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USING GEOVIA SURPAC 3D SOFTWARE INSTEAD OF MANUAL METHODS TO ACCURATELY ESTIMATE ORE RESERVE POTENTIAL IN LIBYAN QUARRIES AND MINES

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استخدام برنامج GEOVIA Surpac ثلاثي الأبعاد بدلاً من الطرق اليدوية لتقدير احتياطيات الخام بدقة في المحاجر والمناجم الليبية

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الملخص

تتطلب التنمية المستدامة للموارد المعدنية تقديرات دقيقة لاحتياطيات الخام. ومع ذلك، لا تزال معظم المناجم في ليبيا اليوم تعتمد على مناهج التعدين التقليدية التي تعاني من عدم الدقة. تستكشف الدراسة الحالية كيف يمكن استخدام برنامج GEOVIA Surpac لتحديث صناعة التعدين الليبية من خلال تقديم استراتيجية رقمية ثلاثية الأبعاد (D3) لتقدير احتياطيات الخام. تصف مجموعة بيانات أبار الحفر التمثيلية التي أنشأتها Surpac سير العمل الموصى به، بدءًا من إعداد قاعدة البيانات وانتهاءً بالإبلاغ عن الاحتياطي. يُظهر العرض التوضيحي بوضوح تفوق Surpac مقارنة بالنهج اليدوي، خاصة فيما يتعلق بقابلية التكرار والتصور ثلاثي الأبعاد والامتثال لمعايير الإبلاغ. علاوة على ذلك، تؤكد النتائج قدرة GEOVIA Surpac على بناء أطر مرجعية للتقدير الرقمي عالية الدقة لتعدين احتياطيات الخام الليبية.

الكلمات المفتاحية: GEOVIA Surpac، صناعة التعدين الليبية، التصور ثلاثي الأبعاد، مجموعة بيانات أبار الحفر، الموارد المعدنية.

ABSTRACT

The sustainable development of mineral resources requires accurate estimations of ore reserves. However, most mines in Libya today still rely on traditional mining approaches that are plagued by inaccuracy. The present study explores how the software GEOVIA Surpac can be used to modernize Libyan mining industry by offering a three-dimensional (3D) digital strategy for estimating ore reserves. A representative drillhole dataset constructed by Surpac describes the recommended workflow, starting with database preparation and ending with reserve reporting. The demonstration clearly shows Surpac's superiority compared to manual approaches, especially with regard to reproducibility, 3D visualization, and reporting standards compliance. Furthermore, the results validate GEOVIA Surpac's ability in building highly accurate digital estimation reference frameworks for mining Libyan ore reserves.

KEYWORDS: GEOVIA Surpac, Libyan mining industry, 3D visualization, drillhole dataset, mineral resources

INTRODUCTION

Mining requires a high degree of estimation accuracy to be economically viable and environmentally sustainable over the long haul. For centuries, traditional approaches have relied on hand-drawn mapping as well as manually performed grade assessments and other calculations [1], [2]. Despite being relatively low cost and simple to use, these methods are prone to miscalculation, subjectivity, and other human errors. They are also unable to fully capture the complexity of an ore deposit in three-dimension (3D) [3].

Emerging computer technologies have enabled 3D modeling for mine planning, substantially boosting the accuracy of geostatistics related to mining operations [4], [5]. The most popular of these softwares, e.g., Micromine and GEOVIA Surpac, offer a unified digital environment that seamlessly integrates the various aspects of mine planning such as drillhole databases, reserve reporting, and grade interpolation [6]. The software not only builds 3D models, but also performs other tasks like tonnage and volume calculations and resource classification, all with extreme accuracy and in compliance with NI 43-101, JORC (2012), and other reporting codes [7], [8].

Mine planning in Libya is similar to that carried out in most developing nations, meaning that it relies heavily on traditional manual methods. For example, reserve estimation of Libyan mines is mostly conducted using hand-drawn maps, spreadsheet calculations, and manual cross-sectional and polygonal techniques. While helpful for roughly approximating resource calculations, these methods lack accuracy, reproducibility, and full compliance with accepted reporting standards. At the same time, the lack of digital models prevents mine planners and other stakeholders from integrating key aspects (e.g., economic evaluation and pit optimization) with geological interpretation [9].

As mentioned above, GEOVIA Surpac software is currently among the most popular of emerging digital options for mine planning. It offers a broad range of applications, including geological interpretation, grade estimation, block model construction, and so on [10]. Several studies have validated Surpac's extensive capabilities, especially in reserve estimation of gold and other ore deposits[11], [12] .

