Ore resource estimation based on radial based functions - Case study on União Luiz and Morro do Carrapato Gold Deposits (Alta Floresta Gold Province)

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Taís Celestino dos Santos[1,3]
https://orcid.org/0000-0003-0667-923X
Jorge Kazuo Yamamoto[2,4]
https://orcid.org/0000-0002-2177-6794

[1]Universidade de São Paulo - USP, Instituto de Geociências, Departamento de Recursos Minerais e Hidrogeologia, São Paulo - São Paulo - Brasil.

[2]Universidade de São Paulo - USP, Instituto de Geociências, Departamento de Geologia Sedimentar e Ambiente, São Paulo - São Paulo - Brasil.

E-mails: [3]tais918@gmail.com, [4]jkyamamo@usp.br

Abstract

Radial basis functions can be used as an alternative method for mineral resource estimation when ordinary kriging cannot be done because it is impossible to calculate an experimental variogram. Interpolation based on radial based functions is a method that is similar to ordinary kriging. In this context, this article presents the results of gold resource estimation and modeling of the União Luis and Morro do Carrapato gold deposits located in Alta Floresta Gold Province, Mato Grosso. Experimental variograms in the main direction (90-degree strike) resulted in a pure nugget effect, whereas in the orthogonal direction (180/85), they resulted in a structured variogram. However, the structured variogram for 180/85 is useless because three orthogonal variograms are needed to define the anisotropy ellipsoid for deriving a correlation model used in ordinary kriging. Thus, mineral resource estimation was done using multiquadric equations, a very popular radial based function kernel. The 3D model for gold grades showed a vertical distribution suggesting a structural conditioning for gold mineralization. The grade-tonnage curve with a simulated cutoff of 5.0 g/ton resulted in a gold mineral resource of 2.122 tons. Through the above, the gold estimation and multiquadric equation-based 3D model for the studied area can be considered effective in its objective to estimate ore resources from the available data.

keywords: Radial basis functions, mineral resource estimation.

1. Introduction

Geostatistics has been accepted as a mining industry standard for mineral resource estimation, and ordinary kriging is the estimation technique used by geostatisticians to compute mineral resources. This technique depends on the spatial correlation model given by the variogram. However, experimental variograms cannot always be calculated because of data quantity and its distribution throughout the study area. There are some cases where the variogram cannot be calculated, such as: when the direction of mineralization or spatial phenomenon is unknown, the distribution is random, or due to poor sampling. In these cases, an alternative method should be used to replace ordinary kriging. Usually, the inverse of distance has been adopted as an alternative method, but a method based on the radial based function method, a method very similar to ordinary kriging, has been suggested by Yamamoto (2002).

This article presents the results of gold resource estimation and modeling using an alternative method based on radial based functions, since the variogram computation was not possible for the main direction of mineralization. The variogram for greater continuity in the study area resulted in a pure nugget effect. The study was carried out on the União Luis and Morro do Carrapato gold deposits located in Alta Floresta Gold Province, Mato Grosso.

2. Radial Based Function

Radial functions are a generalization of the original multiquadric equations as proposed by Hardy (1971). Multiquadric equations can be used to approximate any arbitrary surface with any degree of exactness by the summation of mathematically defined quadric surfaces (Hardy, 1977). The quadric forms are the simplest and the most efficient way to converge on an irregular surface (Hardy, 1977).

Yamamoto (2002) indicated that although radial based functions are defined on a global scale, local approximation can provide reliable results. Moreover, this approach transforms a large global problem into many small local problems by domain decomposition that can improve the accuracy and reduce computational efforts (Kansa, 1990).

According to Yamamoto (2002), the estimator by multiquadric equations can be written as equation (1) and the constraint condition is given by equation (2) (Yamamoto & Landim, 2013, p. 111).

$$Z^*(x_o) = \sum_{i=1}^{n} W_i Z(x_i) \quad (1)$$

$$\sum_{i=1}^{n} W_i = 1 \quad (2)$$

The multiquadratic weights are calculated by solving a system of linear equations (Yamamoto & Landim, 2013, p. 111), and according to Yamamoto (2002), the radial based functions that are used more commonly today are linear, cubic, generic multiquadric, splines and Gaussian.

