24-048

Geoistical Evaluation of Polymetallic Veins

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ABSTRACT

This study is carried out in the Zenit mining concession, which is located in the city of San Pablo in the department of Cajamarca in Peru. The Project has 33 mineralized structures and according to laboratory analyzes we have the presence of gold and silver. The geostatistical evaluation provides an analysis on the distribution of precious metals in the vein. This information is used to improve the efficiency of metal extraction and to reduce costs. The general objective is to evaluate the polymetallic veins (Au and Ag), for which the classification of resources (measured, indicated, and inferred) has been carried out, taking into account the parameters of minimum distance from the composite, corresponding volume and tonnage calculation.

In addition, an inventory of estimated geological resources was carried out with the block grades obtained to generate the tonnage-grade curves.

INTRODUCTION

Investing in a greenfield project carries significant risks, so it is crucial to have a deeper understanding of the uncertainty associated with resources in mining concessions. In the mining industry, mineral resource modeling focuses especially on grade estimation. In this context, the variogram becomes relevant, an essential tool used to analyze the spatial variability of the data. It provides valuable information on the distribution of grade values or mineral concentrations as a function of distance and direction, thus contributing to more informed decision-making (Zaki, et al. 2022). For the planning and operation stage, the tonnage- grade curve influences the extraction sequence, mine design, and provides information on the profitability of the mining operation and long-term economic viability, this through visualization of the distribution of mineral tonnage and its average grade. The identification of the inflection point in this curve is known as the cut-off grade, which marks the threshold from which the mineral is considered economically exploitable. (De La Torre Palacios, 2019)

In the Zenit mining concession, located in the city of San Pablo in the department of Cajamarca, an exhaustive geostatistical evaluation of 33 mineralized structures was carried out. This analysis focused on detailed data review to define domains and perform parameter estimation, such as grade interpolation, cubing, and statistical analysis. The comprehensive process included a thorough variogram analysis. The strategic decisions were based on the information derived from the tonnage- grade curve for the polymetallic veins.

METHODS

The objective of this chapter is to describe the geostatistical methods and procedures that were used to collect, analyze and interpret data from the mineralized structures (33 polymetallic veins of Au and Ag).

Structures

A total of 30 of the 33 structures previously proposed for delimitation were modeled; three structures were not considered in the analysis due to the small amount of data obtained. The elaboration of the solids was carried out using an economic approach, considering the width of the structure. In this way, the drilling section that crossed the

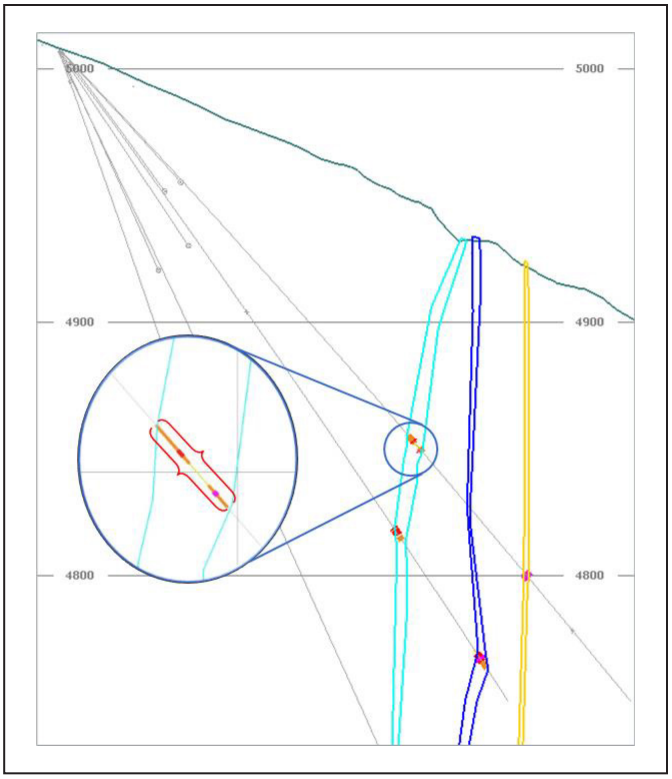

Figure 1. Front view of the modeling of the most profitable structures

structure was selected and coded for subsequent modeling, prioritizing economic efficiency in the choice of the area.

The initial process of coding, data loading and solid modeling was carried out exhaustively, using MinePlan software.

Composites:

Statistical tables and graphs corresponding to the compositions of Au, Ag elements and vein thickness were prepared. Data collection for the Au and Ag variables was carried out on composites with a fixed length of 2 meters, while the statistics related to vein thickness were based on the measured data of the actual vein thickness of the structure.

Cubing

Cubing is a process intended to determine the volume of a mineral in a specific area or mineral deposit. This analysis provides us with accurate estimates of the size and economic value of the mineral deposit. (Bai et al., 2023)

The blocks used for the project are 4 meters wide, 4 meters long and 2 meters high, (Figure 3).

It should be noted that the compound was made every two meters (Figure 2) for this reason of the height of the block.

