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DETERMINATION OF THE EXPLOITATION PARAMETERS OF THE BLED EL HADBA PHOSPHATE DEPOSIT, ALGERIA

The beneficiation of mineral resources not only bolsters a country's economy but also improves quality of life and fosters sustainable growth. The development of the phosphate mine in the Bled El Hadba region represents a pivotal move to meet increasing demand. This study aims to develop a comprehensive 3D geographic model of the deposit, estimate its phosphate reserves, and assess the parameters and characteristics for effective exploitation. Utilizing the block model method in Surpac 6.6.2, a detailed analysis is achieved that supports informed decision-making for sustainable resource management. This approach underscores the importance of technological innovation in the strategic planning and efficient utilization of mineral resources.

The results revealed total reserves of 425,304,000 m^3, equivalent to 893,138,400 tons, with an average grade of 21.65 %. The stripping ratio was determined to be 3.3:1. These findings provide valuable insights into the deposit's potential and the optimal depth range for extracting the highest concentration of P_2O_5. For detailed extraction planning and estimating P_2O_5 concentration over five-year periods from 2023 to 2066, with an average annual phosphate ore production of 20.7 million tons, Minesched software was utilized. This comprehensive approach ensures efficient resource management and maximizes the economic return from the deposit. These findings have profound implications for enhancing both the efficiency and sustainability of Algeria's mining industry. By securing a consistent supply of phosphate products, particularly for agriculture, this research addresses the rising demand for phosphates. Additionally, the data can inform strategic planning, enabling optimized resource extraction and reduced environmental impact. This contributes not only to the immediate needs of the industry but also to the long-term economic and ecological sustainability of the region. Ultimately, the study supports sustainable development by balancing industrial growth with environmental stewardship, ensuring that future generations can continue to benefit from these vital resources.

Keywords: *exploitable reserves, phosphate, highest concentration of P_2O_5, rational mining, Surpac 6.6.2 and Minesched.*

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1. Introduction

Phosphorus plays a crucial role in Algeria's economic development, both due to its scarcity and its multiple applications across various key sectors of the national economy, especially in agricultural fertilizers. As Algeria moves towards adopting an agricultural economy in the future, there is a corresponding increase in demand for phosphates. Indeed, this mineral holds strategic importance and could be a major asset for the country's food security. Given Algeria's significant phosphate reserves, which can be exploited for local phosphate fertilizer production, the country can reduce its reliance on costly imports while creating jobs and stimulating the industrial sector. Thus, the valorization of any mineral resource could not only strengthen the country's economy but also contribute to improving quality of life and fostering sustainable economic growth.

The opening of the phosphate mine in the Bled El Hadba region represents a crucial step in meeting this growing demand. However, to maximize the benefits, sustainable exploitation is necessary [1–3]. Therefore, before commencing exploitation, an evaluation study of reserves, exploitable content, exploitation elements, etc., is essential for future rational exploitation. Hence, exploitation can only begin once the extent and value of the deposit and the quantity of ore are known.

In this work, it is possible to determine the parameters and exploitation elements necessary for the rational exploitation of the Bled el Hadba phosphate mine – Bir Elater, region of Tébessa, as depicted in Fig. 1, utilizing specialized software for deposit planning and design, particularly to identify high-quality zones and schedule extraction operations [4, 5]. Consequently, the approach to mine layout has evolved to integrate data from various sources, employ advanced technologies, and utilize specialized software to optimize mining operations and determine high-grade zones. This combination of tools enables mining companies to make informed decisions while minimizing risks and environmental impacts.