The uncertainty associated with multiquadric interpolation can be calculated by the interpolation variance expression proposed by Yamamoto (2000, p. 491):

$$S_o^2 = \sum_{i=1}^{n} \left(Z(x_i) - Z^*(x_o)\right)^2 \quad (3)$$

3. 3D Model of Blocks

The 3D block model below is a discrete representation of the mineral deposit (Figure 1a). Each block of the model is computed as a weighted average of neighboring data points (Yamamoto and Landim 2013), as expressed by equation (1). The best approach for searching neighboring data points is by octants as shown in Figure 1b.

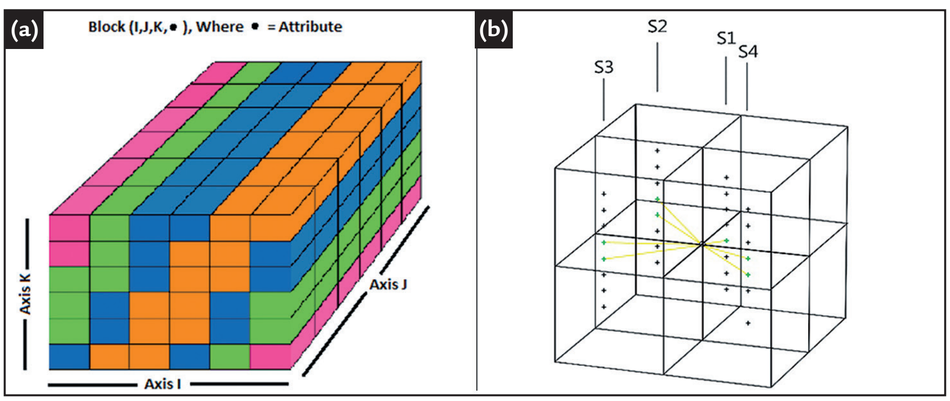

Figure 1
(a) 3D model of blocks (Yamamoto, 2001, p. 123); (b) Searching neighboring data points by octants from the nearest boreholes (Yamamoto, 2001, p. 128).

Considering that there are nx blocks in the X direction, ny blocks in the Y direction and nZ blocks in the Z direction, the 3D model results in a total of nx x ny x nz blocks. However, not all blocks are computed because some are above the topographic surface or are further from the available boreholes.

4. União Luiz and Morro do Carrapato Deposits

The Alta Floresta Gold Province (PAAF) located in the southern portion of the Amazon Craton has a significant number of gold deposits in its easternmost segment distributed along a NW-SW striking belt (Peru – União do Norte belt; Miguel Jr., 2011). The gold deposits in this region are hosted by plutonic and volcanic rocks of granitic composition (Paes de Barros, 2007; Assis, 2008; Assis, 2011; Miguel Jr.; 2011). Within this context, the União do Norte District (where the União Luiz and Morro do Carrapato gold deposits are found) represents the main study area in this project. These deposits are structurally controlled with low gold content (<5 ton) associated with base metals (Zn + Pb ± Cu), confined to quartz veins (thickness from 3 cm to 2 m) and hosted by granodioritic rocks with a global anisotropy of 180/85 (Trevisan, 2015; Matos & Xavier, 2016).

5. Materials and methods

To conduct this study, a database with all geological information and mineral content, including the gold grades of 62 boreholes were released by BioGold, the former owner of the deposits. A site-specific database was created with the geographic information (UTM coordinates and elevations), borehole direction and gold content (ppm). The location of the study area is not presented herein, due the confidentiality of the gold assays.