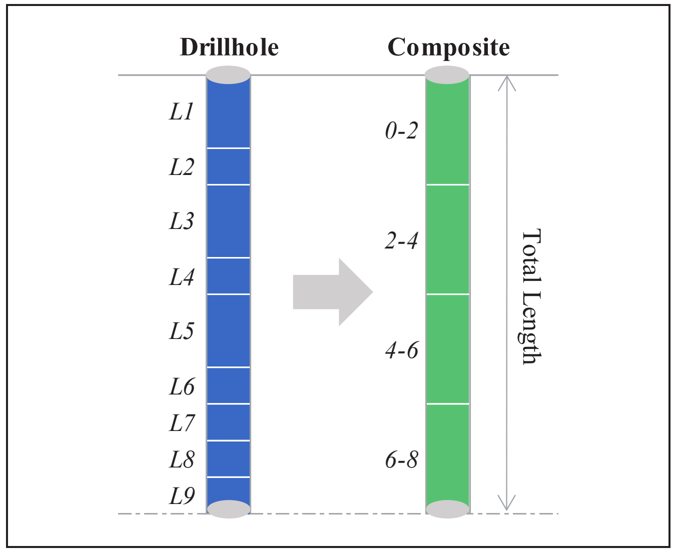

Figure 2. Length of composite used in the project

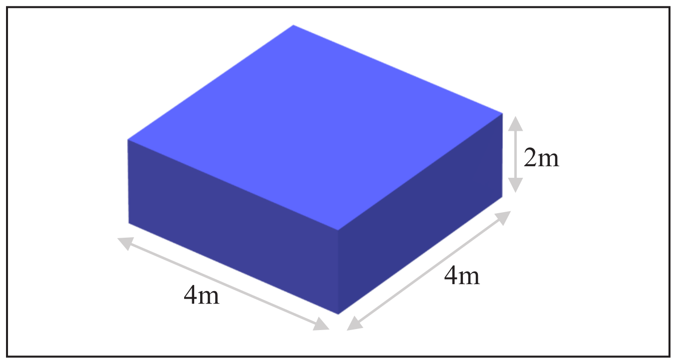

Figure 3. Graphical display of the block

Specific Weight

Samples of the 33 mineralized structures (veins) were taken to a certified laboratory to obtain specific weight and other important data for the analysis.

In Table 1 provides the names of the 33 mineralized structures along with their respective codes, except for those that are not part of the study (03) and includes the corresponding specific weight for each mineralized structure.

From the specific weight analysis results delivered, the data per vein was extracted to be averaged and used in the estimation. For veins with less than 10 data, the average specific weight of the deposit was taken, with the exception of the group of Española veins, where the average between them was used.

Variogram

The first step before using geostatistics to interpolate data is to calculate the experimental variogram (semi-variogram). (Boumpoulis et al., 2023)

Table 1. Coding, name, and specific weight of mineralized structures

Id	Code	Name	Specific Weight
1	01_AÑA	No participation	—
2	02_BRI	Brigith	2.67
3	03_CHA	Charapita	2.49
4	04_CHO	Cholita	2.55
5	05_COL	Colonial	2.55
6	06_ESC	Escondida	2.55
7	07_ESP B	Española B	2.58
8	08_ESP BN	Española B Norte	2.57
9	09_ESP C	Española C	2.61
10	10_ESP C1	Española C1	2.57
11	11_ESP S1	Española Sur 1	2.57
12	12_ESP S2	Española Sur 2	2.57
13	13_ESP S3	Española Sur 3	2.57
14	14_ESP S4	No participation	—
15	15_ESP S5	No participation	—
16	16_ESP_A	Española A	2.6
17	17_GLA	Gladys	2.55
18	18_MEZT	Mestiza	2.55
19	19_ORS	Órsola	2.55
20	20_SORP	Sorpresa	2.55
21	21_PER	Peruanita	2.55
22	Veta 22	—	2.55
23	Veta 23	—	2.55
24	Veta 24	—	2.55
25	Veta 25	—	2.55
26	Veta 26	—	2.55
27	Veta 27	—	2.55
28	Veta 28	—	2.55
29	Veta 29	—	2.55
30	Veta 30	—	2.55
31	Veta 31	—	2.55
32	Veta 32	—	2.55
33	Veta 33	—	2.55

The variogram measures the spatial dependence of a variable. It shows how the values of a variable change with distance, and at what distance the variable becomes spatially independent.

The variogram is a key tool used in geostatistics to study how a variable changes in space. It is used to measure the spatial variability and continuity of the variable of the study. (Cantú-González et al., 2024)

The variograms are also called semi- variograms, the formula used for the calculation is as follows:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i}^{N(h)} [Z(x_i) - Z(x_i + h)]^2 \quad (1)$$

Table 2. Coding, name and specific weight of the most profitable family of polymetallic veins

Id	Code	Name	Specific Weight
A	Fam. Española	Veta Española	2.57
B	General Average	General Average of Vein	2.55

Inverse Distance (ID) or Inverse Distance Weighting (IDW)

IDW is a popular method for estimating the value of a variable at a point based on the values of that variable at nearby points. IDW assumes that the values of the variable are more similar at closer points than at further points. The weight given to each nearby point is inversely proportional to the distance from the point to be estimated. This means that points closer to the point to be estimated are given more weight. IDW calculates the estimated value by taking a weighted average of the values at the nearby points. (Boumpoulis et al., 2023)

The formula used for the calculation is as follows:

$$Z(x_0) = \frac{\sum_{i=1}^{n} \frac{x_1}{d_{ij}^r}}{\sum_{i=1}^{n} \frac{1}{d_{ij}^r}} \quad (2)$$

Grade- Tonnage Curve

Grade tonnage curves act as a visual tool for assessing the exploitation potential of a deposit under various cut-off grade scenarios. The curve illustrates the average grade and quantity of ore above a specified cut-off.

Grade tonnage curves show how the amount of mineralized material in a deposit change as the cut-off grade is changed. If the deposit contains multiple metals of economic value, then the grade tonnage curve should be calculated

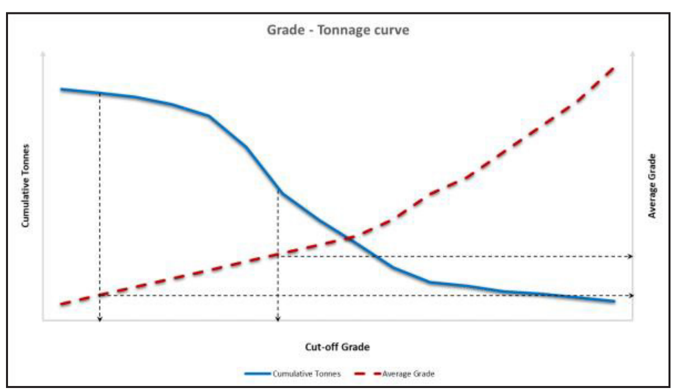

Figure 4. Example of Graphical of grade- tonnage curve

based on the metal equivalent relationship, which takes into account the different metal ratios. (Karpekov, 2016).

