SAMPLING OPTIMIZATION OF A VOLCANO-SEDIMENTARY DEPOSIT USING AN APPROACH BY GEOSTATISTICAL SIMULATIONS

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ABSTRACT

Exploration drillholes usually provide block estimates with large confidence intervals. Additional drilling is then required to achieve a more accurate resource classification. The paper presents an innovative methodology based on geostatistical simulations to quantify the relationship between the additional drillholes density and the confidence in the resource classification.

The key principle is to generate, by means of simulations, several realizations of the main parameters of the mineralization, i.e. geological features and grades. In a second stage the simulated deposits are sampled by "fictitious" drillholes that may be added to the existing ones. These drillholes are then used for estimating ore tonnages and grades. The comparison with the simulated values provides statistics on the estimation errors. This exercise can be repeated with another set of planned drillholes. The optimum between the number of drillholes and the confidence in the resource estimation can then be obtained from a limited number of tests.

An application to the Rosario Oeste deposit of Collahuasi copper mine is presented. The mineralization is concentrated in a high sulphidization vein system slightly inclined and located below a leached zone covering the orebody.

The resource classification is based on tonnage and grades estimates obtained after a three step approach:

(i) determination of the volume of the leached zone by simulating the surface boundary between this volume and the mineralized zone, (ii) simulations of the geometry of the mineralized veins. simulation of the alteration code, that is the determinant factor of the mineralization and (iii) simulations of grades within the mineralized veins.

The paper emphasizes the original approach, combining different techniques chosen to fit at best the characteristics of the deposit. Discussion about the practical results and the consequence on resource classification will be presented.

INTRODUCTION

"Rosario Oeste" Cu – Ag (Au) deposit is an orebody that is under several work of advanced exploration by Compañía Minera Doña Inés de Collahuasi. It is a huge high sulphidization system of sub vertical fault - veins and breccias located inside an area of 3.5 by 2.5 km toward southern part of Rosario Mine. The drill holes campaigns performed in this project just today

summarize over 101,000 meters in 384 diamantine drill holes. The grid of sampling is approximately equivalent to 150 x 150 meters.
The preliminary resources estimation shows inferred resources for more than 800 millions tons with an average grade of 0.8% of total copper. The major part of ore is related to secondary sulphides (chalcocite) associated with pyrite related to structural zone, the upper part of deposit is covered by an important leached and barren zone and the deep zone is not open yet. The mineralization is present over 800 meter from surface. A simplified geological model is shown in Figure 1.
We could define Rosario Oeste like a high sulphidization system of structural controlled zone with copper sulphide related to veins and breccias.
The uncertainty on the resource estimates from the actual drillholes has to be quantified in order to achieve appropriate resource classification. Another issue is to predict from how much the uncertainty is reduced by drilling more. For giving appropriate answers to these two questions an approach based on geostatistical simulations has been carried out.

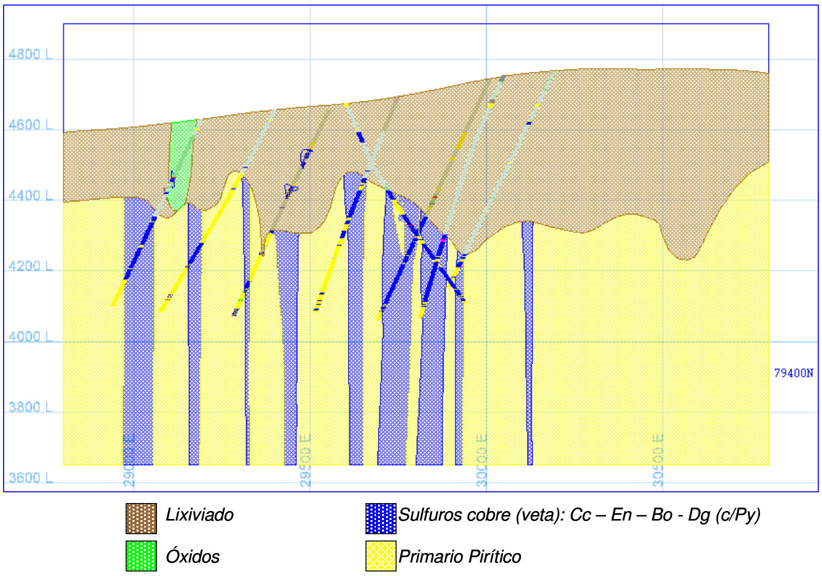

Figure 1: Schematic vertical section EW of Rosario Oeste deposit, showing the major domains.