A 3D model of blocks with 9,302,400 blocks was computed with 408 blocks in X, 120 blocks in Y and 190 blocks in Z number. The block X, Y and Z axis dimensions were 6.25 m, 6.25 m and 1.0 m respectively. Not all blocks were calculated because they were outside the domain of interest. The global anisotropy was equal to 180° dip direction and 85° dip. The search for neighboring points was conducted using an anisotropy ellipsoid with an 88.39 x 88.39 x 5 m radius. In addition, two points were used per octant, totaling a maximum of 16 neighboring data points. These parameters were applied for deriving the numerical model of gold grades based on multiquadric interpolation. The gold grades were presented on a Gaussian scale due to strong positive asymmetry of the frequency distribution. In this regard, the data was transformed to normal distribution scores and divided into 21 value classes. These normal classes were then recalculated to the original scale values by reverse transformation. The modeling process was made using the Geokrige software.

Two cross sections are presented in Figure 2 to illustrate borehole direction. Boreholes are intersecting the ore body in two different directions, dipping from 50 to 60 degrees with an azimuth around zero (North) or 180 (South).

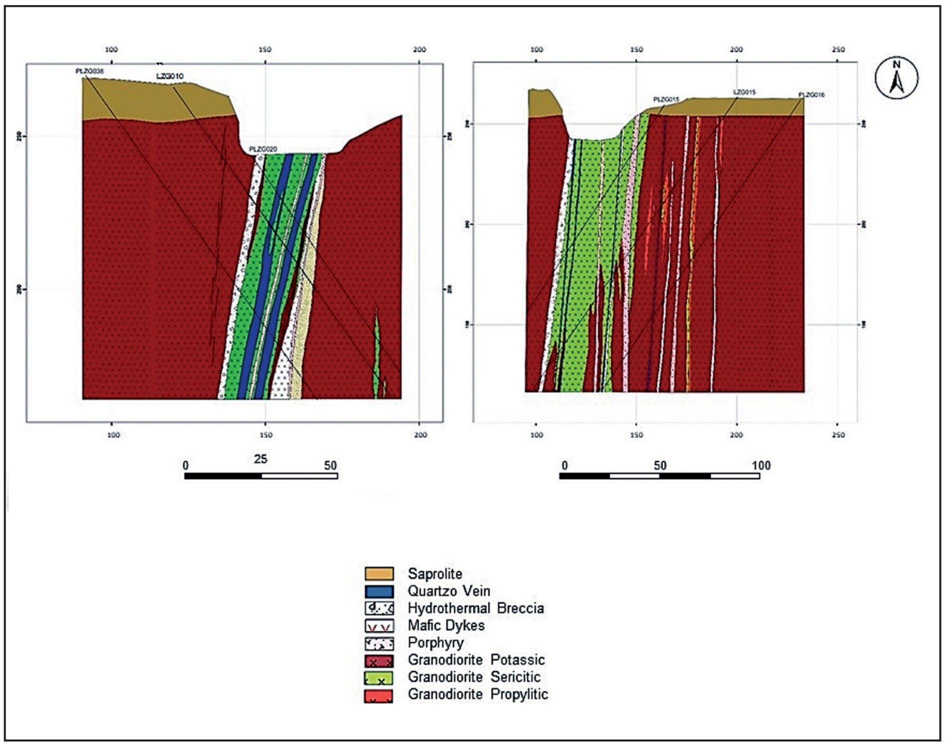

Figure 2
União Luiz Deposit cross sections.

6. Results and discussion

In these deposits, gold assays present a frequency distribution showing a high positive asymmetry typical in gold deposits. Descriptive statistics (Table 1) confirm the high variability as given by the coefficient of variation (CV) equal to 6.85. This is a very high CV even for a gold deposit. It may be explained due to the deposit structure (sub-vertical and structure controlled) reflecting on the occurrence of extremely high and low gold contents. It is also observed that a significant distance between the average and median values and a maximum value were much higher than the lower value, evidence of the extreme values presented in the data. The maximum value of 85.78 ppm may be related to native gold occurrence. The upper quartile shows that the sampling contents higher than 0.18 ppm represent only 25% of the total sampled.

N	X	STD Deviation	CV	Max	UQ	Med	LQ	Min
3342	0.55	3.79	6.85	85.78	0.18	0.05	0.02	0.01

Table 1
Descriptive statistics for gold grades.

The experimental variograms were calculated for a main direction of continuity given by a 90-degree strike (Figure 3a) and for an orthogonal direction of 180 dipping 85 degree strike (Figure 3b).

