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Optimised Open Pit Design Using Minessight Software - A Case Study at the Bisha Mining Share Company, Eritrea East Africa

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Abstract: This study investigates the optimization of open pit design using the Lerchs-Grossman (LG) method within the Minesight Economic Planner software, focusing on the Volcanogenic Massive Sulphide (VMS) orebody at the Bisha Mining Share Company in Eritrea, East Africa. The primary objective is to develop an optimized pit outline that ensures both profitability and safety, considering geological, geotechnical, and economic factors. The research employs a systematic methodology encompassing literature review, comprehensive data collection, and iterative pit optimization and design processes. Key inputs include geological data, geotechnical parameters, and economic variables such as fluctuating metal prices. Geotechnical assessments by BGC Engineering provided critical insights into slope stability and rock mass characteristics, essential for safe pit design. The LG method facilitated the generation of optimized pit shells, which were refined to produce detailed pit designs incorporating practical mining considerations. Results indicated an optimized pit containing 28.31 million tonnes of ore with significant grades of gold, silver, copper, and zinc, with a minimal deviation of 2% from the detailed design. This study underscores the efficacy of integrating advanced computational tools and multidisciplinary data in open pit optimization, demonstrating the approach's robustness in achieving feasible and profitable mining operations. The findings also highlight the importance of dynamic economic modeling and continuous geotechnical evaluation to adapt to market fluctuations and ensure long-term operational stability. This research contributes valuable methodologies and insights for the mining industry, promoting enhanced efficiency, safety, and sustainability in open pit mining practices.

Keywords: Open Pit Optimization, Pit Design, Lerchs-Grossman Method, Bisha VMS Orebody, Geotechnical Parameters, Mining Economics, Minesight Economic Planner, Eritrea Mining, Resource Modelling, Volcanogenic Massive Sulphide (VMS)

1. INTRODUCTION

The objective of open pit optimization and design is to determine, prior to the start of mining operations, the final shape and size of the pit that contains ore which can be mined safely and profitably, considering vital factors such as geological setting, topography, grade distribution, cut-off grade, resource and reserve minimization, geotechnical characteristics affecting bench height and slope stability, environmental constraints, mining and processing costs, and mineral prices (Akisa & Mireku-Gyimah, 2015; Mariko & Mireku-Gyimah, 2018). Nevsun Resources of Canada, operators of Bisha Mining Share Company (BMSC) in Eritrea, completed an intensive exploration activity by the end of 2005. This exploration revealed a Volcanogenic Massive Sulphide (VMS) deposit containing commercial quantities of gold, silver, copper, and zinc at Bisha in Eritrea. The company aims to determine an optimized base case pit for mining the deposit profitably. Given that metal prices fluctuate over time, the company also seeks to determine optimized pit outlines corresponding to different metal prices and to produce detailed pit designs based on these outlines. The study objectives were to determine and design optimized pit outlines to serve as a guide for mining the Bisha VMS orebody effectively and profitably.

Open pit mining optimization is a crucial aspect of modern mining operations, aiming to maximize profitability and ensure safety by determining the most efficient pit design. The Lerchs-Grossman (LG) method, implemented within various mining software such as Minesight Economic Planner, has become a standard tool for this purpose due to its robust framework for optimizing pit outlines (Akisa & Mireku-Gyimah, 2015; Mariko & Mireku-Gyimah, 2018). The Bisha Mining Share Company, operated by Nevsun Resources of Canada, discovered a Volcanogenic Massive Sulphide (VMS) deposit in Eritrea containing significant quantities of gold, silver, copper, and zinc, necessitating an optimized pit design to exploit these resources efficiently (Thomas, 2011). The process of pit optimization involves integrating various parameters, including geological, geotechnical, and economic factors, to determine the final shape and size of the pit before commencing mining operations (Akisa & Mireku-Gyimah, 2015). Geotechnical considerations, such as slope stability and rock mass characterization, are critical to ensuring the safety and feasibility of the pit design. For instance, BGC Consultancy conducted comprehensive geotechnical assessments for the Bisha Main Zone, including rock mass rating (RMR) evaluations and slope stability analyses, to inform the pit design (Thomas, 2011; BGC, 2013).