In the present study, GEOVIA Surpac was used to demonstrate several advantages over traditional manual methods for estimating ore reserves in Libya. The aim here is not to validate certain deposits but to show the superiority of Surpac's 3D digital workflow in comparison to 2D manual methods. The results can also provide a frame of reference for professional practice and mining education in Libya and elsewhere. Equally as important, the outcomes can help support developing nations' transition to more modern methods of mine planning that better align with international standards.

LITERATURE REVIEW

Ore reserve estimation approaches have been established from conventional approaches to modern digital solutions. This evolution includes traditional techniques, 3D modeling, and resource estimation software.

Traditional Techniques for Estimating Ore Reserves

Prior to the widespread use of computers, the main methods employed to estimate ore reserves involved traditional approaches like simple calculations and 2D geological interpretation. For the latter, cross-sectional, triangular, and polygonal methods were the most commonly used techniques, while calculations were derived from hand-drawn plans [1, 2]. Such strategies were especially popular in developing countries, thanks to their low data needs and minimal cost. However, because they depend heavily on human-subjective data interpretations and consider sectional blocks always to have uniform grade distribution (rather than idiosyncratic deviations), these methods were unsuited to incorporating 3D geometry, uncertainty quantification, or spatial grade continuity[13]. They also lacked reproducibility along with auditable estimations, making them incompatible with the latest classification and reporting requirements [7, 8].

Development of Mining Geostatistics and 3D Modeling

Mining geostatistics is a mathematical framework used to analyze geological variables that are spatially correlated. Journel and Huijbregts [4] originated geostatistical concepts such as variogram modeling and regionalized variables, which were later developed by Isaaks and Srivastava into applied form [5]. By enabling 3D grade estimation, these techniques can take anisotropy, spatial continuity, and sampling configurations into consideration. Geostatistical principles for mining now form the basis for estimating reserves and mineral resources.

The process of mining geostatistics involves discretizing orebodies as block arrays. The blocks are then allocated estimated measures, such as densities, grades, and classifications, which allows for key calculations (e.g., metal content, tonnage, etc.) to be made [11, 12]. Research indicates that while geometric methods can estimate variables such as tonnage reasonably accurately, they still lead to major differences in comparison to geostatistical models when estimating, for instance, grade. These differences are especially pronounced when large spatial variabilities are present in the deposit being estimated [13]. Moreover, recent studies have found that the type of estimation method chosen, such as inverse distance or polygonal, directly affects critical features such as resource classification and grade distribution [14].

Mine Planning and Resource Estimation Software

In today’s developed world, mine planning and resource evaluation rely heavily on 3D models. Authors Napier-Munn and Read [6] assert that the accurate estimation of reserves combines geological interpretation with spatial continuity and drillhole data, all subjected to 3D models. These frameworks then provide the necessary data to formulate key aspects such as production scheduling, pit optimization, and estimated economic evaluations [9].

Enabling these 3D-based strategies are recently developed mine planning software systems, the most popular of which are Datamine, Micromine, and GEOVIA Surpac. These software packages help users comply with established standards while also integrating key data that can be applied to the building of block models for resource estimation as well as to the managing of drillhole databases, the estimation of geostatistics, and other important mine planning activities [6, 7, 8]. Surpac in particular has demonstrated its superiority over other strategies in areas like grade-tonnage analysis, data validation, and variography [15]. Moreover, in using these tools, work flows have been shown to substantially improve in terms of update speed, visualization, etc., compared to traditional manual approaches. These improvements are particularly significant when estimating deposits that are heterogenous or otherwise structurally complex [16]. Geostatistical validation tools are also useful in standardized resource classification as well as in sensitivity analyses, cross-validation, and gauging the accuracy of block model estimates[17], [18] .

DATA DESCRIPTION AND ANALYSIS

This section provides a detailed explanation of the procedures followed in using Surpac, including the data utilized and the outcomes obtained.

Analyzing and Validating the Data

After being collected, the data used in this study were classified under the headings “survey data”, “geology data”, “assay data”, and “collar data” and input in Microsoft Excel tables. Next, the data were analyzed for reliability and screened for inconsistencies, e.g., incorrect values or duplications. This process intended to uncover and remove any errors in the data that could potentially degrade database validity in reporting the grade, tonnage, classification, etc., of the resource. As no errors were found during the close analysis, the reserve estimation database is used in its original form.