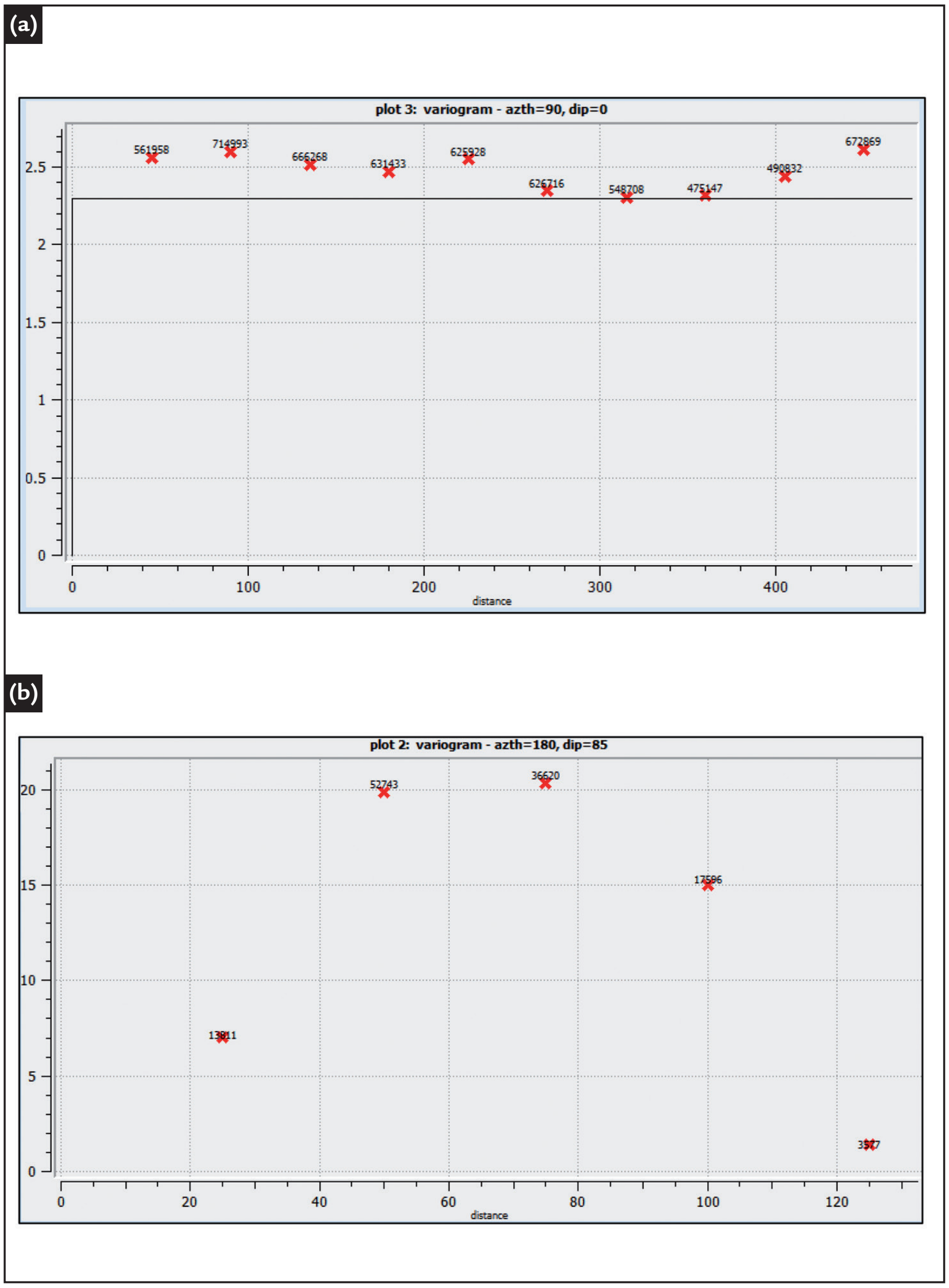

Figure 3
Experimental variograms calculated for the main direction (a) and its orthogonal direction (b).