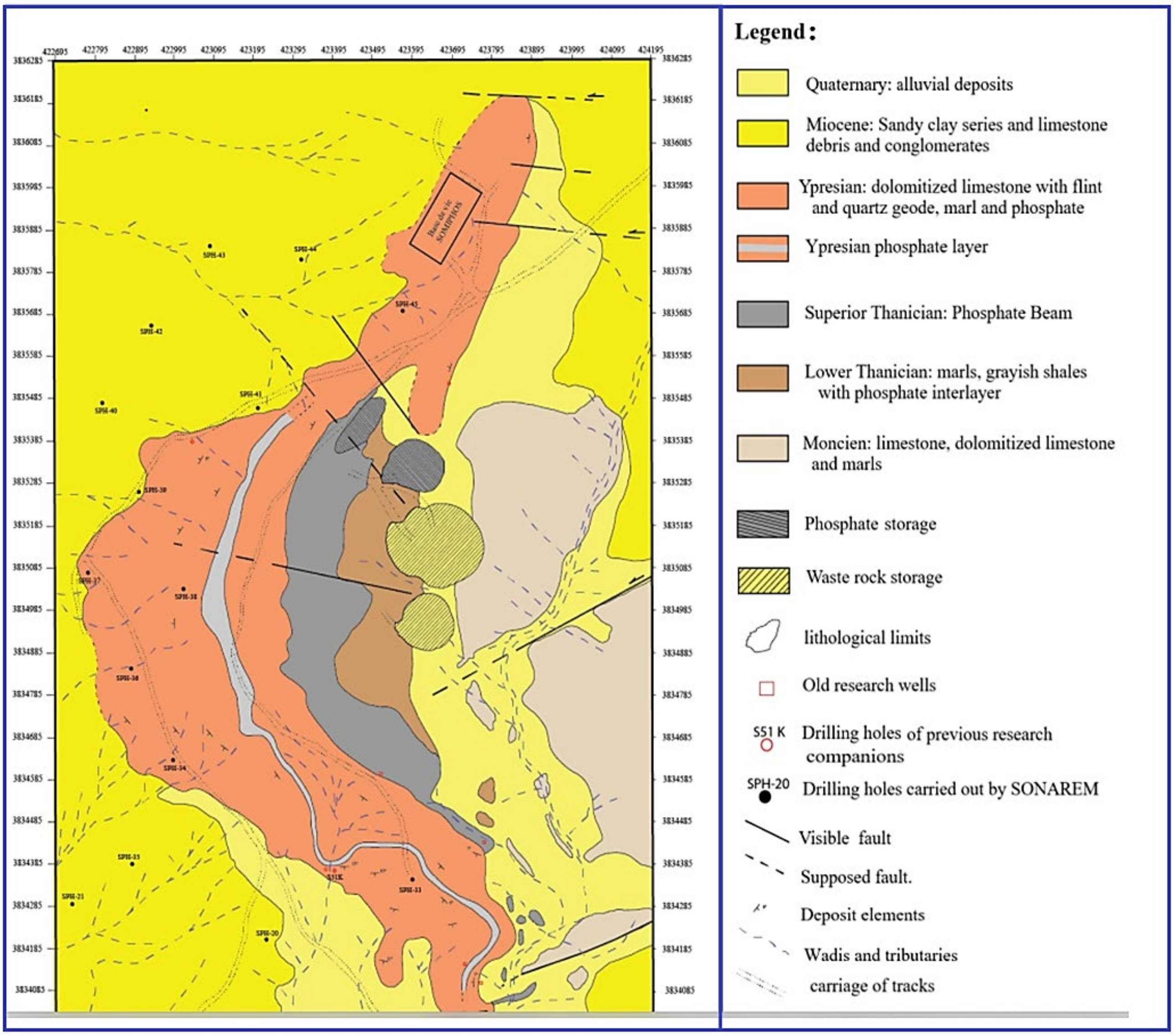


Fig. 1. Geological composition of Bled El Hadba deposit

The state of the art in the field of mine deposit modeling relies on a combination of geo-scientific technologies, computer modeling, and 3D visualization tools [6, 7]. These methods enable mining companies to optimize deposit exploitation while minimizing environmental impacts. 3D geological modeling software such as Leapfrog, Gemcom, and Surpac allow for the creation of detailed numerical models of the deposit by integrating previously gathered geological data [8, 9]. These models aid in visualizing the distribution of minerals, structures, and alterations, facilitating the identification of high-grade zones for future exploitation. These tools help maximize operational efficiency while minimizing losses and costs.

Our research focuses on the Bled El Hadba deposit, located 14 kilometers southeast of Bir El Ater and 6 kilometers west of the border between Algeria and Tunisia. This area lies on the western side of the Djebel Zrega anticline, which serves as the boundary between the two countries [10]. The presence of phosphates in the Bled El Hadba region has been known since Thomas' discovery in 1888. The geology of the phosphate zone was extensively described by Dussert (1924), and Ranchin, based on Cayeux's data (1941), identified five phosphate layers in the region in 1962. The deposit has been studied and thoroughly examined during four distinct campaigns: SONAREM, EREM, BRGM-SOFREMINES, and ORGM. Exploration work involved drilling 83 boreholes (with a total depth of 12,076 meters) over an area of approximately 12 square kilometers and excavating 12 trenches.

The aim of this research is to construct a 3D geological model of the Blad El Hadba phosphate deposit using data obtained from boreholes and utilizing Surpac software [11–13]. This model aims to assess the potential of the deposit and identify the optimal depth for extracting the highest concentration of P_2O_5. Additionally, it aims to develop necessary strategies to meet the increasing demand for phosphates while ensuring the sustainability and profitability of phosphate mining operations. This allows for the optimization of production schedules and efficient resource management to maximize yield and meet market demands. Thus, the study involves analyzing geological data to determine zones containing the most interesting minerals, the spatial distribution of the mineral body, boundaries, and exploitation elements [14, 15].