METHODOLOGY

The geostatistical framework considers the observations such as rocktype and grades as realizations of stochastic processes. One can then generate using stochastic simulations other realizations of the same random variables, that are as many possible "realities". The spread of these different realities may characterize the uncertainty of the parameters and can be used to calculate confidence intervals on ore and metal tonnages on different supports.
Hereafter are detailed the major points for achieving the two objectives of the study.

Quantification of the uncertainty on the resources.

We have split into three major points the source of uncertainty on the resource: (i) the limit between the leached and the mineralized zone, (ii) the volume of the sulphide ore veins and (iii) the variability of ore grades, namely total copper and arsenic.
For each grade element, simulations have been carried out on a grid of blocks 5xmx5mx5m (Figure 2), using the most appropriate method, i.e.:

- Simulations by turning bands method of the leached zone bottom surface from the drillholes intercepts and guided by the geological model of the leached zone volume.
- Simulations of the geological codes (sulphide ore and waste) in the mineralized zone by means of truncated gaussian simulations adapted to repeated sequences from west to east of facies oriented about vertically. This part is the most delicate and resource consuming one [1,2]
- Co-simulations of Cu and As grades of the ore using turning bands method.

We have considered to match simulations of each of the three elements by their rank, as we decided to achieve only 25 simulations of grades it results that we can make the statistics on 25 realizations of ore tonnage and metal.
Besides the final simulated models is obtained by applying cookie cutting procedure, in order to keep for each simulation only the relevant part of it, i.e. for each simulation: the blocks in the leached zone are eliminated and the ore and metal of blocks with the waste code are put to 0.

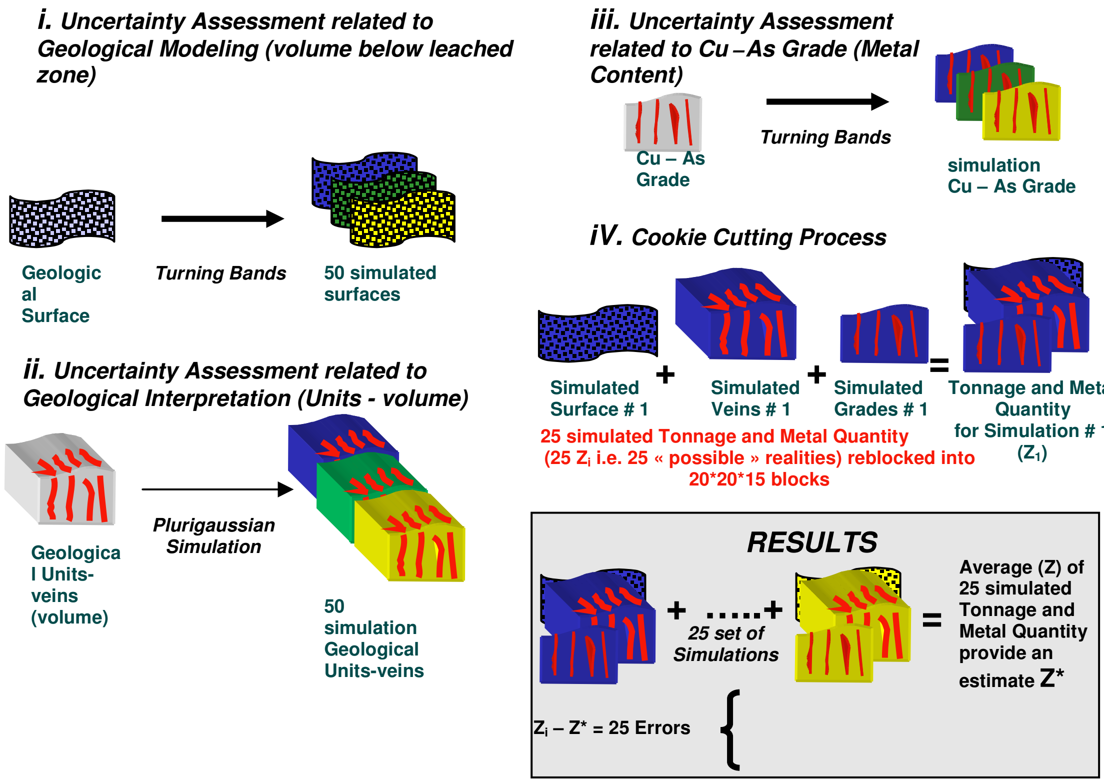

Figure 2: Workflow for simulating leached bottom surface, geological veins and Cu-As grades.