Exploratory Data Analysis

The data were reviewed to determine appropriate interpolation domains, and appropriate estimation as well as grade interpolation parameters. Statistical procedures were applied to the data to establish different domains based on the availability of geological information. The Ninajassa fault in the central part of the project, the Uchuro fault to the north and the Azuca fault to the south, establish domains.

The statistics for the variables Ag, Au and thickness of veins were completed. The results obtained were used to validate the construction of the block model and the development of estimation plans. Analyzes were performed on composite assay data.

RESULTS

Composites

Statistical tables for composites of the elements Au, Ag and thickness were prepared. The statistics of the Au and Ag variables were carried out on composites with a fixed length of 2 meters, while the thickness statistics were carried out with the measured data of the real thickness of the structure.

To establish the boundaries, the threshold and eventually, for the veins with more data, the probability plot graphs were taken as elements of judgment.

Table 3 shows the results of the composites of each vein, for the Silver (Ag) element, as well as the statistical analysis of the vein grades.

The probability plot was made for the Ag element composites every two meters in length.

Table 4 shows the results of the composites of each vein, for the Gold (Au) element, as well as the statistical analysis of the vein grades.

The probability plot was made for the Au element composites every two meters in length.

Table 5 shows the results of the composites of each vein, for the thickness of veins.

The probability plot was made for the thickness of all structures.

Variogram

The variography of the project was reviewed; first evaluating the veins with more composite data, then making groupings by systems and finally grouping all the veins. The elements Ag and Au were evaluated.

Table 3. Statistics of the composites for Ag of the 33 veins

Code of Vein	Min	Max	Avg	Var	SD	CV
01_AÑA	10.7	109.3	60.0	4860.0	69.7	1.2
02_BRI	2.4	296.0	100.3	13684.0	117.0	1.2
03_CHA	5.3	194.8	52.6	4189.0	64.7	1.2
04_CHO	1.7	685.4	101.0	20294.0	142.5	1.4
05_COL	2.8	740.5	166.7	47750.0	218.5	1.3
06_ESC	0.3	859.7	108.1	36187.0	190.2	1.8
07_ESP B	0.8	839.8	118.0	23100.0	152.0	1.3
08_ESP B N	1.1	583.6	270.9	49481.0	222.4	0.8
09_ESP C	1.9	947.0	156.1	91036.0	301.7	1.9
10_ESP C1	3.2	402.1	56.9	6631.0	81.4	1.4
11_ESP S 1	1.6	486.4	69.6	7883.0	88.8	1.3
12_ESP S 2	12.3	131.7	41.5	1541.0	39.3	1.0
13_ESP S 3	51.2	1522.1	401.4	397851.0	630.8	1.6
14_ESP S 4	32.3	64.2	48.3	508.0	22.5	0.5
15_ESP S 5	82.5	82.5	82.5	0.0	0.0	0.0
16_ESP_A	2.8	714.7	130.2	27327.0	165.3	1.3
17_GLA	34.9	290.9	140.2	17924.0	133.9	1.0
18_MEZT	1.5	976.0	215.1	53.0	229.4	1.1
19_ORS	1.3	499.0	146.4	30634.0	175.0	1.2
20_SORP	53.2	1239.1	529.3	269658.0	519.3	1.0
21_PER	8.7	585.4	124.8	16719.0	129.3	1.0
22	173.0	202.9	188.0	448.0	21.2	0.1
23	38.4	125.2	94.2	2345.0	48.4	0.5
24	8.3	567.2	207.9	68761.0	262.2	1.3
25	168.0	669.0	440.2	64162.0	253.3	0.6
26	120.8	311.0	206.3	9321.0	96.5	0.5
27	254.6	254.6	254.6	0.0	0.0	0.0
28	51.2	344.0	180.1	10420.0	102.1	0.6
29	32.7	236.1	130.6	7737.0	88.0	0.7
30	16.2	290.1	101.5	12932.0	113.7	1.1
31	15.9	445.0	117.1	22846.0	151.1	1.3
32	10.4	355.5	183.8	13167.0	114.7	0.6
33	239.0	1772.9	1005.9	1176409.0	1084.6	1.1