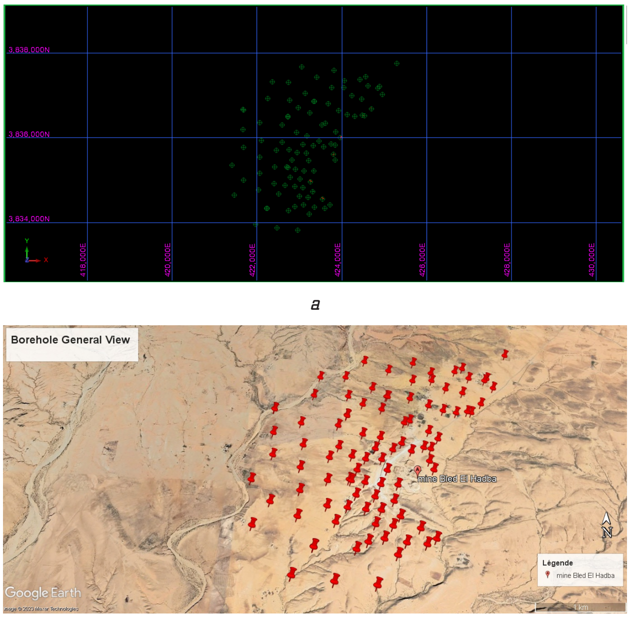
2. Materials and Methods

2.1. 3D Modeling. To generate a 3D representation of the deposit, it is possible to employ Surpac 6.6.2 software, utilizing data pertinent to the region. The foundational information for block modeling is sourced from exploration data, specifically borehole logs obtained from the geological report of BRGM (Geological and Mining Research Office). This valuable data was acquired during our internship at the Center for Studies and Research Applied to Development (CERAD). To streamline the modeling procedure, it is possible to organize the data into Microsoft Excel CSV files, ensuring compatibility with the Surpac software database.

Once the database was created by Access from four Excel files, the data were imported into Surpac for visualization of the drill holes (Fig. 2).

The drill holes can be represented in various ways, such as a series of points on a map or in a 3D view, and can be color-coded based on different grades. Labels were constrained by the parameter of the P_2O_5 cut-off grade, set at 16 %. The rows of drill holes were then digitized using the section mode to select only the contents located within and above the cut-off value in the scanned region, as shown in Fig. 3.

In this process, sections were utilized for the delineation and digitalization of the ore zones in all sections producing a series of ore zone strings. The ore zone strings were then triangulated to form a solid model (as shown in Fig. 4), which was then validated.



a

b

Fig. 2. Borehole General View:
a – with Surpac (NE); *b* – with Google Earth

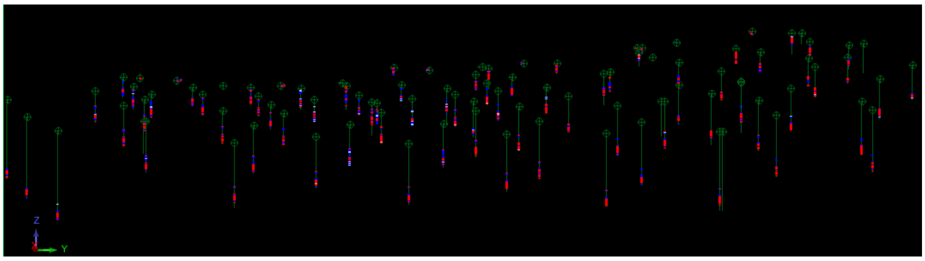
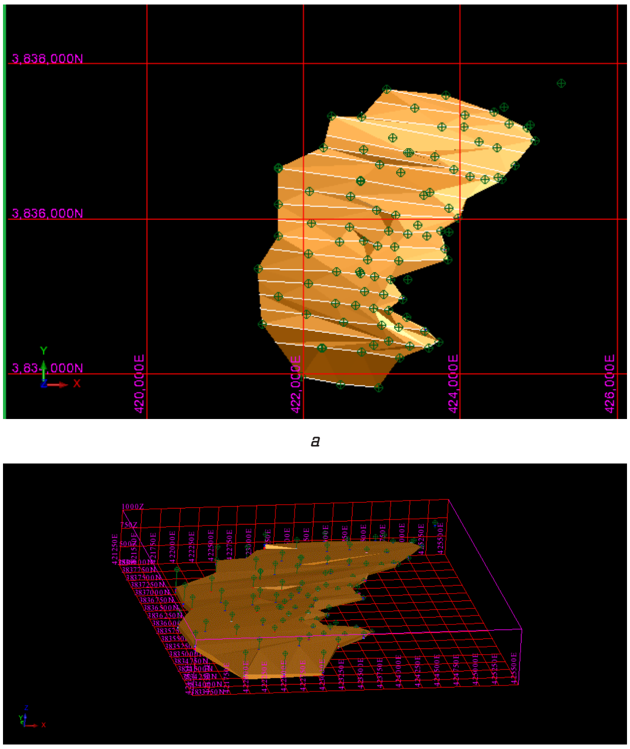