Economic parameters, including metal prices and cost factors, also play a vital role in pit optimization. The fluctuating nature of metal prices requires dynamic pit designs that can adapt to market conditions, ensuring sustained profitability (Mariko & Mireku-Gyimah, 2018). The Bisha project incorporated such considerations, using spot metal prices to develop base case optimized pit outlines and conducting sensitivity analyses to assess the impact of varying economic conditions on pit design (Thomas, 2011). Moreover, the detailed pit design process involves iterative refinement of the initial optimized outlines, incorporating practical considerations such as ramp designs, berms, and wall smoothing to address geotechnical challenges (BGC, 2013). The Bisha study demonstrated this approach by producing a detailed pit design that closely aligned with the optimal pit outline, deviating by only 2%, which is within industry standards (Thomas, 2011). The successful implementation of open pit optimization techniques at the Bisha Mining Share Company highlights the importance of integrating multidisciplinary data and advanced computational tools in modern mining practices (Akisa & Mireku-Gyimah, 2015; Mariko & Mireku-Gyimah, 2018). This study provides a valuable case example of how comprehensive planning and optimization can lead to effective and profitable mining operations.

The optimization of open pit mines has been a subject of extensive research and development, driven by the need to improve efficiency, safety, and profitability in mining operations. A significant portion of this research has focused on the application of computational methods and software tools to achieve optimal pit designs. The Lerchs-Grossman (LG) algorithm, introduced in the early 1960s, remains a cornerstone in the field of pit optimization, offering a systematic approach to determine the most profitable pit configuration (Lerchs & Grossman, 1965). Recent advancements have further enhanced the capabilities of pit optimization software. For instance, studies have demonstrated the effectiveness of integrating the LG method with advanced economic and geotechnical modeling to produce more refined pit designs. According to Akisa and Mireku-Gyimah (2015), the use of sophisticated software tools like Minesight has significantly improved the accuracy and reliability of pit optimization outcomes. This integration allows for the consideration of complex geological and economic variables, resulting in more robust pit designs (Akisa & Mireku-Gyimah, 2015).

Geotechnical factors play a crucial role in open pit design, influencing the stability and safety of mining operations. Research by BGC Engineering (2013) highlighted the importance of detailed geotechnical assessments, including rock mass characterization and slope stability analysis, in developing safe and efficient pit designs. These studies emphasize that neglecting geotechnical factors can lead to significant operational risks and increased costs (BGC, 2013). Economic parameters, such as metal prices and mining costs, are equally critical in pit optimization. Mariko and Mireku-Gyimah (2018) explored the impact of fluctuating metal prices on pit design, suggesting that dynamic optimization approaches are necessary to maintain profitability under varying market conditions. Their research underscored the need for continuous re-evaluation of pit designs to adapt to economic changes (Mariko & Mireku-Gyimah, 2018).

Several case studies have illustrated the practical application of these optimization techniques in real-world mining operations. The Bisha Mining Share Company in Eritrea is one such example, where the use of the LG method within Minesight software facilitated the development of an optimized pit design that closely aligned with industry standards (Thomas, 2011). This case study demonstrated the practical benefits of integrating comprehensive data analysis and advanced computational tools in pit optimization. Further research by Dimitrakopoulos (2011) has focused on the uncertainty and risk management in pit optimization, highlighting the need for probabilistic approaches to account for geological variability and economic uncertainties. This approach ensures that pit designs are not only optimal but also resilient to potential risks and changes in mining conditions (Dimitrakopoulos, 2011).

The environmental impact of open pit mining has also been a subject of research, with studies emphasizing the need for sustainable mining practices. Karanam and Misra (2014) discussed various strategies to minimize the environmental footprint of open pit operations, including proper waste management and rehabilitation of mined-out areas. These practices are essential to ensure the long-term sustainability of mining projects (Karanam & Misra, 2014). Moreover, the role of technology in enhancing the efficiency and safety of open pit mining has been widely recognized. Innovations such as autonomous drilling and hauling systems have been shown to improve operational efficiency and reduce human exposure to hazardous conditions (Thompson et al., 2015). These technological advancements are becoming increasingly important in modern mining operations.

2. METHODS

Research Design

This study utilized a comprehensive and systematic approach to optimize the open pit design for the Bisha Mining Share Company, focusing on the Volcanogenic Massive Sulphide (VMS) orebody. The methodology was structured into several key phases: literature review, data collection and analysis, pit optimization using the Lerchs-Grossman (LG) method, and detailed pit design. A thorough review of existing literature was conducted to establish a theoretical foundation and understand current practices and advancements in pit optimization and design. This review included key studies on the application of the LG method, geotechnical assessments, and economic modeling in open pit mining (Akisa & Mireku-Gyimah, 2015; Mariko & Mireku-Gyimah, 2018). The review aimed to integrate the latest research findings into the study to enhance the robustness and accuracy of the optimization process.