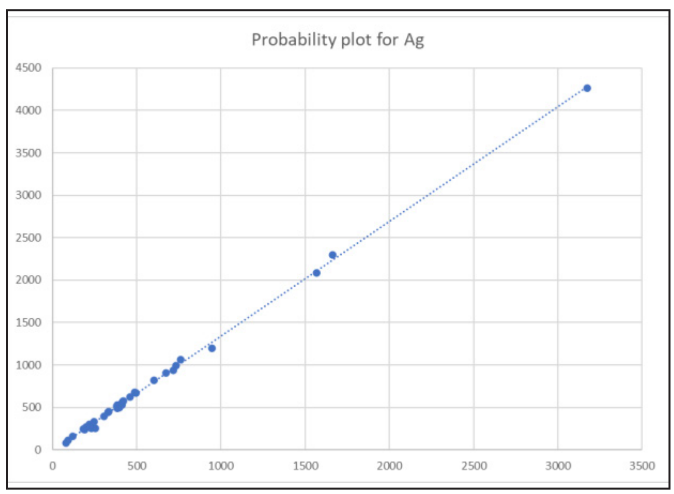

Figure 5. Probability plot for Ag element

Table 4. Statistics of the composites for Au

Code of Vein	Min	Max	Avg	Var	SD	CV
01_AÑA	0.1	0.9	0.5	0.3	0.6	1.3
02_BRI	0.0	1.3	0.6	0.3	0.5	0.9
03_CHA	0.1	1.3	0.6	0.2	0.5	0.8
04_CHO	0.0	4.9	0.7	1.0	1.0	1.4
05_COL	0.1	7.3	1.6	4.2	2.1	1.3
06_ESC	0.0	9.3	1.0	4.0	2.0	1.9
07_ESP B	0.0	22.6	1.2	5.6	2.4	1.9
08_ESP B N	0.0	2.5	1.1	0.9	1.0	0.8
09_ESP C	0.0	3.8	0.7	1.5	1.2	1.6
10_ESP C1	0.0	26.1	1.9	26.3	5.1	2.7
11_ESP S 1	0.0	1.5	0.6	0.2	0.4	0.8
12_ESP S 2	0.1	1.2	0.5	0.1	0.4	0.8
13_ESP S 3	0.5	19.9	5.5	68.8	8.3	1.5
14_ESP S 4	0.2	0.5	0.4	0.0	0.2	0.5
15_ESP S 5	0.7	0.7	0.7	0.0	0.0	0.0
16_ESP_A	0.0	11.5	1.6	5.8	2.4	1.5
17_GLA	0.3	1.6	0.9	0.4	0.7	0.8
18_MEZT	0.0	16.0	2.6	11.1	3.3	1.3
19_ORS	0.0	3.8	1.0	1.5	1.2	1.2
20_SORP	0.6	17.2	7.1	53.3	7.3	1.0
21_PER	0.0	2.6	0.6	0.3	0.6	1.0
22	1.1	1.2	1.1	0.0	0.1	0.1
23	0.2	1.4	0.9	0.4	0.7	0.8
24	0.1	3.1	1.1	2.1	1.4	1.3
25	0.7	3.6	2.2	2.1	1.5	0.7
26	0.6	1.7	1.1	0.3	0.6	0.5
27	1.6	1.6	0.0	0.0	0.0	0.0
28	0.3	5.3	2.0	3.1	1.8	0.9
29	0.2	2.6	1.4	1.3	1.1	0.8
30	0.1	9.5	2.1	10.4	3.2	1.5
31	0.1	7.8	1.5	8.0	2.8	1.9
32	0.1	4.1	1.9	2.0	1.4	0.7
33	1.6	19.0	10.3	150.9	12.3	1.2

Table 5. Statistics of the thickness of veins

Code of Vein	Min	Max	Avg	Var	SD	CV
All Veins	0.2	15.0	1.8	3.8	1.9	1.1
01_AÑA	1.8	1.8	1.8	0.0	0.0	0.0
02_BRI	0.4	1.3	0.9	0.2	0.4	0.4
03_CHA	0.6	3.7	2.2	1.9	1.4	0.6
04_CHO	1.0	6.5	3.0	5.3	2.3	0.8
05_COL	0.4	15.0	2.4	16.5	4.2	1.8
06_ESC	0.4	3.9	1.0	0.7	0.8	0.8
07_ESP B	0.3	11.0	2.1	5.1	2.3	1.1
08_ESP B N	1.5	7.1	4.3	15.7	4.0	0.9
09_ESP C	0.3	2.4	0.8	0.5	0.7	0.9
10_ESP C1	0.3	6.0	1.5	2.4	1.5	1.1
11_ESP S 1	0.6	8.7	3.8	8.1	2.8	0.7
12_ESP S 2	0.4	1.9	1.0	0.2	0.5	0.5
13_ESP S 3	1.8	3.3	2.7	0.7	0.9	0.3
14_ESP S 4	1.9	1.9	1.9	0.0	0.0	0.0
15_ESP S 5	1.4	1.4	1.4	0.0	0.0	0.0
16_ESP_A	0.3	7.1	2.0	3.5	1.9	0.9
17_GLA	0.9	3.9	2.4	4.6	2.1	0.9
18_MEZT	0.2	6.3	1.9	4.5	2.1	1.1
19_ORS	0.3	3.5	1.6	1.6	1.3	0.8
20_SORP	2.4	2.7	2.5	0.1	0.3	0.1
21_PER	0.3	3.8	1.6	0.7	0.8	0.5
Veta22	0.4	0.5	0.4	0.0	0.0	0.2
Veta23	0.8	2.4	1.6	1.3	1.1	0.7
Veta24	0.4	3.6	2.0	5.1	2.3	1.1
Veta25	0.4	1.7	0.8	0.5	0.7	0.9
Veta26	0.5	3.7	2.1	5.2	2.3	1.1
Veta27	1.0	1.0	1.0	0.0	0.0	0.0
Veta28	0.3	1.8	0.9	0.3	0.5	0.6
Veta29	1.0	1.4	1.1	0.1	0.3	0.2
Veta30	0.3	1.6	0.8	0.2	0.5	0.6
Veta31	0.5	1.2	1.0	0.1	0.3	0.3
Veta32	0.6	3.0	1.8	2.9	1.7	0.9
Veta33	0.2	1.3	0.7	0.6	0.8	1.0