Fig. 3. Borehole showing mineralized zones



a

b

Fig. 4. Solid model of the ore deposit: *a* – 2D; *b* – 3D

2.2. Estimation of reserves and grades. To facilitate resource estimation, a block model of the deposit was created by dividing the solid ore model into smaller regular blocks of a customized size (30×30×10 m) using block modeling techniques [16, 17]. Each block was assigned attributes such as grade, density, waste, and rock type, with constraints added to control block selection based on factors like the topography's Digital Terrain Model (DTM) and a grade threshold (16 %) to distinguish between waste and ore blocks [18]. The parameters for creating the empty block template have been set as shown in Table 1.

Table 1

The parameters for creating the empty block template

Type	Minimum coordinates	Maximum coordinates	User block size	Total blocks
Y (m)	3,832,930.178	3,838,480.178	30	1,348,650
X (m)	420,605.419	425,465.419	30	
Z (m)	350.0	800.0	10	

For reserve and grade estimation, geological modeling techniques were used, including the inverse square distance and kriging methods [19–21]. These methods were employed to estimate the P_2O_5 grade of specific blocks, as indicated in Tables 2, 3. The results were then visualized using colors, with the block model displayed in a window where blocks were colored based on the solid's membership rate, as illustrated in Fig. 5.

Table 2

P_2O_5 grade using inverse distance

P_2O_5	Volume	Tonnage	Average grade (P_2O_5)
16.0->20.0	25,407,000	53,354,700	19.43
20.0->22.0	221,139,000	464,391,900	21.21
22.0->24.0	165,753,000	348,081,300	22.94
24.0->26.0	13,014,000	27,329,400	24.11
Total	425,313,000	893,157,300	21.87

Table 3

P_2O_5 grade using kriging

P_2O_5	Volume	Tonnage	Average grade (P_2O_5)
16->20.0	24,939,000	52,371,900	19.3
20.0->22.0	269,118,000	565,147,800	21.25
22.0->24.0	100,242,000	210,508,200	22.56
24.0->26.0	31,005,000	65,110,500	24.07
Total	425,304,000	893,138,400	21.65

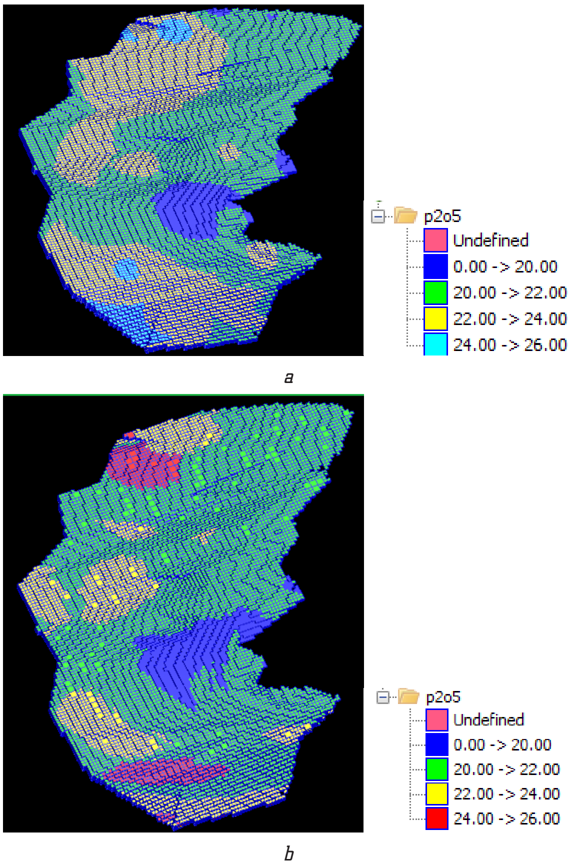


Fig. 5. Constraint of block model estimated by: *a* – the inverse square distance; *b* – kriging

The mean density determined was 2.1 t/m^3.

2.3. Final pit design using Surpac. The final pit design using Surpac software will involve the creation of a 3D model of the pit. Table 4 shows the applied design parameters. The plan can then be used to create a detailed schedule for mining operations and to ensure that all safety regulations are met.