Improvement on the resources estimates confidence by adding more drillholes

Once the simulations are available we sample them by “fictitious” drillholes designed according to a feasible layout. For a given simulation we get a new data set, made of the actual data merged to the fictitious ones. These new data are then used to estimate ore tonnage and metal quantities that are compared to the original simulation, representing the reality.
Repeating the estimation process on the 25 simulations we obtain 25 errors, on which we calculate statistics, that are compared to the same issued from the actual data only (Figure 3).
The grade estimates are obtained by co-kriging, while the ore tonnage is estimated by making 10 simulations with truncated gaussian method conditioned by the new data set [3].

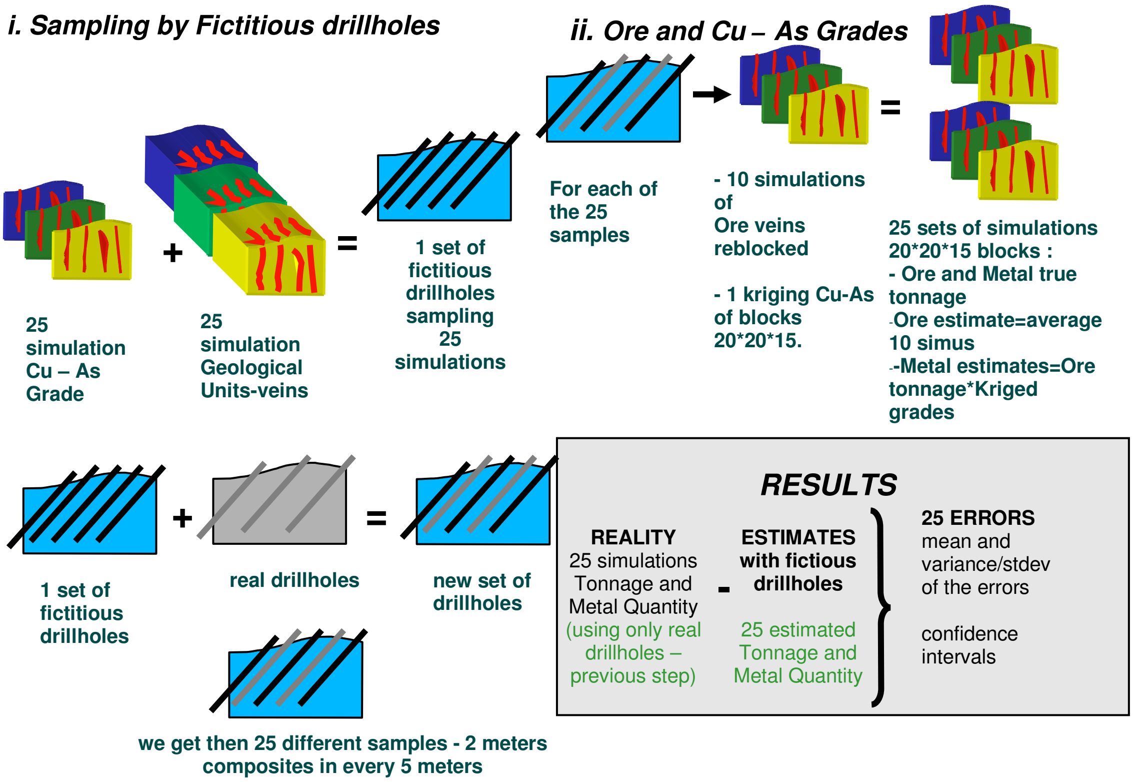

Figure 3: Workflow for estimating ore tonnage and metal quantities by adding new drillholes.

DATA ANALYSIS AND MODELING

Simulations of the leached zone bottom surface

The bottom of the leached zone volume, modeled as a wireframe, is interpolated on a regular 2D grid with a resolution 5mx5m. The uncertainty on that surface is simulated by adding residuals characterized by:

- They are equal to zero at the drillholes intercepts
- They have a structure of spatial correlation made of a spherical variogram of range 800 as indicated by the experimental variogram of the bottom leached zone elevation at the drillholes intercepts.
- The variability (sill value) is evaluated by difference of the dispersion variances between the modelled surface and the surface interpolated by kriging.