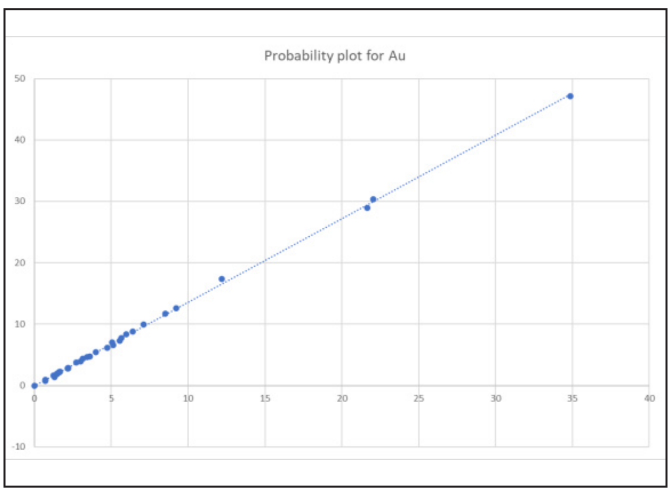

Figure 6. Probability plot for Au element

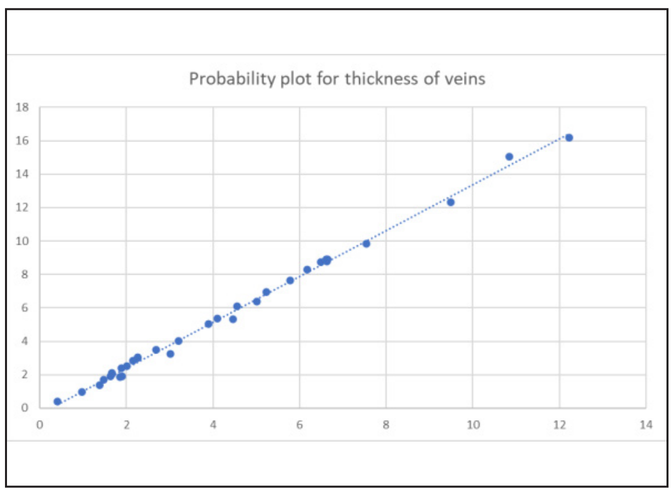

Figure 7. Probability plot for thickness

The study was done in the plane of the vein, rotating the axes of the project until the plane formed by the main and secondary axes is parallel to the plane of the vein (rotated axes). The vertical axis ended in a transverse position to the vein under study (in the power direction).

We have also worked with composite data at a fixed length of 2 meters. Evaluations were made every 15° on the general vein plane, obtaining 6 pairs of directions perpendicular to each other to be evaluated; 0°-90°; 15°-105°; 30°-120°; 45°-135°; 60°-

150° and 75°-165°.

The data from the Española B vein (07_ESP B) and Española A vein (16_ESP_A) do not form a robust variographic structure due to the few data they have.

In the variography of the N-NW system, made up of the Española B, Española A, Española C and Española C1 veins, it is generally observed that the Ag variable of the deposit has a range of 80 meters and the Au variable, a range of 40 to 45 meters.

In Figure 8 and Figure 9, The composite Ag variography, with a range of 80 meters in the 90° direction. It was evaluated in the Vein Plane, with MEDS rotation 350° - 0°- 90°.

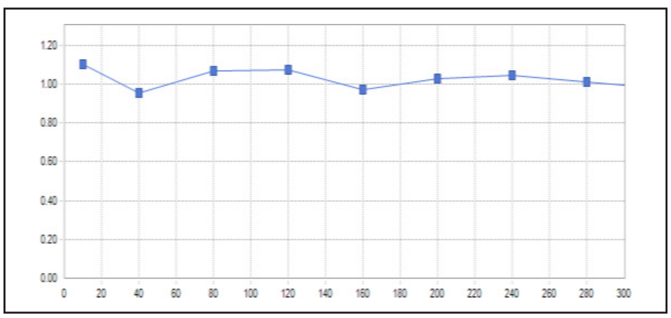

Figure 8. The variogram for Ag with Azimuth on Plane 0° - Range 80 meters

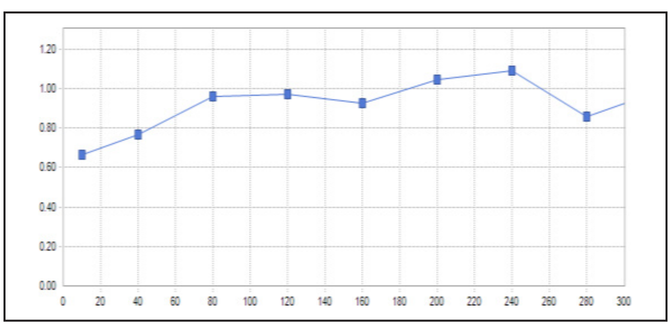

Figure 9. The variogram for Ag with Azimuth on Plane 90° - Range 80 meters

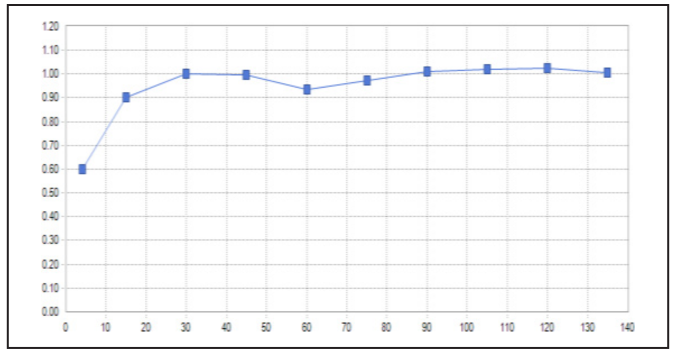

Figure 10. The variogram for Ag with Azimuth on Plane 0°-Range of 40–45 meters

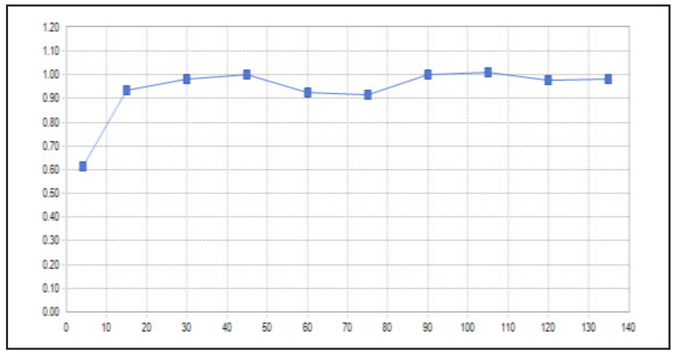

Figure 11. The variogram for Ag with Azimuth on Plane 0°-Range of 40–45 meters

In Figure 10 and Figure 11, Composite Au variography of the NNW system, direction 90°. Evaluated on the MEDS plane 350°_0°_-90°. Range of 40–45 meters.

