.52	0.86	1817.01
Waste	930.22	0.04	353.48
Strip ratio	4.38		
C30			
Ore	224.42	0.80	1804.30
Waste	918.32	0.04	348.96
Strip ratio	4.09		

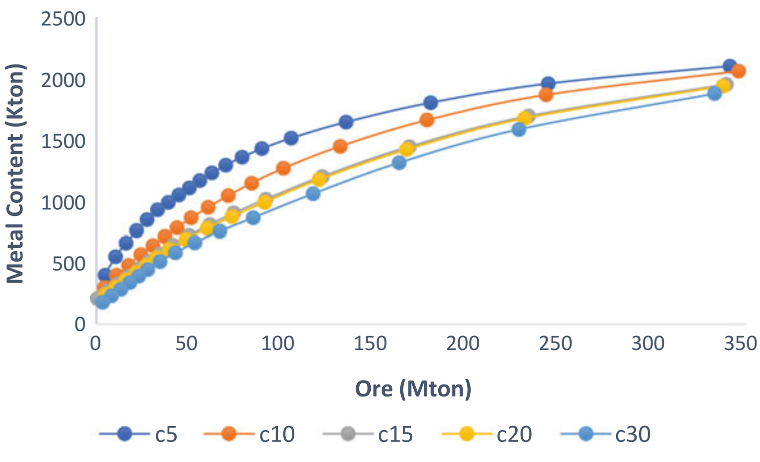

Fig. 4 Selectivity curve for each SMU

Figure 5a shows the percentages of the extreme categories O-O and W-W decrease while for the intermediate categories, O-W and W-O increase in a similar proportion. Figure 5b shows the increase of waste and the decrease of ore of small blocks. For

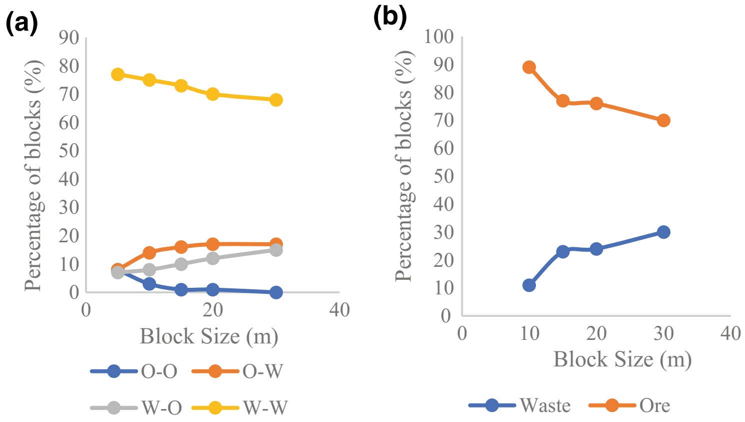

Fig. 5 **a** Proportions of the categories. **b** Ore and waste of small blocks in large blocks of ore present for each block size

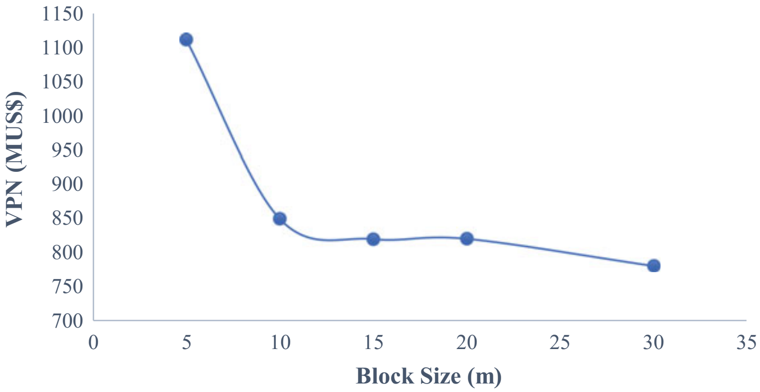

Fig. 6 NPV from the project according to the SMU

the small blocks, the amount of ore and waste material decreased and increased, respectively, up to 30 (%).

4.2 Strategic Planning

Figure 6 expresses the NPV obtained for the production plans for each case. There is an inverse relationship between the value of the project and the block size.

During the re-blocking, there is a difference of 20 (MTon) between C10 and 65 (MTon) for C30 between the amount of mineral of bigger blocks and the mineral of smaller blocks that composes it. This represents the conversion of 19 (%) from