Using Surpac Tools to Block Model the Deposit

An open-access drillhole exploration dataset comprises the exploration data for the present study. The dataset was applied to a gold deposit and serves as the main input in the deposit’s constructed block model. Using the Surpac software tool to enable modelling, the open-access data was made to a readable access file in Excel, and then created the text files “collar”, “survey”, “assay”, and “geology”, respectively, as stipulated by Surpac. Tables (1) to (4) present the text files’ field and record arrangements.

Table 1: Excerpt from the Collar Text File (Collar.txt).

hole_id	Y	x	Z	max_depth	hole_path	section
WD004	7362.082	1724.725	205.749	100	CURVED	7360
WD005	7239.18	1643.45	170.242	100	CURVED	7240
WD011	7280.282	1562.176	163.773	130	CURVED	7280

Table 2: Excerpt from the Survey Text File (Survey.txt) – hole_ id (WD004).

depth	dip	azimuth
0	-90	0
30	-88.7	5.23
60	-87	2.5

Table 3: Excerpt from the Assay Text File (Assay.txt) – hole_ id (WD004).

samp_id	depth_from	depth_to	gold
WS689231	0	2	0.03
WS689232	2	4	0.02
WS689233	4	6	1

Table 4: Excerpt from the Geology Text File (Geology.txt) – hole_ id (WD004).

depth_from	depth_to	Rock_type
0	2	S2
2	6	SH
6	15.4	ST

Using Surpac to Build a Database

The first task in the mine planning exercise was to build a geological database with Surpac, which then loaded with CSV files. Data that were incompatible with the database definitions were rejected. The deposit sections and the drillhole was extracted to layout from the database to plot and display with the software's display module. The primary purpose for including a drillhole layout is to assist geologists and mining engineers in the process of familiarizing themselves both with the plan and the drillhole pattern. After they become familiar with these features, they can then decide which sections to focus on. The abbreviations used are as follows: B (Bericia), IN (Intrusive), MU (Mudstone), QV1 (Quesvain), S2 (Sandstone), SH (Shale), ST (stibnite).

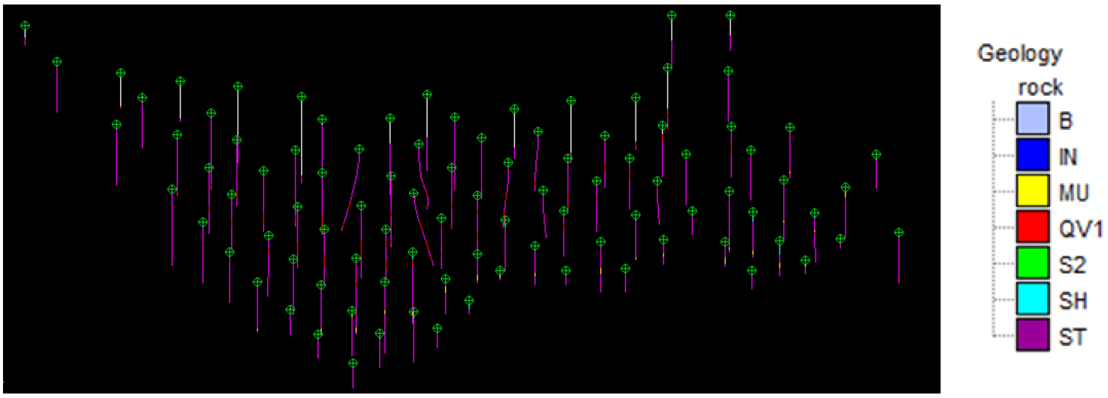

Figure 1: Drillhole display showing embedded rocks.

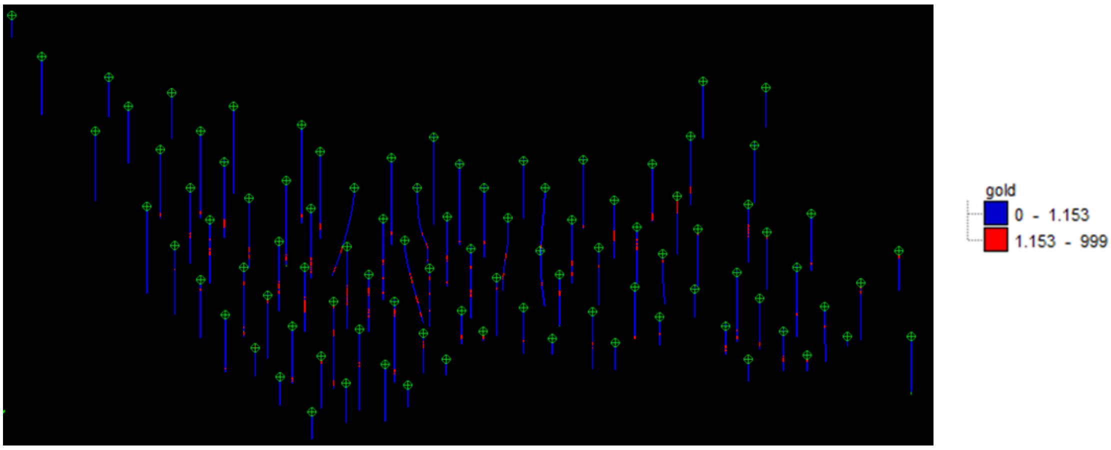

Figure 2: Drillhole display showing gold.