In Figure 12 and Figure 13, The variography for all veins (1–33) confirms the range for Ag of approximately 80 meters and for Au of 40–45 meters, in the orientation of the Main and secondary axes of 90°_0°

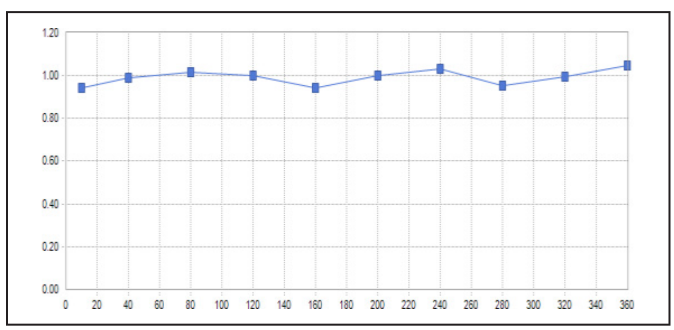

Figure 12. The variogram for all veins with Azimuth on Plane 0°-Range of 80 meters

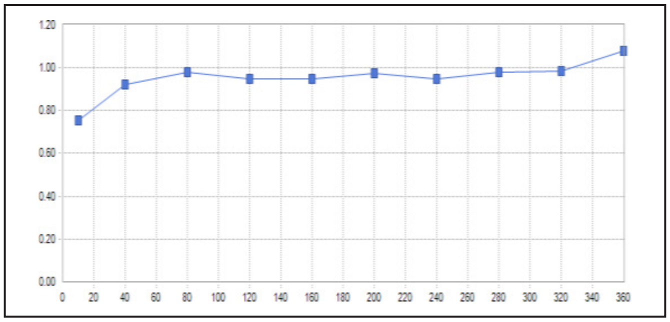

Figure 13. The variogram for all veins with Azimuth on Plane 90°-Range of 80 meters

Variography of composite Ag, of all coded veins (1–33) showing the pair of axes with orientation at 90° and 0°, with an approximate range of 80 meters.

In Figure 14 and Figure 15, composite Au variography for all veins (1–33). The variography is shown in the orientation at 90° and 0° with a range of 40 to 45 m. It was evaluated in the MEDS 350° - 0°- 90 plane.

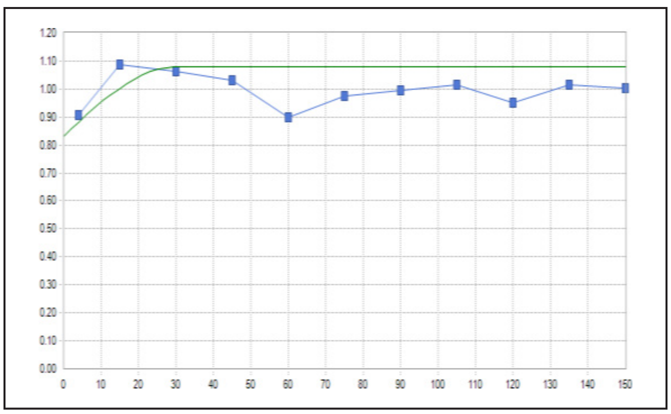

Figure 14. The variogram for all veins (Au) with Azimuth on Plane 0° - Range of 40 to 45 meters

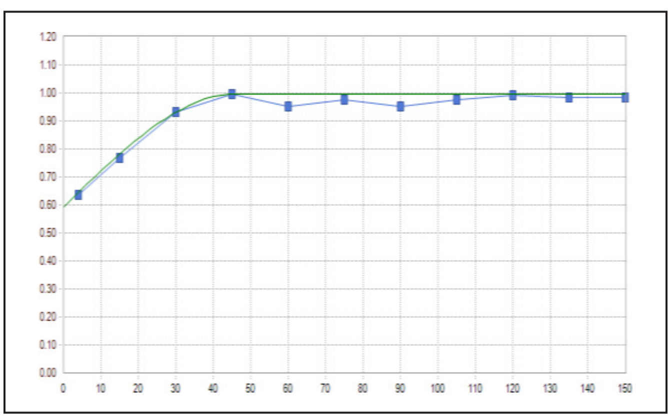

Figure 15. The variogram for all veins (Au) with Azimuth on Plane 90° - Range of 40 to 45 meters

Variogram Modeling

Table 5. NNW System, elements for modeling of variogram

Element	Ag	Au
Variogram Type	spherical	spherical
Nugget	0.55	0.65
Sill Total	1	1
C1	0.25	0.20
Major Axis Range 1	25	30
Minor Axis Range 1	30	25
Vertical Range 1	25	30
C2	0.20	0.15
Major Axis Range 2	60	45
Minor Axis Range 2	30	30
Vertical Range 2	25	30

Axis Rotation: Plane Vein

Type of Rotation	MEDS	MEDS
ROT	80	80
DIPN	-90	-90
DIPE	0	0

Resource Classification

For resource classification, the parameters of minimum distance from the compound to the block (DIST field) and number of drillholes involved in delivering grades to a block (NMUE field) were taken into account. These parameters are evaluated and the result is recorded in the "CATEG" name field of the block model, and will be used to classify the resource type.

Measured Resources will take 2/3 of the range up to 40 m, Indicated Resources will take the last third of the range (from 40 to 60 m). Finally, the areas between the drill holes within the mineralized zone and restricted by the solids of each vein will be considered Inferred Resources.