Table 4

Parameters included in pit design

Parameter	Values
Bench height	15 m
Bench face angle	60°
Ramp and Haul Road Width	27 m
Ramp Gradient	10 %
Safety berm width	5 m
Final Slope Angle	46°
Type of Ramp	switchback

The design started at the bottom of the pit to make more workable space and worked its way up to the surface topography. The contour was extended in such a way that it contained the mineable ore blocks while also following the optimized pit contour. Fig. 6 depicts a detailed pit design.

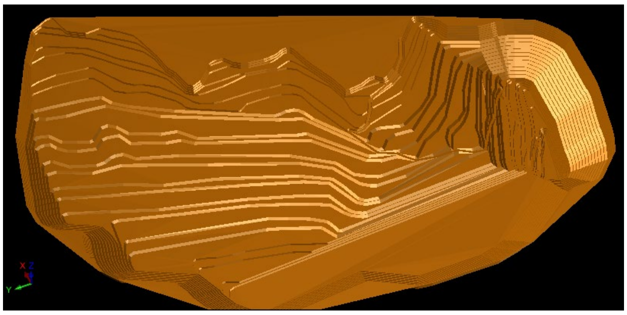


Fig. 6. Final pit design

After creating the final pit and modeling the solid ore body, it is possible to calculate the waste rock volume, given that the ore volume has already been determined. The stripping ratio for the Bled Elhadba phosphate deposit is 3.37:1. This indicates that for every 3.37 cubic meters of waste removed, one cubic meter of ore is extracted (Table 5).

Table 5

Parameters included in the stripping ratio

Parameters	Values
Pit volume	1,861,910,781 m^3
Ore volume	425,313,000 m^3
Waste volume	1,436,597,781 m^3
Stripping ratio	3.37

2.4. Planning the exploitation process. To conduct cost-effective planning of the exploitation process, let's utilize Minesched software [22–25]. This tool enables to optimize the mining operation process through the use of various steps and tools. It's worth mentioning that one of the key aspects of this planning is the initial step.

3. Results and Discussion

3.1. Defining geological parameters. During this phase, the software imports a block model previously generated by Surpac, incorporating essential attributes such as P_2O_5 content and material density. These attributes are specified in the block model. Through color-coded block ranges and variations, it accurately identifies different material qualities in the extraction area. In this initial phase, it is possible to conduct a classification of various material classes, encompassing the different types necessary for operations.

Three distinct material categories emerge: low-grade (poor), medium-grade, and high-grade (rich) materials. These categories are defined by a set of quality parameters and constraints that the software allows to input. For instance, materials are considered low-grade if their content falls below 20 %, medium-grade if it ranges between 20 % and 22 %, and high-grade if it exceeds 22 % of P_2O_5. The software enables to specify these categorizations.

It is worth noting that the software has assigned class 1 to low-grade content, class 2 to medium grade, class 3 to high-grade, and class 4 to waste material. Once the information is validated in the software, it provides with a series of graphs illustrating the volumes and percentages of various attributes such as P_2O_5 and density for different material classes.

3.2. Setup schedule. In this step, various locations are entered, corresponding to the mine, a stock for waste rock, and a stock for ore. It is crucial to establish connections between these locations, elucidating that the workflow progresses from the mine to the ore stockpile.

At this stage, it is essential to import different chains and DTM files generated in Surpac, representing the initial topography and the topography after extraction, including the quarry design. Additionally, it helps configure how the material was extracted, such as employing 3 benches of 15 meters in height, and specifying that the operation transitioned from a height of 800 to a height of 350. This configuration enables the generation of a graph illustrating the mass and/or extraction volumes of the material in different elevation ranges, as depicted in Table 6.

It is essential at this stage to establish the movements of the material types, here it has been established that class 1, class 2, and class 3 materials are intended for ore stock, and that class 4 materials are intended for sterile stock.