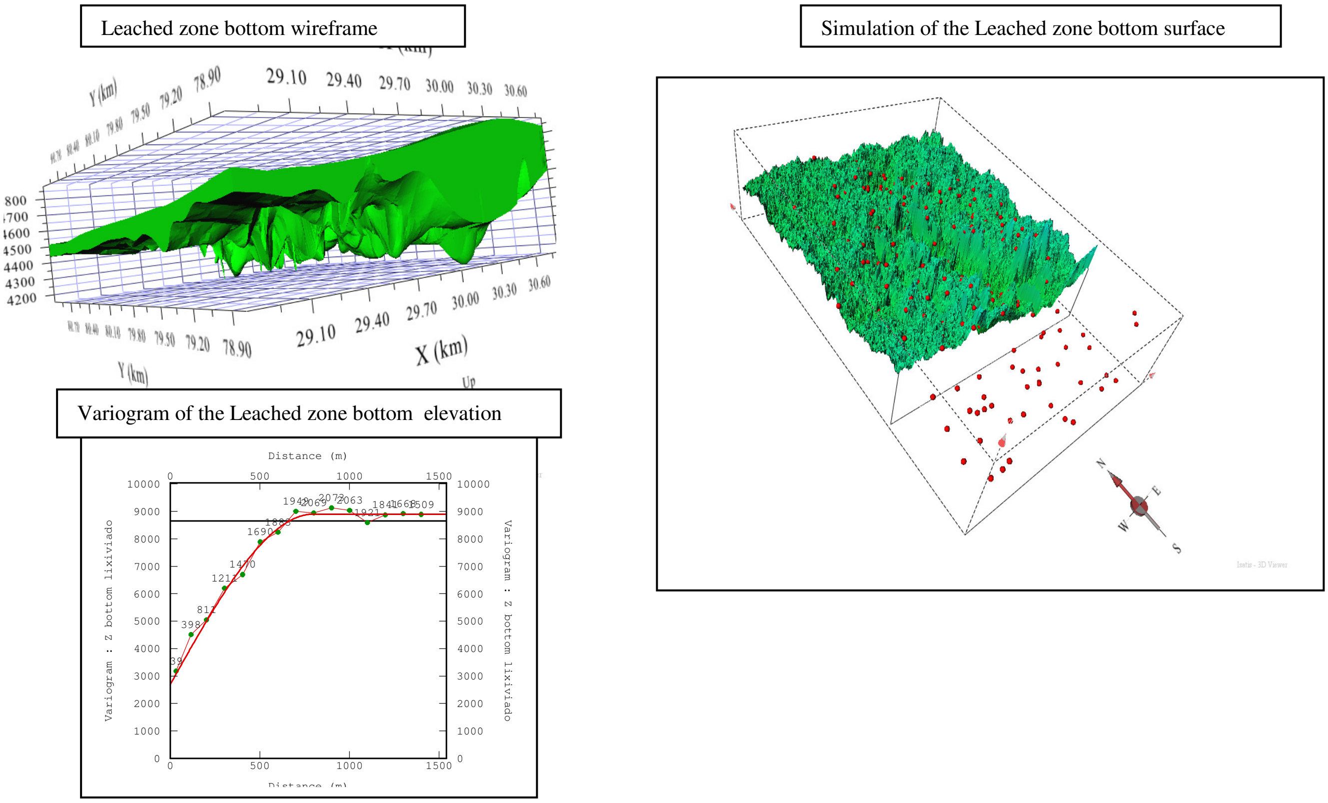

Figure 4: Modelling of the leached zone bottom from the leached zone wireframe and drillholes

Ore veins modelling

A change of coordinates has been applied to transform the vertical reference plane, giving the general orientation of the ore veins, into horizontal. We have then calculated the “vertical” proportion curves by grouping the drillholes into 8 groups (Figure 5). As a matter of fact they show the variations from west to east of the proportions of ore and waste.

In the truncated gaussian method, the lithotypes are obtained by truncation of a Gaussian random function. In case of 2 lithotypes (ore and waste) one threshold based on the proportions is sufficient. As there are o data for the Gaussian variable we fit the indicator variograms giving the models for the Gaussian random function. It is possible to proceed to that indirect fitting because the relationships between variograms of the Gaussian function and the variograms of the indicators are known. On the Figure 6 we show the variograms calculated in 3 main directions of the space.

25 simulations have been achieved then transformed to the real space after a rotation around the OY axis in the opposite direction and truncated by the leached zone bottom surface. On Figure 7 we can see how the vertical structures are reproduced.