Table 6. The criteria followed to categorize resources in this work

Distance	N° of Drillholes	Field CATEG	Category: Resource
0–40	≥3	1	Measured
0–40	≥2	2	Indicated
40–60	≥2	2	Indicated
>60	1	3	Inferred

Table 7. Total Resources measured, indicated, and inferred

Grade Block	Tn	AuEq (g/t)	AuID (g/t)	AgID (g/t)	THK (m)	Fines (Oz)
0	5,000,597	3.34	1.23	122	2.95	536,970
0.5	4,408,781	3.75	1.38	138	3.14	532,006
1	3,844,348	4.19	1.54	154	3.31	518,266
1.5	3,191,368	4.80	1.77	176	3.52	492,008
2	2,563,275	5.55	2.04	204	3.57	456,980
2.5	2,003,253	6.47	2.40	236	3.32	416,398
3	1,622,315	7.35	2.77	267	3.34	383,145
3.5	1,387,077	8.03	3.05	292	3.24	358,141
4	1,282,978	8.38	3.18	304	3.22	345,649
4.5	1,173,758	8.77	3.35	316	3.24	330,797
5	1,061,471	9.19	3.51	331	3.23	313,659
5.5	873,222	10.04	3.89	359	3.23	281,966
6	753,394	10.73	4.19	382	3.29	259,928
6.5	684,200	11.18	4.38	399	3.30	246,033
7	629,191	11.58	4.54	412	3.27	234,153
10	312,599	14.80	5.99	517	3.73	148,741

Table 8. Total Resources inferred

Grade Block	Tn	AuEq (g/t)	AuID (g/t)	AgID (g/t)	THK (m)	Fines (Oz)
0	3,378,270	3.31	1.20	121	2.82	359,634
0.5	2,913,871	3.80	1.37	139	3.04	355,858
1	2,499,854	4.30	1.55	158	3.23	345,713
1.5	2,101,703	4.88	1.75	179	3.44	329,667
2	1,709,430	5.60	2.01	206	3.52	307,712
2.5	1,329,120	6.55	2.37	240	3.25	280,077
3	1,056,298	7.55	2.78	273	3.32	256,304
3.5	879,112	8.40	3.11	304	3.15	237,343
4	833,846	8.65	3.21	313	3.13	231,931
4.5	772,483	9.00	3.36	324	3.14	223,580
5	700,348	9.44	3.50	340	3.11	212,575
5.5	569,875	10.40	3.92	372	3.06	190,638
6	483,328	11.24	4.26	401	3.16	174,738
6.5	456,022	11.54	4.38	412	3.18	169,228
7	428,035	11.86	4.51	421	3.10	163,213
10	213,221	15.30	6.03	534	3.65	104,856

General Inventory of Estimated Geological Resources

The information is presented at different block grades, organized by the Au Equivalent (AuEq) field. For the equivalence a Au/Ag ratio of 57 was taken. The grades presented in the Au and Ag fields of the general tables were taken from the Inverse Power Distance 3 estimator. The other methods were used only for the review part of the results.

Grade- Tonnage Curve

The Grade-Tonnage Curves in Figures 16–18 were building in Au-eq.

DISCUSSION

The key importance of these findings lies in their ability to carry out a geostatistical assessment of veins in a greenfield project. These results are significant, as they not only provide a solid basis for the statistical analysis of vein characteristics, but also have substantial implications for the field of study and, in particular, for the detailed understanding of the specific phenomenon related to the data analysis of mineral resources.

The geostatistical evaluation of minerals is influenced by various factors, from the composition of veins every

Table 9. Total Resources measured and indicated

Grade Block	Tn	AuEq (g/t)	AuID (g/t)	AgID (g/t)	THK (m)	Fines (Oz)
0	1,622,327	3.40	1.30	125	3.20	177,336
0.5	1,494,910	3.66	1.41	135	3.35	176,148
1	1,344,494	3.99	1.54	147	3.48	172,553
1.5	1,089,665	4.63	1.79	170	3.68	162,341
2	853,845	5.44	2.11	199	3.66	149,268
2.5	674,132	6.29	2.46	230	3.47	136,321
3	566,017	6.97	2.76	255	3.38	126,841
3.5	507,965	7.40	2.95	270	3.38	120,798
4	449,132	7.88	3.15	286	3.39	113,718
4.5	401,275	8.31	3.33	300	3.42	107,217
5	361,123	8.71	3.52	314	3.47	101,084
5.5	303,347	9.36	3.85	334	3.54	91,328
6	270,066	9.81	4.07	349	3.54	85,191
6.5	228,177	10.47	4.38	373	3.54	76,806
7	201,156	10.97	4.59	391	3.63	70,940
10	99,379	13.74	5.90	479	3.88	43,885

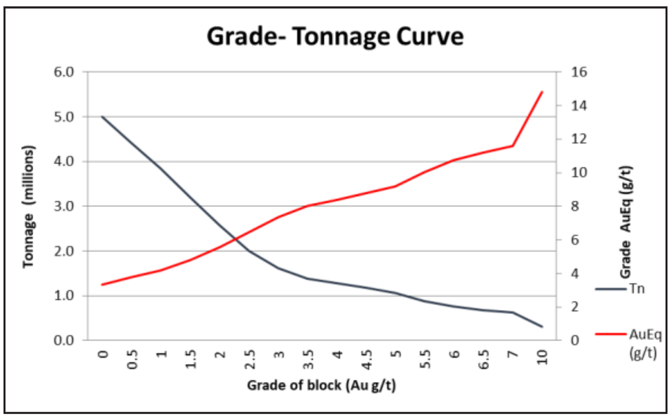

Figure 16. Grade- Tonnage Curves with Resource total measured, indicated, inferred