As can be seen in Figures (1) and (2), the cut-off grade was calculated as 1.153, classifying it as either ore or waste. Note that 0 to 1.153 is waste, while 1.153 to 999 is ore. The two figures also indicate that the ore occurs in QV1 (Quesvain) and MU (Mudstone).

Modelling the Deposit in 3D

Based on the drillhole layout, we extracted certain sections and performed ore delineation using on-screen points digitization in a clockwise direction, forming closed segments. After being created, each section was checked against the following criteria:

- Duplicate points.
- Excessive number of points.
- Fold-backs (also called spikes): all spikes were removed.
- String direction: ensuring all string direction was clockwise.

Next, the triangulation was used to join the closed segments together to create a wireframe model. The model was validated to represent the ore outline. Figures (3) and (4) illustrate the segments as well as the ore/solid model generated after digitizing the segments.

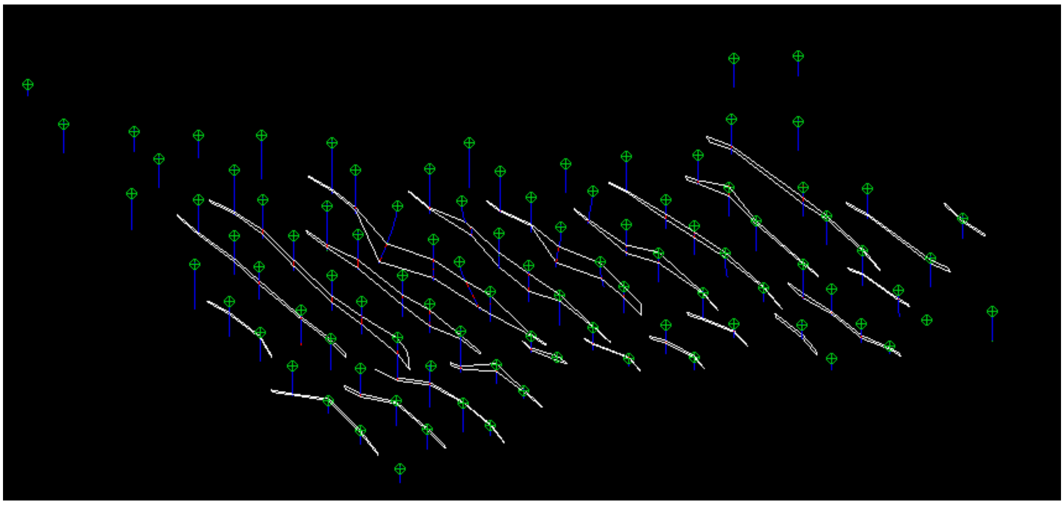

Figure 3: Drillhole display showing digitized sections of ore.

Figure 4: Deposit’s body of ore modeled in 3D using Surpac.

Using the Krigging Technique to Block Model and Estimate the Deposit’s Grade

Following the creation of the ore model, the ore body was divided into blocks in a process known as “block modelling”. This process first requires the software user to estimate each block’s size. In this case, the block size was estimated as 10m*10m*5m.

Next, the grades of the blocks were estimated, as the blocks are initially not assigned any. To assign grades, the one of a few methods was used, the most popular of which are Krigging and Inverse distance weighting (IDW). Note that each block’s tonnage is determined based on the tonnage factor and block volume, with the blocks viewed as point values instead of volumes. In cases where a block has been sub-divided into a number of smaller blocks, the sub-block was calculated and combined the results.

The Surpac software package includes estimation tools such as Simple Krigging, Ordinary Krigging, and Inverse Distance. Using the geostatistical and geospatial knowledge, the Ordinary Krigging was chosen as the most appropriate for the present purposes. This approach gauges whether the data contains any directional bias or spatially correlated distance, both of which can skew results. Figure (5) shows the main steps involved in Surpac block modelling and grade estimation.