Table 6

Material movement results

Period	Destination	Material	Volume (m^3)	Mass (tons)	P_2O_5	Density	Elevation
2023–2028	process_1	poor	5,352,750	11,240,775	19.55	2.1	680–785
2023–2028	process_1	medium	40,313,919.6	84,659,231.1	20.89	2.1	
2023–2028	process_1	rich	3,814,875	8,011,237.5	22.41	2.1	
2023–2028	stockwaste	waste	403,310,250	846,951,525	/	2.1	
2028–2033	process_1	poor	11,003,625	23,107,612.5	19.3	2.1	650–710
2028–2033	process_1	medium	36,209,082.6	76,039,073.5	20.96	2.1	
2028–2033	process_1	rich	2,296,125	4,821,862.5	22.33	2.1	
2028–2033	stockwaste	waste	256,618,125	538,898,062.5	/	2.1	
2033–2038	process_1	poor	6,901,013.2	14,492,127.7	19.44	2.1	620–680
2033–2038	process_1	medium	37,907,497.8	79,605,745.4	21.11	2.1	
2033–2038	process_1	rich	4,673,250	9,813,825	22.45	2.1	
2033–2038	stockwaste	waste	227,971,125	478,739,362.5	/	2.1	
2038–2043	process_1	poor	1,556,736.8	3,269,147.3	19.77	2.1	605–650
2038–2043	process_1	medium	28,054,125	58,913,662.5	21.17	2.1	
2038–2043	process_1	rich	19,870,983.6	41,729,065.7	22.9	2.1	
2038–2043	stockwaste	waste	136,970,092.3	287,637,193.8	/	2.1	
2043–2048	process_1	poor	88,875	186,637.5	19.81	2.1	575–605
2043–2048	process_1	medium	18,645,750	39,156,075	21.46	2.1	
2043–2048	process_1	rich	30,747,237.8	64,569,199.4	23.26	2.1	
2043–2048	stockwaste	waste	118,489,225.6	248,827,373.8	/	2.1	
2048–2053	process_1	medium	14,034,375	29,472,187.5	21.65	2.1	545–605
2048–2053	process_1	rich	35,474,607.7	74,496,676.2	23.24	2.1	
2048–2053	stockwaste	waste	93,198,432.1	195,716,707.4	/	2.1	
2053–2058	process_1	medium	13,713,750	28,798,875	21.68	2.1	545–500
2053–2058	process_1	rich	35,768,162.7	75,113,141.7	23.07	2.1	
2053–2058	stockwaste	waste	62,239,500	130,702,950	/	2.1	
2058–2063	process_1	medium	15,989,399.4	33,577,738.8	21.61	2.1	455–530
2058–2063	process_1	rich	33,492,508.1	70,334,267	22.79	2.1	
2058–2063	stockwaste	waste	69,097,500	145,104,750	/	2.1	
2063–2066	process_1	medium	13,382,100.6	28,102,411.2	21.53	2.1	350–485
2063–2066	process_1	rich	11,594,250	24,347,925	23.06	2.1	
2063–2066	stockwaste	waste	61,440,750	129,025,575	/	2.1	

At this stage, it is possible to include production parameters, such as machines and their capacities, the number of active benches (3 bench), performance parameters which in this case is possible to configure as maximum yields, and of course, dates have also been established.

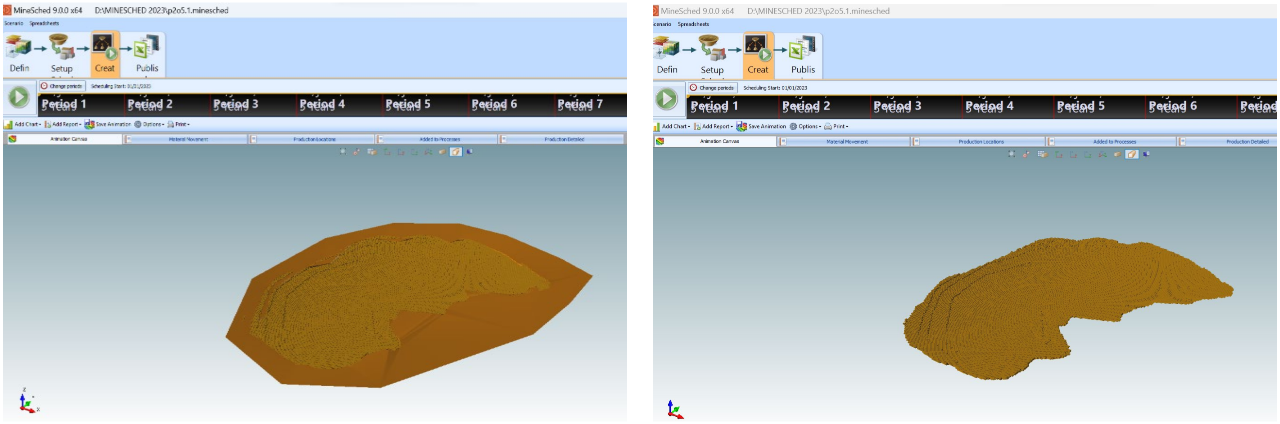
The lifespan is calculated here based on the mineral resources or reserves in tons (43 years). The work schedule for the mine and processing plant is as follows: three shifts of 8 hours per day and 7 days per week.

3.3. Creation of the planning. Continuing the process, one of the final stages involves generating various types of charts to illustrate the extraction movements of different materials over the established period, in this case, 43 years (Fig. 7, 8).