Data Collection and Analysis

The data collection phase involved gathering comprehensive input data essential for pit optimization. This included geological data from resource models, geotechnical parameters from rock mass characterizations, and economic data such as metal prices and mining costs. Geotechnical data were sourced from detailed assessments conducted by BGC Consultancy, which included rock mass ratings (RMR), slope stability analyses, and laboratory testing of rock samples (BGC, 2013). Geological and economic data were obtained from exploration reports and market analyses, ensuring that the input data were accurate and reflective of current conditions (Thomas, 2011). These data were then processed and analyzed to identify critical factors influencing the pit design, such as ore grades, metal recoveries, and cost structures.

Pit Optimization Using the Lerchs-Grossman (LG) Method

The core of the optimization process involved the application of the LG method within the Minesight Economic Planner program. The LG algorithm was used to generate optimized pit shells by evaluating the economic value of each block in the resource model and determining the most profitable pit configuration (Lerchs & Grossman, 1965). The base case optimized pit outline was developed using spot metal prices and incorporating geotechnical constraints to ensure safety and feasibility. The LG method allowed for the assessment of various pit configurations under different economic scenarios, enabling the identification of an optimal pit design that maximized profitability while maintaining stability. Sensitivity analyses were conducted to evaluate the impact of fluctuating metal prices and cost factors on the optimized pit outline (Mariko & Mireku-Gyimah, 2018).

Detailed Pit Design

Following the optimization phase, detailed pit designs were developed using the Minesight pit expansion tool. This phase involved refining the optimized pit outlines by incorporating practical design considerations such as ramp designs, berms, and wall smoothing to address geotechnical challenges (BGC, 2013). The detailed pit design aimed to produce a realistic and implementable mining plan that adhered to industry standards.

Geotechnical parameters, such as slope heights, face angles, and inter-ramp angles, were applied to ensure the stability of the pit walls (BGC, 2013). The final detailed pit design included a double lane ramp with a width of 27 meters, a ramp gradient of 10%, and a nominal minimum mining width of 25 meters. These design elements were crucial in maintaining operational efficiency and safety. The methodology employed in this study integrated multidisciplinary data and advanced computational tools to achieve an optimized and detailed pit design for the Bisha VMS orebody. The combination of thorough literature review, comprehensive data collection and analysis, and the application of the LG method within Minesight software ensured the development of a profitable and safe mining plan. The study's findings highlight the importance of integrating economic, geological, and geotechnical considerations in open pit optimization to achieve successful mining operations.

Study Area

The Bisha property consists of an exploration license, located 233 km by road from Asmara, 43 km south west of the regional town of Akurdat (referred to as Agordat on some maps), and 50 km north of barentu, the regional or zone administration centre of the Gash- Barka District in Eritrea as show (figure 1)

Figure 1 Bisha's Location on the Map of Eritrea (Source: Thomas, 2011)