The variogram for the main direction resulted in a pure nugget effect (Figure 3a). It occurred due to borehole distribution arranged in “X” positions, and due to insufficient sampling, as the distance between boreholes (from 100 to 400 meters) is much bigger than the mineralizing structure (up to 2.0 m).

On the other hand, the variogram for 180/85 (Figure 3b) resulted in a reasonably structured variogram, but useless because three orthogonal variograms are needed to define the anisotropy ellipsoid based on ordinary kriging.

Thus, ordinary kriging cannot be used, since it depends on the variogram model. In view of this fact, mineral resource estimation was made using multiquadric equations. Figures 4a to 4c and Figure 5a to 5c present the 3D model for gold grades, where the gold anomaly can be observed in all its extension. Most of the gold grades show a supposed no-economic content considering a cutoff grade equal to 1 ppm. The gold grades higher than 1 ppm (represented by blue tons) are observed concentrated in specific regions, with a vertical structure, suggesting a structurally controlled mineralization (Figure 4b and 4c and Figure 5b and 5c).

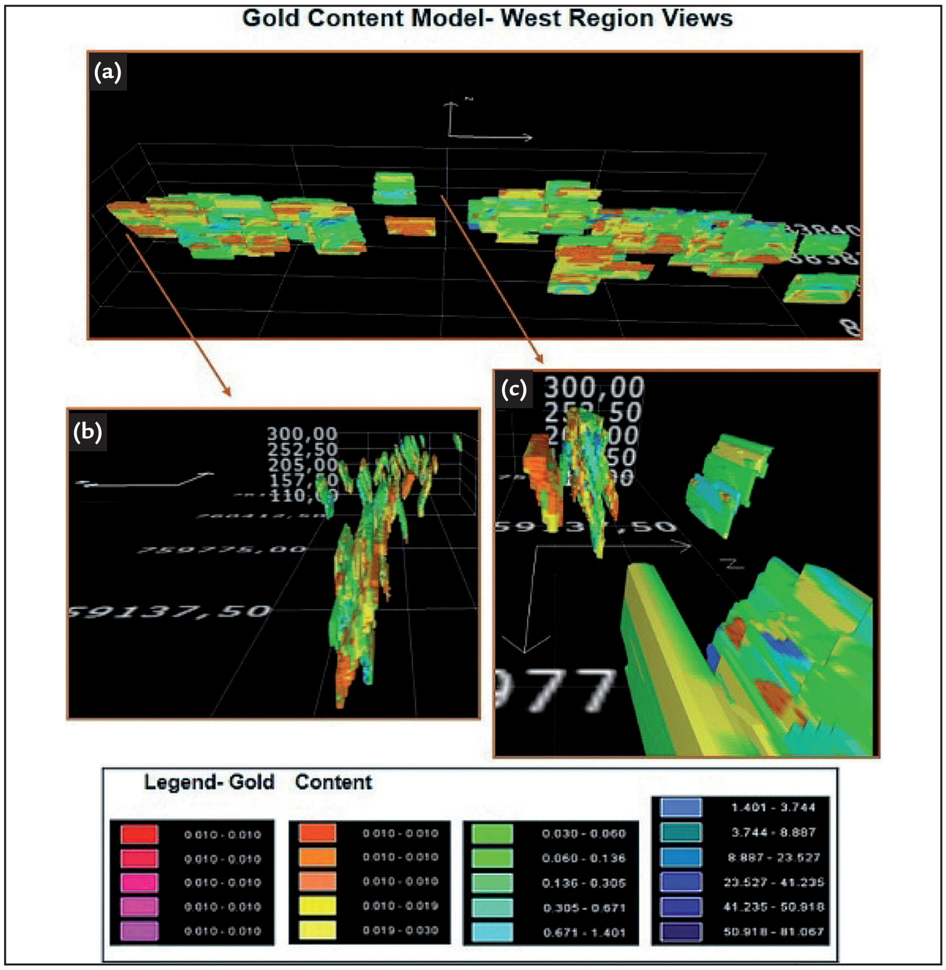

Figure 4
Products of 3D model for gold content- (a) General view; (b) and (c) West region views.