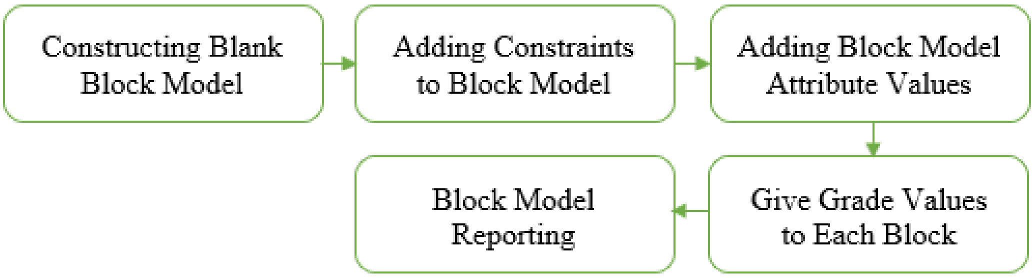

Figure 5: Flow chart showing the work processes of Surpac’s block modelling and ore grading.

Constructing a Block Model

Next, the following information was used to construct a block model:

- Block size: 10 m × 10 m × 5 m.
- Model extent.
- Model identification name.
- Model origin.

Adding Constraints to Block Model

As a subsequent step, the constraints were added to control block selection pertaining to interpolation or other important information. Topography was the key constraint imposed. Accordingly, blocks that fell within the topographic constraint range were classified as ore or waste, whereas those that fell outside the constraint were classified either as ore/solid model, airblocks, or grade. As depicted in Figure (2) above, blocks of 1.153 or less (1.153 being the cut-off) were classified as waste, whereas blocks of 1.153 or above were classified as ore. Furthermore, because the block model was quite large Figure (6), only its mineral content was discerned, as illustrated below in Figure (7).

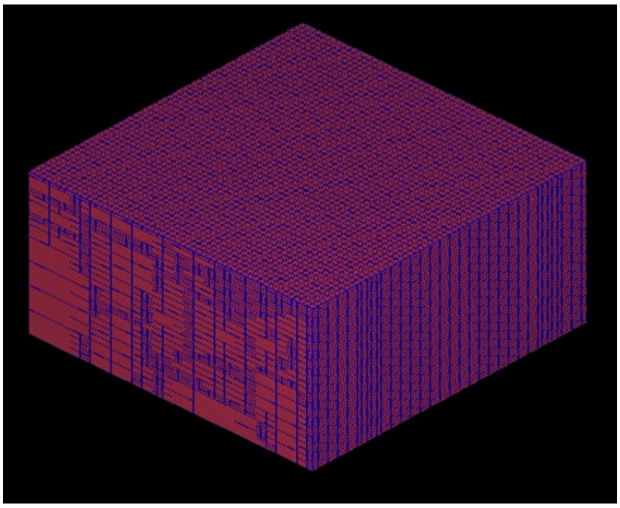

Figure 6: Constructing a block model from the defined metrics.

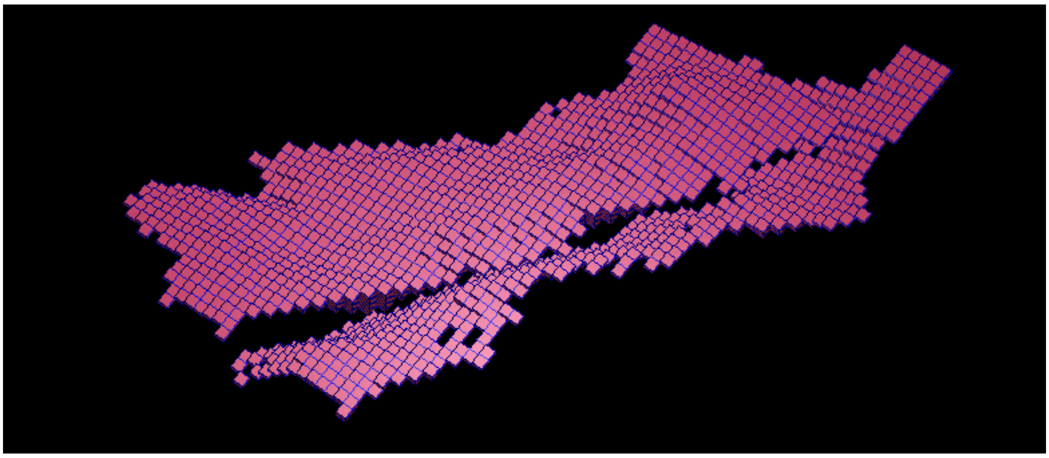

Figure 7: Benching the constructed block model.