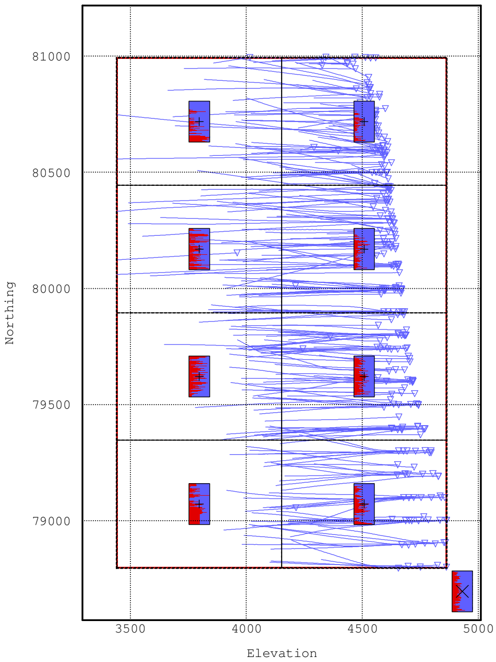

Figure 5: East-West proportion curves in 8 parallelepiped boxes.

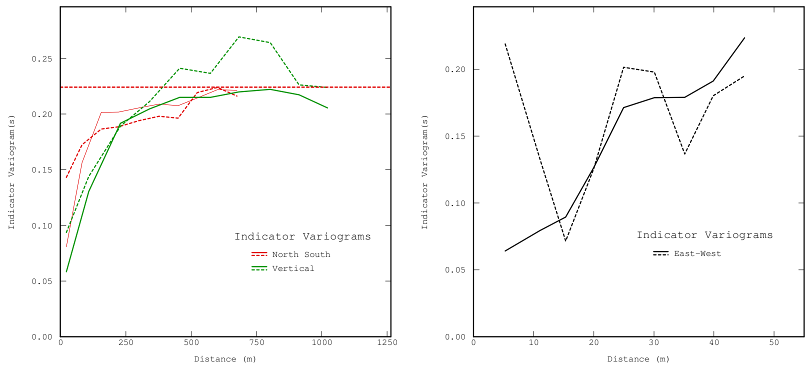

Figure 6: Indicator variograms fitted for the plurigaussian method in the 3 main directions of the space (in dotted line the experimental indicator variogram, in solid line the modelled indicator variogram.

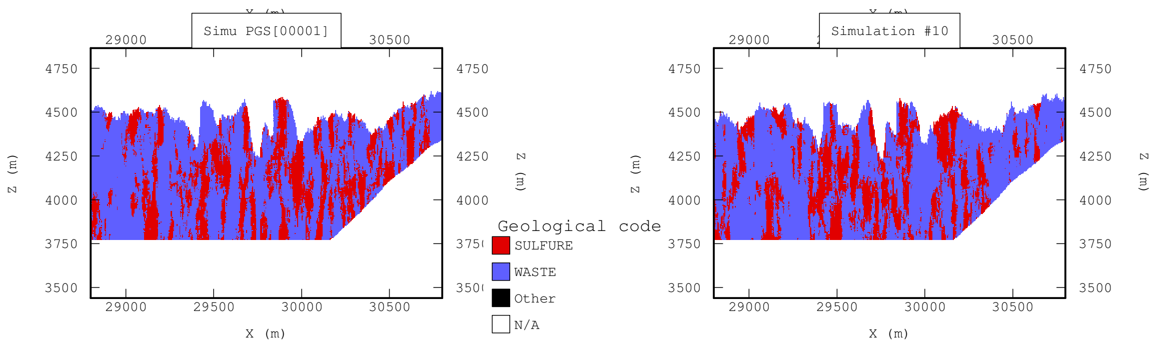

Figure 7: 2 simulations of the ore/waste codes on a vertical XOZ section.

Cu and As ore grades

The simulations of grades require to achieve a transform into Gaussian distribution. Because of the long tail distribution on the composites 2m grades, it has been decided to cap high grades by cutting off the grades above the 99% quantile. Then declustering weights have been applied before to perform a gaussian anamorphosis. A development into Hermite has been achieved providing satisfactory reproduction of the grades distribution (Figure 8).