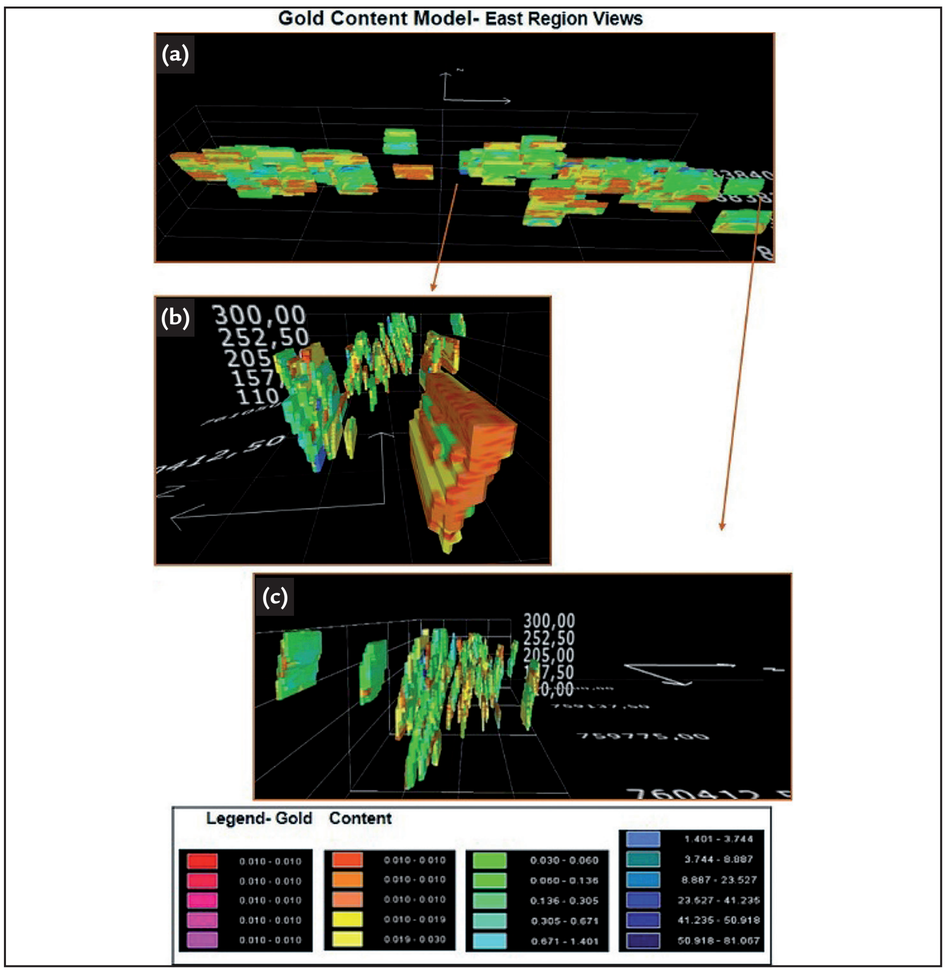

Figure 5
Products of 3D model for gold content- (a) General view; (b) and (c) East region views.

Figure 6 presents a 3D model for gold variance. The uncertainty, dispersion around the average value is bigger in the highest gold content regions, which confirms the proportional effect, a property of lognormal distribution.

The gold grade-tonnage curve is presented in Figure 7. The gold geologic resources have a total of 6.4 tons which represent the in-situ geological resource value. For instance, considering a simulated cutoff grade of 5.0 g/ton, we have a mineral reserve of 2.122 ton. However, the conversion of mineral resource to mineral reserve depends on modifying factors (Whitham, 2014)