Adding Block Model Attribute Values

The employed attributes to individual blocks were derived from properties either given or assigned to them. Specifically, some values were assigned directly, while others (e.g., grade) were interpolated. Tables (5) and (6) below present lists of assigned attributes.

Table 5: List of Assigned Attributes in the Block Model.

	Attribute	Value
1	Grade of gold	Interpolated
2	Material class	W, LG, MG, HG
3	Rock code	WAST, AIR & ORE
4	SG	2.8

Table 6: Detailed List of Block Model's Assigned Attributes.

	Name	Type	Decimals	Background	Description
1	Gold Tonnes	Calculated	-	-	Gold Volume* SG
2	Gold Volume	Calculated	-	-	y*x*z
3	Grade	Real	2	0.00	Grade of Gold
4	Material	Character	-	-	Material (HG LG MG W)
5	Rock Code	Character	-	-	-
6	SG	Real	2	2.8	Specific Gravity of Rock

Using Ordinary Krigging to Estimate Grade Value Estimates for Individual Blocks

To assign accurate values to each attribute, the Ordinary Krigging was used to estimate the block grade for each block model. Grades were applied to individual blocks, as shown in Figure (7). According to the values assigned, the ore grades were classified as either "W" (waste), "LG" (low grade), "MG" (medium grade), or "HG" (high grade). To view the grades of a specific block, click on that block as shown in Figure (8). For example, the attributes and values of one selected block model, highlighted in blue, are illustrated in Table (7).

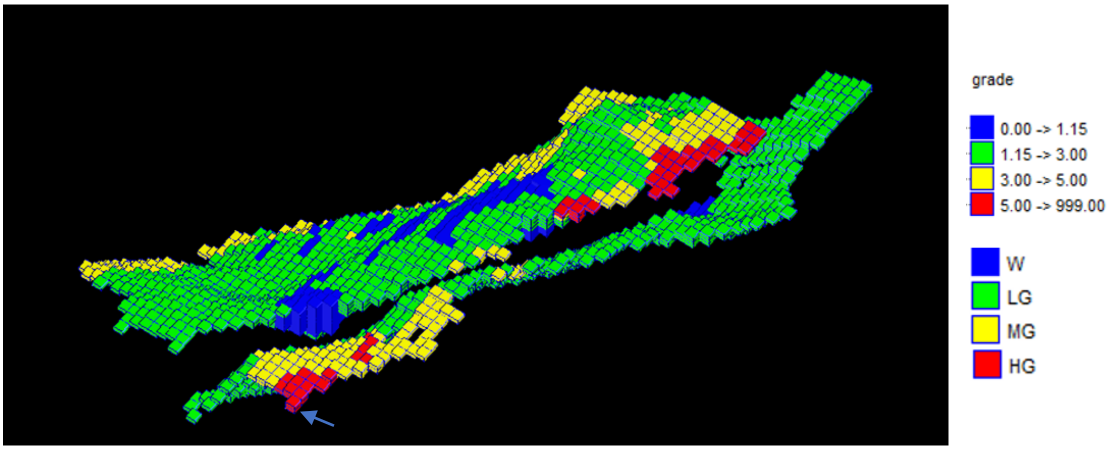

Figure 8: Block model with different colored constraints displaying deposit grade distribution.

Table 7: List Showing Attributes and Values of the One Selected Red Block (High Grade Ore).

	Attribute	Value
1	Gold Tonnes	1400.00
2	Gold Volume	500.00
3	Grade	5.06
4	Material Class	HG
5	Rock Code	Ore
6	SG	2.80

RESULTS AND DISCUSSION

This part includes the detailed results obtained from Surpac, covering processes from block modeling to ore reserve estimation.

Block Model Reporting: From Estimation to Final Mineral Resource Classification

Tables 8 (a), (b) and (c) present a qualitative and volumetric analysis for the studied mineral deposit, showing the resource classification. The data are derived from 10-meter (m) elevation intervals. This measure reflects the 10m bench height operational design used in most mining activities, while also taking into account the excavation equipment's operational capabilities.

Table 8 (a): Attribute Calculations Resulting in the Grand Total.