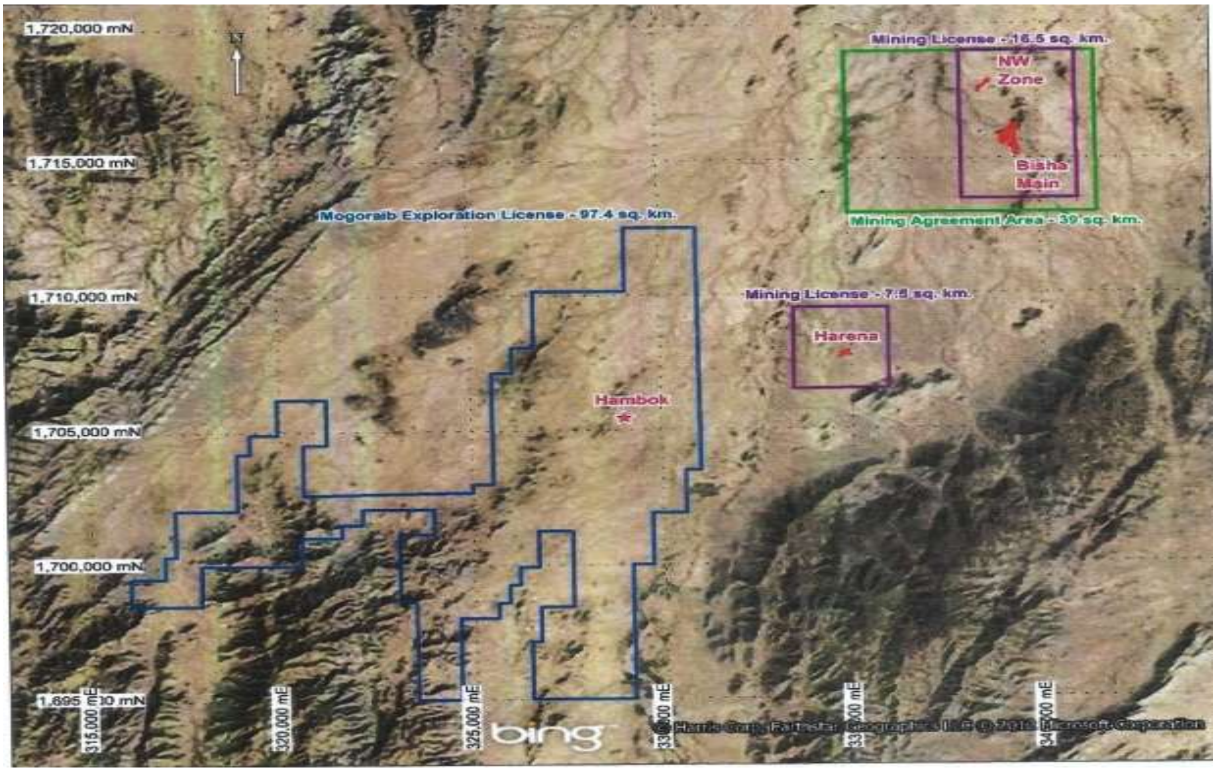

Figure 2: Location of the Bisha Exploration License (Source: Thomas,2011)

The property is at approximate latitude 15* 24'N and longitude 37*30'E. The UTM coordinates of the centre of the Property are 1 711 000 N and 340 000 E. The property is a single exploration licence with dimensions of 14 km x 16 km and covering a total surface area of 224 km2 (Figure 2) the current Bisha exploration licence include the original Bisha Area Exploration Licence (obtained in 1999) and the the Bisha Extension Area Exploration Licence (obtained in 2003). The entire area is now considered by the Ministry of Energy and Mines to be Bisha Exploration Licence. Nevsum, through its Eritrea subsidiary, Bisha Mining Share company, holds the Exploration licence. The state of Eritrea has an automatic right to a free carried 10% interest and has an option, under existing Eritrea minings laws to acquire up to a further 30% interest by agreement with the licensee.

3. RESULTS

Pit Optimization Results

The optimization was initially conducted on the base pit using spot metal prices to determine the optimized pit for the Bisha VMS orebody. This process involved evaluating various economic and technical parameters to identify the most profitable configuration for mining operations.

Geotechnical Design Parameters for Detailed Pit Design

The planned Bisha Pit is approximately 1.5 km long and 1 km wide, with slope heights ranging from 160 m to 290 m. BGC Consultancy completed rock mass characterization, structural geology assessment, and slope stability assessments to develop the open pit slope designs for the Bisha Main Zone. Geotechnical data, including drilling results, oriented core data, discontinuity mapping, and geological models, were provided by BMSC. BGC used data from 33 geotechnical drill holes, photogrammetric mapping, and documentation of existing slopes to assess the performance of the mined slopes. Additional rock core samples were selected for geomechanical laboratory testing, which included small-scale direct shear tests, uniaxial compressive strength tests, and Brazilian tensile strength tests. The rock mass of the Main Zone was divided into three geotechnical units based on weathering intensity, intact rock properties, and geological units: saprock (SRK), weathered rock (WRK), and fresh rock (FRK). The SRK unit includes highly weathered rocks with very poor rock mass rating (RMR), the WRK unit includes slightly to moderately weathered rocks with a good RMR, and the FRK unit consists of strong rocks with a good RMR.