The estimation of the Bled El Hadba phosphate deposit reserves were performed using the Surpac software by applying two interpolation methods (Inverse of the Square Distance and ordinary kriging). The resources calculated by the two interpolation methods are the same and the average grades are rough of the same order. This estimation has given a total reserve of 893,157,300 tons with an average grade of 21.65 % by kriging and 21.87 % by IDS. The results obtained from this estimation can be used to determine the economic viability of mining operations in this area.

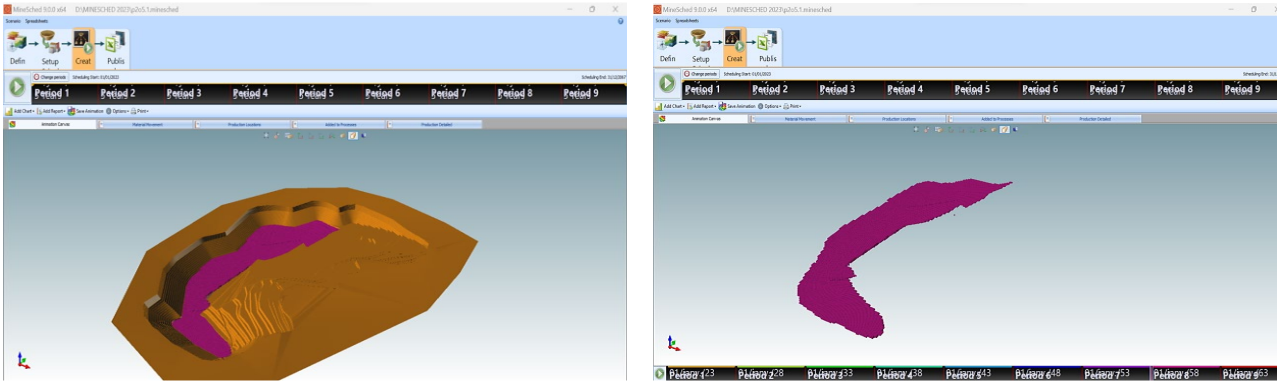
Table 7 provides estimates of the phosphate reserves at different depths and grades of P_2O_5, which can be used to inform decisions on mining operations and resource management, indicating the potential of the deposit and the optimal depth range to extract the highest concentration of P_2O_5 (Fig. 9).

The data show that as the level range increases, the P_2O_5 content decreases, with the highest P_2O_5 content of 24.11 % in levels below 500 meters.



a *b*

Fig. 7. The Mine before exploitation (Northeast section)



a *b*

Fig. 8. Schematic representation of the mine progress using Minesched (after 40 years of operation)

Table 7

P_2O_5 grade using kriging for each level

Z	P_2O_5	Volume	Tons	P_2O_5
1	2	3	4	5
350.0->400.0	22.0->24.0	369,000	774,900	23.94
	24.0->26.0	342,000	718,200	24.11
Sub Total		711,000	1,493,100	24.02
400.0->450.0	22.0->24.0	4,842,000	10,168,200	22.99
	24.0->26.0	1,746,000	3,666,600	24.11
Sub Total		6,588,000	13,834,800	23.29

Continuation of the Table 7

1	2	3	4	5
450.0->500.0	20.0->22.0	8,577,000	18,011,700	21.85
	22.0->24.0	20,421,000	42,884,100	22.56
	24.0->26.0	9,000	18,900	24.11
Sub Total		29,007,000	60,914,700	22.35
500.0->550.0	20.0->22.0	51,237,000	107,597,700	21.59
	22.0->24.0	14,157,000	29,729,700	22.36
	24.0->26.0	7,731,000	16,235,100	24.1
Sub Total		73,125,000	153,562,500	22
550.0->600.0	20.0->22.0	41,202,000	86,524,200	21.49
	22.0->24.0	38,007,000	79,814,700	22.64
	24.0->26.0	11,628,000	24,418,800	24.07
Sub Total		90,837,000	190,757,700	22.3
600.0->650.0	17.0->20.0	3,546,000	7,446,600	19.64
	20.0->22.0	54,603,000	114,666,300	21.13
	22.0->24.0	14,643,000	30,750,300	22.57
	24.0->26.0	9,549,000	20,052,900	24.04
Sub Total		82,341,000	172,916,100	21.66
650.0->700.0	17.0->20.0	14,418,000	30,277,800	19.13
	20.0->22.0	52,461,000	110,168,100	21.14
	22.0->24.0	7,371,000	15,479,100	22.24
Sub Total		74,250,000	155,925,000	20.86
700.0->750.0	17.0->20.0	6,759,000	14,193,900	19.46
	20.0->22.0	51,534,000	108,221,400	20.96
	22.0->24.0	432,000	907,200	22.19
Sub Total		58,725,000	123,322,500	20.8
750.0->800.0	17.0->20.0	216,000	453,600	19.8
	20.0->22.0	9,504,000	19,958,400	20.75
Sub Total		9,720,000	20,412,000	20.73
Grand Total		425,304,000	893,138,400	21.65