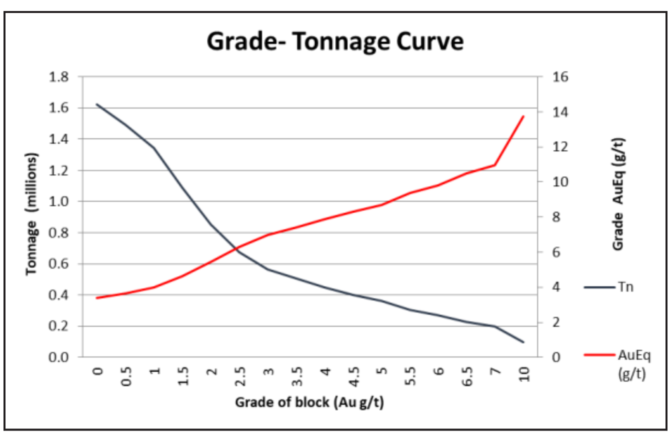

Figure 17. Grade- Tonnage Curves with Resource total inferred

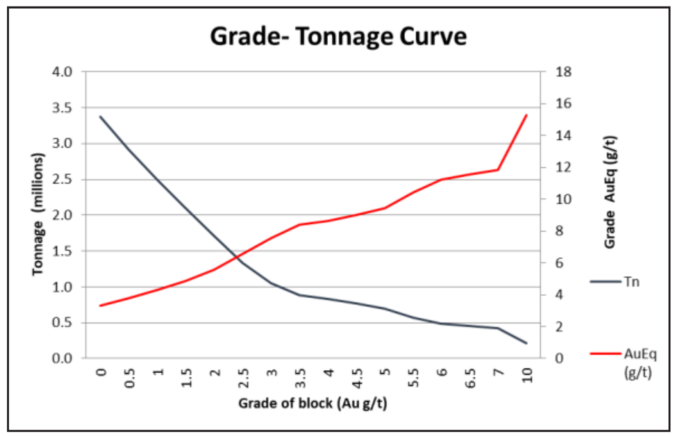

Figure 18. Grade- Tonnage Curves with Resource total measured and indicated

2 meters that encompass gold (Au) and silver (Ag) minerals to the consideration of the potency of these structures at a real thickness. Performing variogram data, through clustering of composite data, systems and veins, enriches our understanding of the spatial variability of minerals of interest.

The inclusion of Au and Ag elements in vein evaluation is essential to ensure the accuracy of the results. This highlights the crucial importance of considering mineral grades, a fundamental aspect in the resource estimation process, where these grades are critical indicators to evaluate the economic potential and viability of exploitation of the area.

Likewise, when addressing the estimation of resources (inferred, indicated and measured) in the Project, key parameters have been considered, such as the minimum distance from the complex to the block and the number of drillings involved in obtaining grades for a specific block. . These parameters add an additional layer of rigor to the analysis, providing valuable information on the distribution and quality of minerals in the project, thus contributing to a more complete and reliable estimate of the resources.

With the abundant information collected, we are in a position to evaluate the economic viability of the Project through the analysis of the tonnage-grade curve. This approach will allow us to determine the economic profitability of the project by exploring the relationship between the amount of tonnage extracted and the grades of the minerals present.

CONCLUSIONS

The modeling of the mineralized structures was carried out by creating interpolation domains of gold (Au) and silver (Ag) grades. These domains were customized based on the specific geological information of each mineralized structure, taking into account the identified faults, such as Ninajassa, Uchuro and Azuca.

A categorization of the Spanish veins into families was carried out, highlighting their importance due to their significant contribution to the grades present in the mineralized structures. This clustering approach allowed a better understanding and characterization of vein trends and behaviors, providing valuable information for analysis and decision making in the geological context of study.

The resulting categorization, recorded in the "CATEG" field of the block model, assigns Measured Resources to two thirds up to 40 meters, Indicated Resources to the last third (40–60 meters), and classifies as Inferred Resources the zones between drillholes in the area. mineralized. This structured approach provides an efficient basis for management and informed decision making in mining.

The variography of the project, evaluating priority veins and systems. The lack of variographic robustness in the Española B and Española A veins was highlighted due to the scarcity of data. For the N-NW system, spanning several veins, ranges of 80 meters for Ag and 40–45 meters for Au were identified. These results offer a key view of the spatial distribution of elements in the deposit, informing about the geological variability in the study area.

Finally, the tonnage-grade curve vs the gold grade (Au) equivalent of the resources was carried out, these were grouped by indicated + measured + inferred resources, resources, measured + indicated and inferred resources, this separation is given by the level of geological knowledge and data trust.

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24-049

Ground Control Monitoring: A Comprehensive Guide for Mine Operators on Instrumentation and Data Acquisition Currently Used by the National Institute for Occupational Safety and Health (NIOSH)

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ABSTRACT

The National Institute for Occupational Safety and Health (NIOSH) is staffed with Engineers, Geologists, and Field Technicians conducting a variety of ground control research. The mission of the ground control teams within the Mine Systems Safety Branch (MSSB) is to eliminate ground failures leading to mineworker injuries and fatalities. Advancing the science behind ground control relies heavily on conducting mutually beneficial research at participating mines which is detailed in specific references throughout the paper.

The ground control teams have several types of field instruments at their disposal to measure the ground response in underground mines. These include borehole pressure cells (BPCs), vibrating wire stress meters (VWs), hollow inclusion cells (Hi-Cells), roof and rib extensometers, load cells, and convergence meters. These instruments are used to measure changes in pressure, strain, and displacement within the underground environment.

Instrumentation data is collected automatically using intrinsically safe or MSHA permissible dataloggers if required. Information is transmitted to the dataloggers using approved cable to distances of 200–1,000 ft. depending on the type of datalogger being used. Once mining is completed, the dataloggers are retrieved and brought to the surface, providing in-mine data to mine management and engineers for the conditions currently being encountered in a particular mine.

This data, in conjunction with geologic data and stress mapping, can be used to validate numerical models. The practical application of these models is extremely important for mine management and engineers, particularly when faced with more challenging mine environments. Insight gained from applying these models can be used to make better engineering-based judgments for areas that will be mined in the future. The impact of such applications can result in a reduction of ground-fall accidents and injuries as well as generally safer working conditions.

INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) relies heavily on field instrumentation to carry out ground control research. The data collected and knowledge gained not only assists in the validation of models and insight on potential ground control hazards but can also be mutually beneficial to the participating mine. The ground behavior analyzed can provide the information to make better engineering-based judgments when planning future mining areas.

Through decades of instrumenting underground mines, NIOSH has adapted, designed, and innovated many aspects of ground-control monitoring. This paper