The Main Zone was divided into three structural domains with boundaries interpreted as fold axes. Domain 1 and Domain 3 are characterized by steep east-dipping foliation, while Domain 2 has steep west-dipping foliation. Local variations in foliation orientation were observed due to tight folding. Slope design recommendations were provided for each design sector within the geotechnical domains, resulting in nine distinct geotechnical domains with recommended inter-ramp angles ranging from 31° to 46°. To achieve the open pit slope designs, depressurization of the slopes is required. The pre-development water table is approximately 15 m below ground surface, and seepage has been identified in some areas. A combination of vertical wells and horizontal drains has been proposed to dewater the pit and depressurize the slopes.

Detailed Pit Base Design

The Bisha ultimate pit designs were guided by LG shells generated using optimization parameters and pit slope guidance. Pit design parameters included a double lane ramp design with a width of 27 m, a ramp gradient of 10%, a nominal minimum mining width of 25 m, and wall smoothing in areas where convex noses could cause geotechnical issues. The ultimate pit design for the base scenario is illustrated in Figure 4.. NSR marginal cut-offs of $46.62/t for oxide and $38.25/t for supergene primary material were used to set up reserve volumetric calculations in Minesight software. The reserve item was coded into the model using the Models.dat procedure within Compass in Minesight for reserve calculation. Tables 1 and 2 show the reserve inventory within the optimal and detailed pit designs. The detailed pit design, incorporating berms and ramps, deviates from the optimal pit outline by 2%, which is within industry practice.

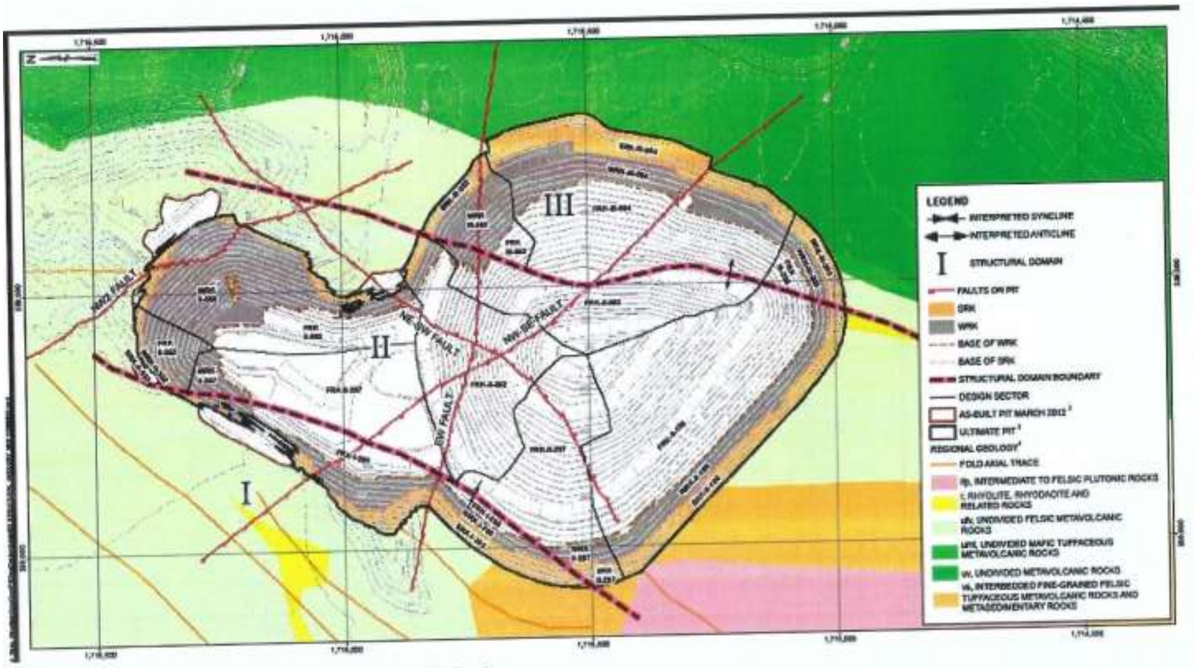

Figure 3: Pit Design for the Base Scenario

Table 1 Geotechnical Parameters for the Detail Pit Wall Design

Geotechnical Domain	Catch Bench Geometry			Inter- Ramp Geometry	
	Design Height	Face Angle	Width (varies with slope azimuth)	Maximum Height	Ange (varies with slope azimuth)
	Bh (m)	Ba (°)	Bw (m)	IRh (m)	IRa (°)