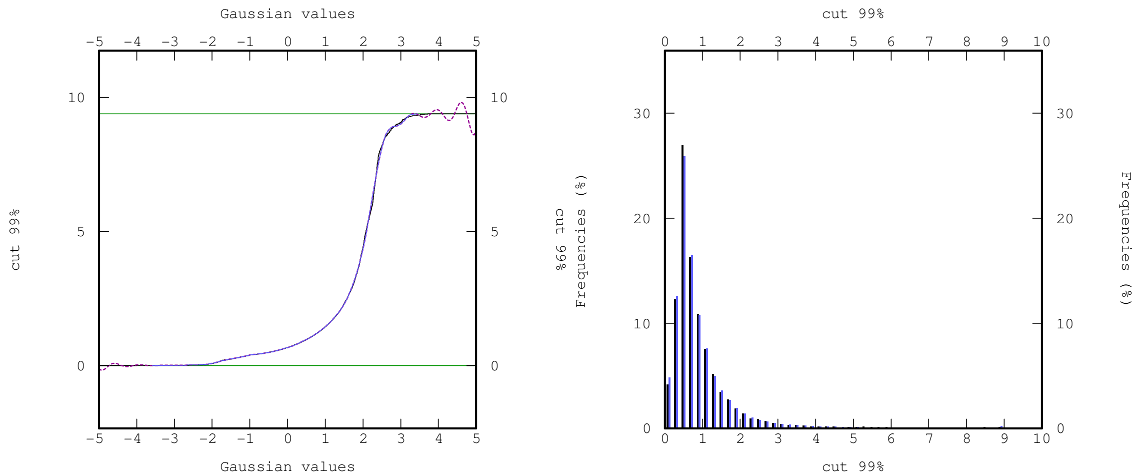

Figure 8: Gaussian anamorphosis of Cut and experimental (in black) and modelled (in blue) histograms.

A bivariate variogram model is fitted in order to perform co-simulations (Figure 9).

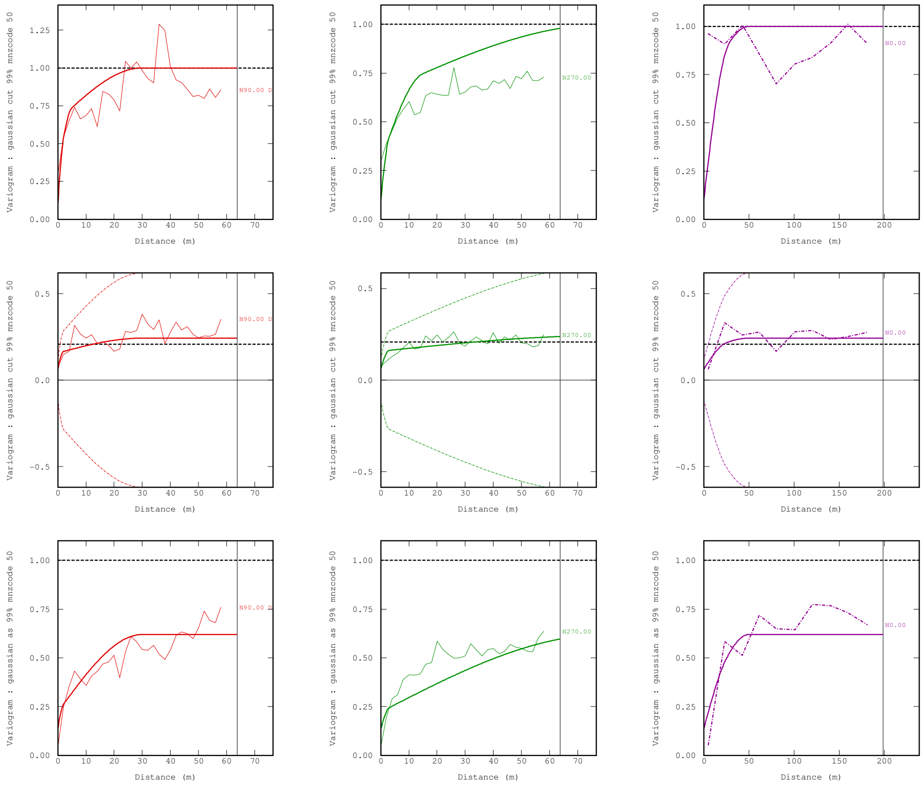

Figure 9: Variograms in 3 main directions of the space of gaussian transforms of Cut and As (dotted line=experimental – solid line=model) . From top to bottom: variograms of Cut-cross-variograms of Cut-As and variograms for As.