Material Class	Grade	Z	Volume	Tonnage	Grade
HG	5.0 -> 999.0	-10.0 -> 0.0	726080	2033023	6.16
		0.0 -> 10.0	718049	2010536	6.28
		10.0 -> 20.0	704389	1972290	6.32
		20.0 -> 30.0	697889	1954090	6.32
		30.0 -> 40.0	693469	1941713	6.29
		40.0 -> 50.0	676469	1894113	6.29
		50.0 -> 60.0	540733	1514051	6.31
		60.0 -> 70.0	498628	1396159	6.31
		70.0 -> 80.0	483031	1352487	6.31
		80.0 -> 90.0	485619	1359734	6.31
		90.0 -> 100.0	534051	1495343	6.31
		100.0 -> 110.0	543330	1521323	6.31
		110.0 -> 120.0	492881	1380066	6.3
		120.0 -> 130.0	495270	1386756	6.29
		130.0 -> 140.0	562070	1573795	6.27
		140.0 -> 150.0	708616	1984123	6.28
		150.0 -> 160.0	437938	1226226	6.25
		160.0 -> 170.0	416566	1166385	6.23
		170.0 -> 180.0	343122	960741	6.18

Table 8 (b): Attribute Calculations Resulting in the Grand Total.

Material Class	Grade	Z	Volume	Tonnage	Grade
		180.0 -> 190.0	369113	1033517	6.14
		190.0 -> 200.0	477811	1337871	6.17
		200.0 -> 210.0	526452	1474064	6.17
		210.0 -> 220.0	561673	1572684	6.18
		220.0 -> 230.0	627749	1757697	6.17
		230.0 -> 240.0	714488	2000565	6.13
	Sub Total		14035483	39299351	6.25
Sub Total			14035483	39299351	6.25
LG	0.0 -> 1.153	40.0 -> 50.0	230	644	1.15
		50.0 -> 60.0	770	2156	1.15
		80.0 -> 90.0	230	644	1.15
		90.0 -> 100.0	1230	3444	1.15
		100.0 -> 110.0	1270	3556	1.15
		110.0 -> 120.0	270	756	1.15
		120.0 -> 130.0	920	2577	1.15
		130.0 -> 140.0	6920	19377	1.15
		140.0 -> 150.0	10000	28000	1.15
		150.0 -> 160.0	8270	23156	1.15
		160.0 -> 170.0	1889	5290	1.15
		200.0 -> 210.0	1000	2800	1.15
	Sub Total		33000	92400	1.15
		220.0 -> 230.0	1461031	4090887	2.09
		230.0 -> 240.0	1465469	4103313	2.1
	Sub Total		46869607	131234898	1.95
Sub Total			46902607	131327298	1.95
MG	3.0 -> 5.0	-10.0 -> 0.0	150080	420223	3.85
		0.0 -> 10.0	161054	450950	3.79
		10.0 -> 20.0	174889	489690	3.78
		20.0 -> 30.0	187040	523711	3.71
		30.0 -> 40.0	185372	519041	3.7
		40.0 -> 50.0	188500	527800	3.75
		50.0 -> 60.0	192960	540289	3.74
		60.0 -> 70.0	224297	628032	3.73
		70.0 -> 80.0	265040	742111	3.69
		80.0 -> 90.0	264500	740600	3.65
		90.0 -> 100.0	268792	752618	3.66
		100.0 -> 110.0	432440	1210833	3.52
		110.0 -> 120.0	503332	1409330	3.51
		120.0 -> 130.0	521872	1461241	3.5
		130.0 -> 140.0	560434	1569215	3.47
		140.0 -> 150.0	666637	1866584	3.46
		150.0 -> 160.0	963934	2699015	3.47

Table 8 (c): Attribute Calculations Resulting in the Grand Total.

Material Class	Grade	Z	Volume	Tonnage	Grade
		160.0 -> 170.0	997983	2794351	3.49
		170.0 -> 180.0	1042213	2918196	3.52
		180.0 -> 190.0	1069519	2994652	3.56
		190.0 -> 200.0	1099739	3079269	3.58
		200.0 -> 210.0	1096787	3071004	3.59
		210.0 -> 220.0	1060035	2968097	3.62
		220.0 -> 230.0	989101	2769482	3.63
		230.0 -> 240.0	900044	2520122	3.63
	Sub Total		14166592	39666459	3.58
Sub Total			14166592	39666459	3.58
Grand Total			75104682	210293108	3.06

As can be seen in the table, the block model software has rigid economic constraints for the deposit. It rejects anything graded below 1.153 as the "cut-off grade". The rest of the material is classified into various grades of ore ranging from “HG” (high grade) to “LG” (low grade). Furthermore, each 10m “bench” (i.e., vertical slice) reveals three crucial metrics for engineering purposes. These are: 1) Average Grade, showing fluctuations in ore quality according to depth; 2) Tonnage, which shows a bulk density of ~2.8t/m3; and 3) Volume (m3). All tolled, the data offer an accurate bench-by-bench inventory of the studied deposit, enabling engineers and geologists to estimate the deposit’s total economic value. Based on this estimation, a mining plan and daily schedule for ore extraction can be constructed.