SRK-I	10	63	6.0 to 11.6		31 to 42
SRK-II	10	63	6.0 to 7.9		38 to 42
SRK-III	10	63	6.0 to 7.9		38 to 42
WRK-I	10	63	6.8 to 9.5	100	36 to 42
WRK-II	10	63	6.0 to 8.5	100	38 to 44
WRK-III	10	63	6.8 to 8.5	100	38 to 42
FRK-I	10	63	6.0 to 9.9	140	37 to 46
FRK-II	10	63	6.0 to 8.9	140	39 to 46
FRK-III	10	63	6.0 to 8.9	140	39 to 46

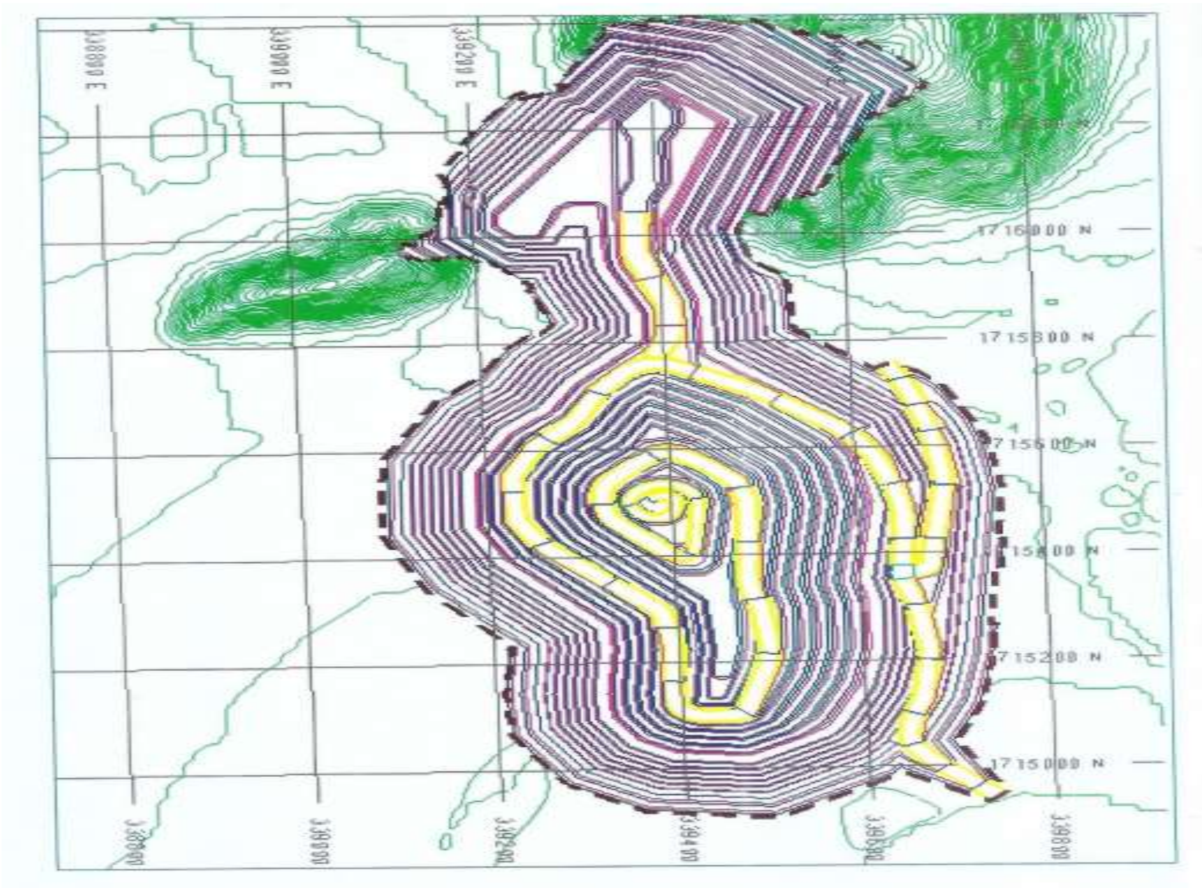

Figure 4: Base Detailed Pit Detailed with Ramps and Berms

Table 2 Optimal Base Pit Inventory

	Ore	Au	Ag	Cu	Zn
Ore Type	Tonnes (000)	g/t	g/t	%	%
Oxide (above $ 46.62/t NSR Cut-off)					
Proven	933	5.75	21.90		
Probable	3 719	7.39	31.48		
Sub-Total Combined	4 651	7.06	29.56		
Supergene (above $ 38.25/t NSR Cut-off)	Tonnes (000)	g/t	g/t	%	%