The cookie cutting procedure is applied to match one simulation of the bottom of the leached zone, one simulation of the geological code and one simulation of Cut-As grades (Figure 10)

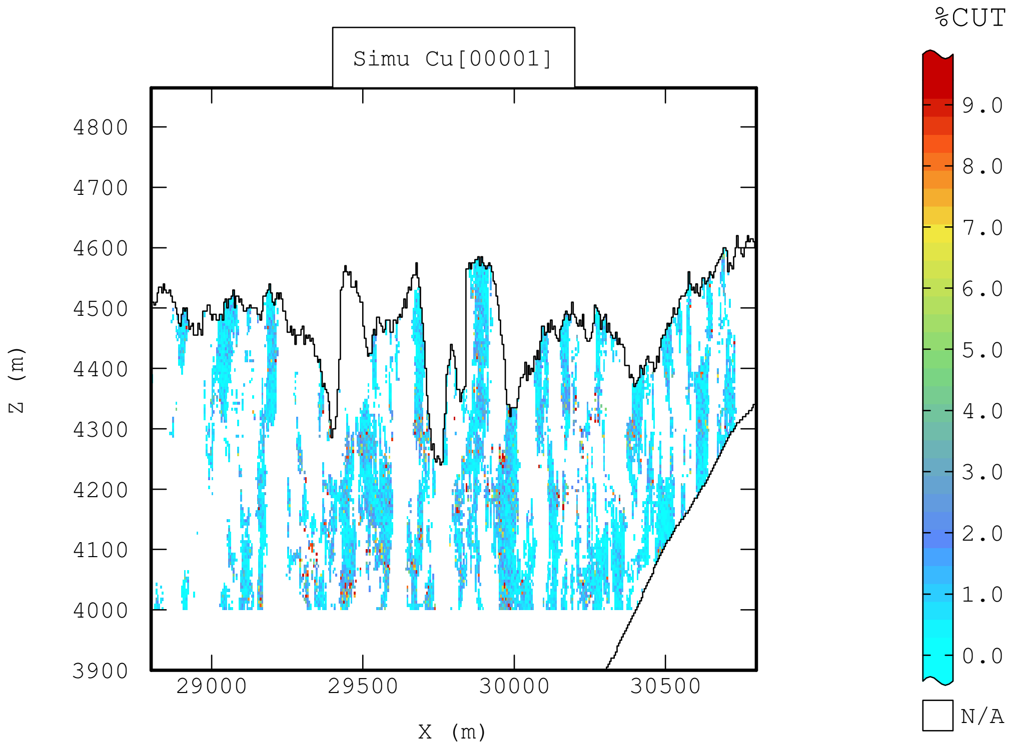

Figure 10: Vertical cross section in the simulated model representing the Cut grades of the mineralized veins below the leached zone.

RESULTS

The simulations of the 5mx5mx5m grid are re-blocked to calculate 25 simulations of ore and metal tonnages in blocks 20mx20mx15m. From these simulations the following statistics are made: dispersion variance, confidence interval at the risk level of 80% calculated as the difference between quantile 90% and 10%. It shows very large uncertainties (100% standard deviation or more particularly for As content), which is not surprising as the support is relatively small compared to the drillhole spacing. By making similar statistics on a larger support, a week production or more we get more reasonable figures, i.e. from about 30% for ore tonnage and Cu metal content to 50% for As metal content.

The simulated models 5mx5mxm have been sampled by drillholes dipping 60° located on a regular pattern of drillholes on a mesh 100mx100m. These new samples (Figure 11) are added to the actual data for estimating the real values represented by each simulation in turn.