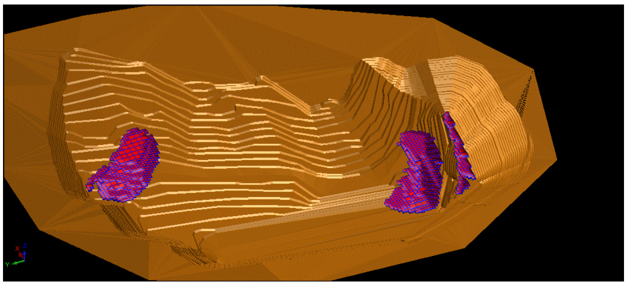


Fig. 9. Pit design with high-quality blocks

Interestingly, the highest estimated reserves of P_2O_5 are located between 550 to 600 meters, with a total of 190,757,700 tones. However, it is important to note that the average grade of P_2O_5 in this depth range is only 22.3 %.

Table 6 represents the results of material movement over different periods, with a focus on mass, P_2O_5 content, and elevation for four distinct material types: poor, medium, rich, and waste. The data pertain to the years from 2023 to 2066, divided into five-year periods. Knowing that the annual production of phosphate ore is around 20,700,000 tons

3.4. The prospects for further research. The results of our research highlight the critical importance of modeling the exploitation of the mining deposit, as well as determining the significance of its uncovering, for the rational and optimal management of this phosphate deposit in Bled El Hadba, Bir Elater, in the Wilaya of Tebessa. This modeling enabled the creation of an accurate three-dimensional representation of the deposit body, thereby facilitating the assessment of its potential. It allowed, among other, to determine the optimal depth for a rational and economically profitable extraction (optimal stripping ratio), where the concentration of P_2O_5 exceeds 27 % in useful mineral substances. Moreover, the development of this detailed strategy addresses the growing demand for phosphates while ensuring the sustainability and profitability of the operation. This represents a significant advantage, allowing for the optimization of production schedules, efficient resource management, and maximized yield, all while meeting market demands. This work thus lays the foundation for a more sustainable and economically viable phosphate mining.

As for further research prospects, the results obtained are promising. In our view, having reliable data from survey logs of any deposit is sufficient for its modelling. From now on, these essential data for block modeling will come from exploration information, particularly in our case, from survey logs derived from the geological report of the BRGM (Bureau of Geological and Mining Research). Thus, an in-depth analysis of the survey log data from the deposit using Surpac 6.6.2 software has yielded encouraging results. Consequently, this modeling approach can be generalized to other mines to fully validate its effectiveness and applicability.

These scientific advance paves the way for new opportunities in the mining sector, particularly for open-pit mines. It offers potentially effective and sustainable solutions for mineral resource extraction. By adopting this methodical and innovative approach, we are not only contributing to scientific progress but also fostering the economic growth of the region, thereby strengthening our positive impact.

4. Conclusions

Rational exploitation associated with any mining enterprise and the management thereof is important aspects of business management in today's competitive world, particularly in the fields of production and mining exploration where even minor errors can lead to catastrophic situations. Therefore:

– The block model method used in Surpac 6.6.2 provided a very accurate estimate of the reserves of the Bled El Hadba phosphate deposit, yielding a total volume of 425,304,000 m^3, a tonnage of 893,138,400 tons, and an average grade of 21.65 %, with a strip ratio of 3.3:1.

– The use of Minesched enabled to plan material extraction over five-year periods, spanning from 2023 to 2066, with an average annual production of phosphate ore totaling 20.7 million tons. The software appears configurable to handle various material types, including low-grade, medium-grade, high-grade, and waste materials, taking into account their respective masses. Furthermore, Minesched could be utilized to estimate P_2O_5 concentrations in the materials, thus playing a crucial role in assessing mineral resource quality and optimizing extraction processes. Another assumption suggests that the software could be employed to adjust extraction schedules based on elevation, indicating a sophisticated and adaptable use of Minesched in mining planning.

– The results indicate that high-quality phosphate concentration of P_2O_5 is significant at depths below 600 meters, and extraction of this quality is expected to commence from the year 2043. These findings can contribute to enhancing the efficiency and sustainability of the mining industry while meeting the growing demand for phosphate products in the agricultural sector.

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Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

There is no data associated with the manuscript.

Use of artificial intelligence

The authors confirm that artificial intelligence technologies were not utilized in the creation of the current work.

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