	Proven	844	0.80	43.47	4.92	
	Probable	6 537	0.77	31.29	3.77	
Sub-Total Combined		7 382	0.78	32.68	3.90	
Primary (above $ 38.25/t NSR Cut-off)		Tonnes (000)	g/t	g/t	%	%
	Proven	521	0.78	52.51	0.91	8.09
	Probable	15 759	0.72	44.12	0.97	5.31
Sub-Total Combined		16 279	0.72	44.40	0.97	5.40
	Total Proven	2 298	2.20	36.77	2.07	1.98
	Total Probable	26 015	1.69	39.09	1.55	3.26
Total combined		**28 313**	**1.78**	**38.90**	**1.60**	**3.15**

Table 3 Detailed Pit Inventory

	Ore	**Au**	**Ag**	**Cu**	**Zn**	**Waste**	**Total Mined**	**Strip**
	Tonnes (000)	**g/t**	**g/t**	**%**	**%**	**Tonnes (000)**	**Tonnes (000)**	**Ratio**
OXIDE	**4 454**	**7.21**	**30.86**	**0.15**	**0.08**			
Supergene	**7 382**	**0.78**	**32.68**	**3.90**	**0.15**			
Primary	**16 280**	**0.72**	**44.40**	**0.97**	**5.39**			
Total	**28 116**	**1.76**	**39.18**	**1.61**	**3.18**	**117654**	**145967**	**4.18**

4. DISCUSSION

The findings from this study demonstrate the effectiveness of using the Lerchs-Grossman (LG) method within the Minesight Economic Planner program to optimize open pit designs for the Bisha Volcanogenic Massive Sulphide (VMS) orebody. The optimized pit inventory produced 28,313,000 tonnes of ore with grades of 1.78 g/t gold, 38.90 g/t silver, 1.60% copper, and 3.15% zinc, closely aligning with the detailed pit design, which yielded 28,116,000 tonnes of ore with slightly different grades. This minimal deviation of 2% between the optimized and detailed pit outlines underscores the robustness of the LG method in producing reliable pit designs, as supported by similar findings in previous studies (Akisa & Mireku-Gyimah, 2015; Mariko & Mireku-Gyimah, 2018).

The integration of geotechnical parameters, such as rock mass characterization and slope stability analysis, was crucial in ensuring the safety and feasibility of the pit design. BGC Engineering's comprehensive geotechnical assessments, including rock mass rating (RMR) evaluations and slope stability analyses, were instrumental in developing stable pit slope designs. The division of the rock mass into distinct geotechnical units (SRK, WRK, FRK) based on weathering intensity and rock properties, along with the application of specific slope design recommendations, aligns with best practices in the industry and existing literature on the importance of geotechnical considerations in pit design (BGC Engineering, 2013; Thomas, 2011).

Economic factors, particularly fluctuating metal prices, significantly influence pit optimization outcomes. The study's approach of using spot metal prices to develop the base case optimized pit outline, followed by sensitivity analyses to assess the impact of varying economic conditions, reflects the dynamic nature of the mining industry. This method ensures sustained profitability and adaptability of the pit design under different market scenarios, echoing findings from Mariko and Mireku-Gyimah (2018) who emphasized the necessity of dynamic optimization approaches in maintaining profitability in response to economic changes.

Furthermore, the detailed pit design phase incorporated practical considerations such as ramp designs, berms, and wall smoothing to address geotechnical challenges, demonstrating the iterative nature of the design process. This approach aligns with the industry standard practice of refining initial optimized outlines to produce realistic and implementable mining plans, as highlighted by BGC Engineering (2013) and Thomas (2011). The study also identified the need for additional drilling to convert inferred material to indicated and measured categories, highlighting the continuous nature of exploration and resource evaluation in mining operations. This finding is consistent with the recommendations from Dimitrakopoulos (2011), who stressed the importance of ongoing exploration and data integration to reduce geological uncertainty and improve the reliability of resource estimates.