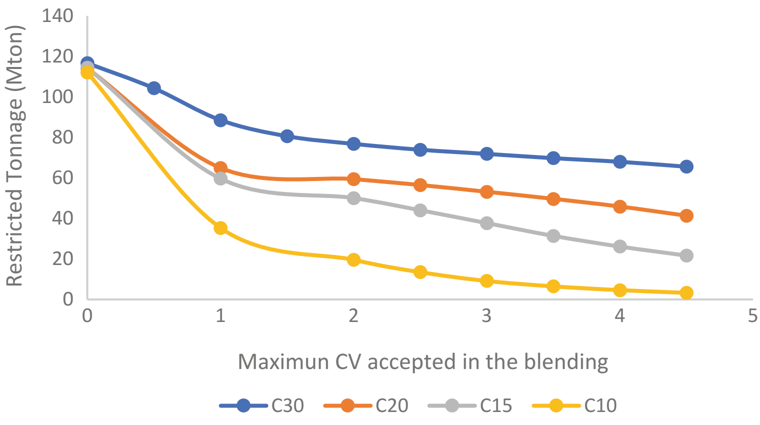

Fig. 7 Ore tonnage restricted by maximum CV

small waste blocks to ore and, thus, the loss of information when using SMU of larger size translates directly into a difference of the amount of ore sent to the plant and the mineral of small blocks that it really contains. This occurs because when working with a larger block size, waste support in contact with ore, it is considered to be ore and is processed as ore, resulting in poor utilization of the loading and processing equipment. In addition, the mixture produces a decrease in the grade punishing directly the fine obtained, with it the cash flows of each period and the final NPV of the project.

The direct translation of the loss of metal content is observed in a decrease of NPV reaching a difference of 291 (MUS$) between the cases C5 and C30. Thus, the loss of information and the softening of grades decrease the value of the project itself by more than 25 (%).

Loss of information and quantity of waste within the block are often ignored in many current operations in the industry, a fundamental result being their consideration for the sale and purchase of new deposits, where, if the buyer does not ensure that the estimated SMU is adequate, the final result can have large variations or losses in the expected economic gains For the different block sizes, a blending restriction is applied for the coefficient of variability: if the CV required is 1, the average of the coefficients sent to be processed in a period must be less than or equal to 1.

For the different block sizes in the same CV and for smaller sizes, there was a smaller amount of restricted resources (Fig. 7). Thus, the variability increases with the block size. The average CV for each size C10, C15, C20, and C30 are 0.209, 0.621, 0.984, and 2.119, respectively, and thus, in addition to the loss of information, there is a significant increase in the variability within the block when changing to a larger support size.

Figure 8 shows the results obtained when applying the mixture restriction and achieving a direct comparison between the different SMU cases, which shows the NPV obtained for each size with an average CV allowed per period.

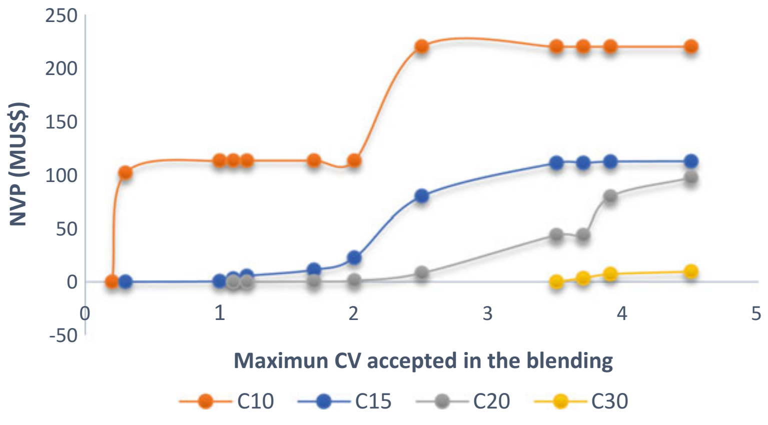

Fig. 8 NVP of the annual plans for different sizes within a restriction range

For all sizes, increasing the CV permitted per period increases the value of the project, unless the latter remains constant, because the NVP reaches the maximum achievable by applying a blending constrain.

The variability of blocks increases with block size. For example, for a block size of 10 m versus a block size of 30 m, the first achieves a value of 220 (MUS$) while the second obtains a value 0 for an average coefficient of variation of 2.5 for the entrance to the plant. The difference in the values obtained is the maximum allowed CV increases with the increase in the block size.

5 Conclusions

It is known that in the operation, block sizes are required that adapt to the operational requirements. Rarely, blocks sized of 2.5 m are used since the current equipment is larger and all the selectivity would be lost at the time of use. Therefore, the use of larger blocks has benefits by allowing an adequate operational geometry and minimum widths. In addition, the number of blocks is reduced and with it the number of components that make up the scheduling problem, so the resolution times decrease considerably. On the other hand, the metal content loss occurs, as shown by the selectivity curve and the quantification of the amount of ore and waste by size presented in this paper.

Another fact to highlight from the NPV obtained is the direct relationship between the range of feasible results and the SMU size. The smaller block sizes being those accept lower restrictions, while larger sizes give different results when the restriction is increased. As the block size is increased, the variation of NPV produced between different CV restrictions becomes smaller. The effect of the variability has greater importance and economic impact in smaller blocks than in the cases with larger SMU size.

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References

1. Bertinshaw, R., Lipton, I.: Estimating Mining Factors (Dilution and Ore Loss) in Open Pit Mines (2007)
2. Ebrahimi, A.: An Attempt to Standardize the Estimation of Dilution Factor for Open Pit Mining Projects (2013)
3. Vargas, M.: Modelo de planificación minera de corto y mediano plazo incorporando restricciones operacionales y de mezcla. Master's thesis in mining. Universidad de Chile, Chile (2011)
4. Rossi, M., Deutsch, C.: Mineral Resour. Estimation **2**(2), 12–18 (2014)