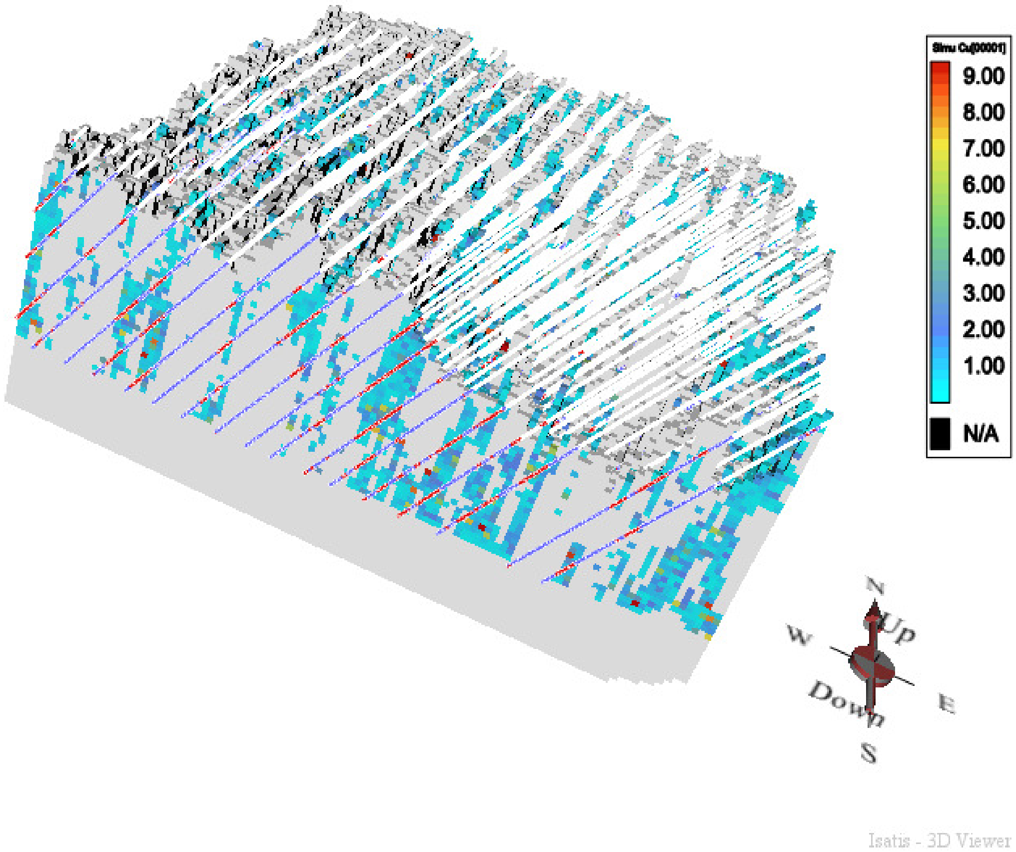

Figure 11: Simulated model with Cut grades sampled by fictitious drillholes.

The reprocessing of the different simulations has been carried out in order to estimate the 20mx20mx15m blocks from the actual and new drillholes as follows:

- The ore tonnage is estimated as an average of 10 simulations by truncated gaussian method. This procedure although resource demanding has been preferred to a more straightforward indicator kriging method, because it fits better to the characteristics of the vein type mineralization.
- The grades are estimated by ordinary block kriging.

The comparison on the support of a week production quantifies the improvement (called gain in Table 1) on the standard deviation of the estimate by means of the difference of standard deviations with or without additional drillholes divided by the standard deviation with the actual drillholes.

Table 1: Standard deviations of the estimation errors on Ore Tonnage and Cu-As Metal Tonnage.

	Actual drillholes	With drillholes 100x100	Gain on stdev (%)
Stdev Ore Tonnage (kT)	95.9	70.9	26
Stdev Metal Cu (T)	1710.4	1406.2	17.8
Stdev Metal As (T)	49.4	44.2	10.4

CONCLUSIONS

The application of geostatistical simulations has provided a quantification of the uncertainty in the resources estimates taking into account the variability of the lithology as well as of the grades. This study shows an example of the application of modeling techniques, initially dedicated to sedimentary oil reservoirs, to porphyry copper deposits where the ore/waste make sequences of sub-vertical bodies. The simulated models can then be processed to generate statistics on different supports and help in making resource classification.

The sampling of the simulated models by fictitious inclined drillholes makes possible to characterize the distribution of estimation errors. The results can then be used in the scope of optimizing a budget for additional drilling.

The capabilities of Isatis software ([4]) have been fully used to achieve all the steps of the study.

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REFERENCES

Armstrong, M., Galli, A., Le Loc'h, G., Geffroy, F., Eschard, R. (2003) *Plurigaussian Simulations in Geosciences*, Springer. [1]

Carrasco, P., **Carrasco, P., Ibarra*, F., Rojas, R., Le Loc'h, G., Seguret, S.*** (2007) *Application of the Truncated Gaussian Simulation Method to a Porphyry Copper Deposit*, Magri ed., APCOM2007, 33rd International Symposium on Applications of Computers and Operations Research in the Mineral Industry, pp. 31-39. [2]

Deraisme, J., Farrow, D. (2004), *Geostatistical Simulation techniques applied to kimberlite orebodies and risk assessment of sampling strategies,* Geostatistics Banff 2004, Springer, pp. 429-438. [3]

GEOVARIANCES (2008) *Isatis Technical References*, 148 p. Géovariances, Fontainebleau. [4]