Grand Total Calculations for Average Grade, Tonnage, and Volume

The block report provides a Grand Total, which is essentially a summation of the mineral resource under study. Below is a breakdown of the obtained numbers:

- **Average Grade (3.06):** The Average Grade represents the Weighted Average Grade for the mine in its entirety. As can be seen in the report, bench grades vary widely. However, if the grades were mixed together, they would yield a combined grade of 3.06, which represents the project’s overall economic value. Based on the value 3.06 grams per tonne (g/t), the amount of material needed can be calculated to obtain 1 gram of gold:
- **Tonnes (210,293,108):** The tonnage amount indicates the deposit’s total tonnage. In other words, the combined total of the material in the blocks is around 210.3 million tonnes.

  - Calculation Note: In dividing tonnage by volume, we get 2.80 t/m^3 as the density. This calculation can be used to confirm the specific gravity in geological calculations.

- **Volume (75,104,682):** The volume amount indicates the deposit's total volume of all the ore-classified material, as measured in cubic meters (m3). In other words, the volume represents the sum of all blocks in the model that exceeded the grade classifying constraint of 1.153 or higher.

Calculating the Grand Total

1. **Ratio:** The grade 3.06 g/t indicates that there are 3.06 grams of gold for every tonne (1,000 kilograms) of material.
2. **Formula:** Material needed = $\frac{1\ gram}{Grade(g/t)}$.
3. **Result:** $\frac{1}{3.06}$= 0.327 tonnes.

To recover 1 gram of gold, 327 kilograms of ore must be mined and processed.

Contextualizing Ore vs. Waste

To obtain 1 gram of gold from the studied mine, the Recovery Rate and Stripping Ratio also need to be taken into consideration. These factors are explained in brief below:

- **Recovery Rate:** Processing plants can never be completely efficient. So, for example, if a plant boasts a relatively high recovery rate of 90% recovery rate, this will translate to 2.75 grams per tonne in the studied mine. Therefore, to obtain 1 gram of gold, 363 kg of material would need to be mined and processed.
- **Stripping Ratio:** It is important to note that the mentioned grade of 3.06 applies to the ore only, not to mined material in general. Reaching the ore means first removing waste rock, i.e., everything that is not ore. So, for instance, if the studied mine has a 3:1 stripping ratio, 3 tonnes of waste need to be removed for each tonne of ore.

Mining and processing 0.327 tonnes (327 kg) of ore to obtain a single gram of gold translates to moving around 1,000 kg of material in total, composed of waste and ore at a 3:1 ratio. The ore must then be further processed, usually with chemicals, to obtain one gram of gold.

CONCLUSIONS

This study used advanced GEOVIA Surpac software rather than traditional manual methods to estimate and classify an ore reserve. Surpac reenvisioned geological data as a highly structured block-modeled inventory of values, allowing the software's users to gauge the economic potential of the studied deposit with extreme accuracy. The following conclusions were made based on Surpac's resource evaluation:

(i) Surpac's geostatistical tools built a detailed 3D block model that accurately represented the studied deposit's grade distribution and spatial limits. The constructed model served as the foundation upon which the ore reserve could be estimated.

(ii) According to the Surpac constructed model, the ore reserve was estimated to contain approximately 210,293,100 tonnes of ore. This total amount was then weighted at a 3.06 g/t average grade, resulting in 75,104,682 m³ as the total ore volume. The calculated final amounts included only material within the assigned 1.153 cut-off grade. The inclusion of stipulated material only in the calculations ensured that only economically viable deposit portions were considered in the resource inventory report.

(iii) Benching, i.e., vertical selectivity, of the deposit in 10-meter elevation intervals during the estimation process succeeded in aligning the height of the mining bench with the constructed model. Such an alignment of these critical inputs ensures the integrity of the reserve statement with regard to economically viable extraction limits, which can then be confidently applied to mine and production planning in the future.

(iv) The Surpac 3D block model enabled highly accurate stripping ratio (waste: ore) estimations using in-depth volumetric analysis. Based on the obtained spatial configurations, the studied deposit showed a favorable (i.e., economically viable) stripping ratio. Transitioning the raw resource of the deposit to a working reserve would be further supported by the high grade of the ore (3.06 g/t), which would adequately offset the removal costs of waste material.

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DECLARATION OF CONFLICTING INTERESTS

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DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

Mendeley Desktop was used to insert the references, and Scholar GPT tool was subsequently used to verify that the citations followed the IEEE style.

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