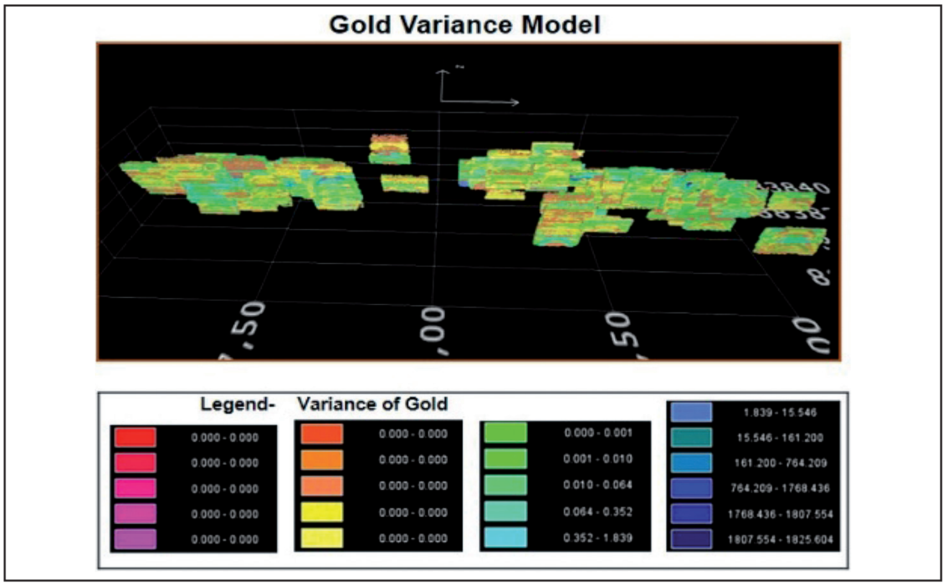

Figure 6
Product of 3D model for gold variance.

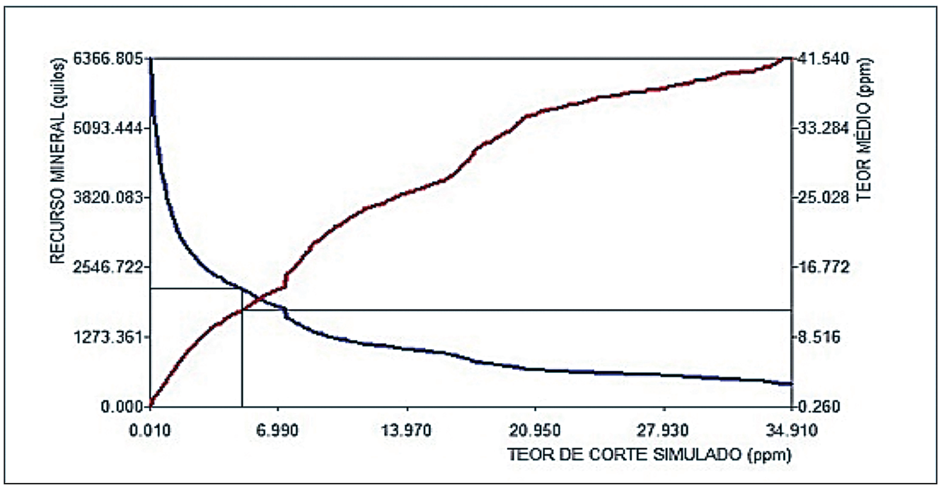

Figure 7
Gold grade- tonnage curve.

7. Conclusions

The variogram model cannot always be determined because of both the amount and distribution of data points in the study area. In this case study, the main direction (strike) showed a variogram reflecting a random phenomenon, i.e. a pure nugget effect. Thus, multiquadric equations were used as an alternative method to compute ore resources. It is important to say that the gold distribution presents a very strong positive asymmetry, as given by the variation coefficient being equal to 6.85. The gold mineralization of the studied deposits is known as structurally controlled, confined to quartz veins and presenting a vertical to sub-vertical structure, which makes it more difficult to calculate the gold resource due to the limited number of boreholes.

The gold 3D model showed the vertical structure for the highest gold grades, representing the main mineralization and suggesting a structural conditioning to gold mineralization. The grade-tonnage curve with a simulated cutoff of 5.0 g/ton gave a gold mineral reserve of 2.122 tons in the deposits. Through the above, the gold estimation and 3D block model based on multiquadric equations for the studied area can be considered effective in its objective to assay the ore from the available data.

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