The successful application of the LG method within the Minesight Economic Planner program, coupled with comprehensive geotechnical assessments and dynamic economic modeling, has resulted in an optimized pit design that maximizes profitability while ensuring operational safety. The findings of this study contribute to the existing body of knowledge on open pit optimization and design, providing a valuable case example of the practical application of advanced computational tools and multidisciplinary data integration in modern mining practices. Future research should focus on further refining pit optimization techniques, exploring the integration of probabilistic approaches to account for geological variability and economic uncertainties, as suggested by Dimitrakopoulos (2011), and implementing sustainable mining practices to minimize environmental impacts, as advocated by Karanam and Misra (2014).

5. CONCLUSION

This study successfully demonstrates the application of the Lerchs-Grossman (LG) method within the Minesight Economic Planner program for optimizing open pit designs at the Bisha Volcanogenic Massive Sulphide (VMS) orebody in Eritrea. The optimized pit inventory and detailed pit design closely aligned, with a minimal deviation of 2%, highlighting the effectiveness of the LG method in producing reliable and feasible pit outlines. Key to the success of this optimization process was the integration of multidisciplinary data, including comprehensive geological, geotechnical, and economic parameters. Geotechnical assessments provided by BGC Engineering played a crucial role in ensuring the stability and safety of the pit design, while the use of dynamic economic modeling allowed for adaptability in the face of fluctuating metal prices. This approach ensured that the pit design not only maximized profitability but also maintained operational feasibility and safety.

The study's findings align with existing literature on the importance of integrating robust computational tools and thorough data analysis in open pit optimization. The successful implementation at the Bisha site underscores the value of incorporating detailed geotechnical and economic assessments in the design process, providing a practical case example for the mining industry. The need for additional drilling to convert inferred material to indicated and measured categories was identified, highlighting the ongoing nature of exploration and resource evaluation in mining operations. Future research should focus on further refining pit optimization techniques, exploring probabilistic approaches to account for geological variability and economic uncertainties, and implementing sustainable mining practices to minimize environmental impacts. The integration of the LG method within Minesight software, combined with comprehensive data analysis and geotechnical assessments, has resulted in an optimized pit design that meets industry standards for safety, feasibility, and profitability. This study provides valuable insights and methodologies that can be applied to similar mining projects, contributing to the advancement of open pit optimization and design practices in the mining industry.

6. FUTURE IMPLICATIONS

The findings from this study on the optimized open pit design using the Lerchs-Grossman (LG) method within the Minesight Economic Planner program have several significant future implications for the mining industry. Firstly, the demonstrated effectiveness of integrating comprehensive geological, geotechnical, and economic data into the pit optimization process sets a precedent for future mining projects. This approach ensures that pit designs are not only profitable but also safe and feasible, providing a model for best practices in open pit mining. The success of this study underscores the potential for continuous advancements in mining software and optimization techniques. As the industry evolves, the integration of more sophisticated computational tools and probabilistic approaches can further enhance the accuracy and robustness of pit designs, allowing mining operations to better adapt to geological and economic uncertainties. This advancement will likely lead to more resilient mining plans that can withstand market fluctuations and operational challenges.

Moreover, the emphasis on sustainability and environmental responsibility highlighted in this study is expected to influence future mining practices. The incorporation of sustainable mining practices, such as efficient waste management, rehabilitation of mined-out areas, and reduction in water and energy consumption, will become increasingly important as the industry faces growing environmental scrutiny and regulatory pressures. These practices will not only minimize the environmental footprint of mining operations but also enhance their social license to operate. Technological advancements, such as the use of autonomous drilling and hauling systems, are poised to revolutionize the mining industry. By improving operational efficiency and safety, these technologies will reduce human exposure to hazardous conditions and increase productivity. Future mining projects are likely to see a greater adoption of such innovations, leading to more efficient and safer mining operations.

Furthermore, the need for continuous training and capacity building for mining personnel will become more pronounced. As optimization techniques and technologies evolve, there will be an ongoing need to equip the workforce with the necessary skills and knowledge to manage advanced mining operations effectively. This focus on education and training will ensure that the industry remains at the forefront of technological and methodological advancements. The implications of this study extend beyond the immediate findings, influencing the future direction of open pit mining practices. By setting a benchmark for integrating multidisciplinary data, adopting sustainable practices, leveraging technological advancements, and emphasizing continuous training, this study provides a valuable framework for future mining projects. As the industry continues to evolve, these implications will play a crucial role in shaping the future of open pit mining, ensuring that it remains efficient, safe, and environmentally responsible.

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