METHODS FOR DEFINING THE PERSPECTIVE PIT SHELL OPTIMAL DEPTH OF THE *ELLATZITE* OPEN-PIT MINE BY USING THE HXGN-MINEPLAN™3D MINING SOFTWARE

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ABSTRACT. Defining the optimum or ultimate mining depths is crucial for designing the final open pit shell extent. Its primary role is interrelated with the main environmental, technological, geotechnical, aesthetic and economic requirements for the project in open pit mining. The pre-feasibility assessment considers the possible profit out of a particular design. The current research presents a different approach for finding optimum pit shells by using the capabilities of the mining software HxGN-MinePlan™3D.

Key words: open pit design, ultimate pit depth, Mine Plan™3D.

МЕТОДОЛОГИЯ ЗА ОПРЕДЕЛЯНЕ НА ОПТИМАЛНАТА ДЪЛБОЧИНА ПРИ РАЗРАБОТВАНЕ НА „ПЕРСПЕКТИВЕН КОНТУР“ ЗА РУДНИК „ЕЛАЦИТЕ“ ЧРЕЗ СПЕЦИАЛИЗИРАН МИНЕН СОФТУЕР „HXGN- MINEPLAN™3D”

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РЕЗЮМЕ. Търсенето на оптимална или пределна дълбочина при разработване на открит рудник е основополагаща за определяне на неговите „крайни“/ „перспективни“ контурни граници. Първостепенната ѝ роля е взаимосвързана с главните екологични, технологични, геотехнически, естетически и икономически изисквания към проекта при откритото разработване. Определянето ѝ във фаза технико-икономическа оценка цели да се оцени приблизителната икономическа ефективност на разработването. Чрез доклада се представя различен подход при търсене на оптималните контурни граници, използвайки възможностите на специализирания минен софтуер „HxGN- MinePlan™3D”.

Ключови думи: проектиране, оптимална дълбочина, Mine Plan™3D.

Introduction

Defining the open pit extent is a main stage for designing an economically feasible optimum, ultimate, and/or perspective open pit shells.

The ultimate depth of an open pit varies and it is governed by many parameters. This imposes that a detailed estimation of the ultimate pit depth variation at alterable parameters and limitations needs to be performed at the pre-feasibility stage.

The main ore deposit type considered in the report is inclined and vertical. It is mined by the open cast method. The open pit ultimate depth is determined at the pre-feasibility stage.

The investigation is performed by the state of the art HxGN-MinePlan™3D software. The software covers most of the activities, such as designing and exploitation of mines around the world.

This research aims to show the developed methodology, which is used to design the optimum depth and extent of the perspective *Ellatzite* open-pit mine. For publication purposes, real estimates of the research are changed by some percentages.

Input models and parameters

Mining software codes consider the following main factors for defining of the ultimate open pit mine:
- Geochemistry – resource block model;
- Economical parameters;
- Cut-off grade by main commodity metal or all extracted metals equated to the single main metal;
- Geotechnical parameters;
- Ore extraction recovery in percentage.

Process and geometrical restrictions

The main process and geometrical restrictions are:
- minimum mine bottom extent at current and planned mining equipment;
- haulage infrastructure width;
- ore processing annual mine capacity;
- restricted extraction zone that affect the existing facilities and infrastructure, because of ecological or other specific reasoning.

Restricted zones are defined as areas, sectors or particular volumes, which do not allow push-backs or any advance of the mining geometry. The restriction in the area can be two- or three-dimensional, and hard (no mining allowed) or soft (mining is possible if economically feasible). The latter can be implemented if a pre-calculated cost-benefit analysis is performed. An example of a two-dimensional restriction is shown in Fig. 1, where a Nature 2000 zone or a water catchment area could be the governing factor.

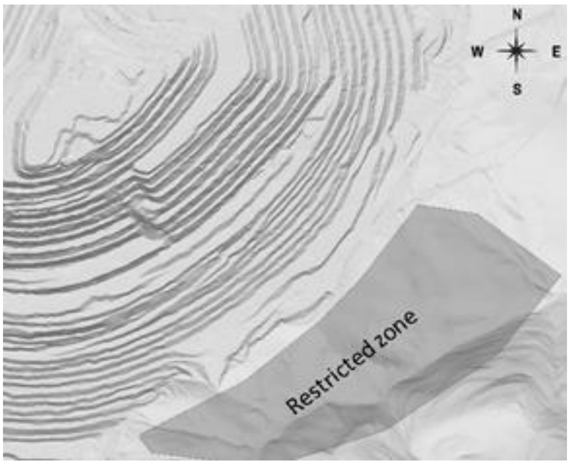

Fig. 1. An example of a restricted area delineated by a polygon

The software algorithm for searching of an optimal geometry, with and without a/any restriction is illustrated in Fig. 2:

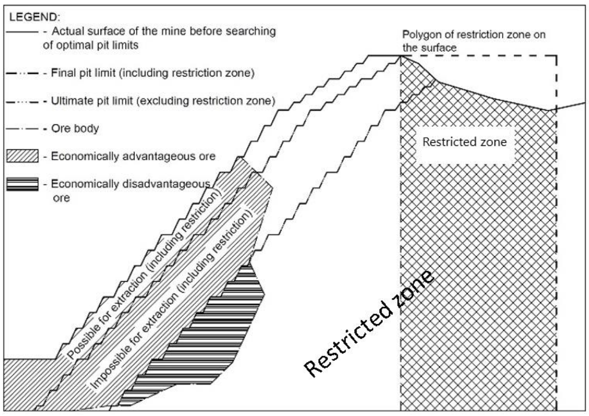

Fig. 2. The logic behind defining of a restricted mining area

A 3D buffer zone containing underground infrastructure, which is a possible restriction, is shown in Fig. 3 and Fig. 4 presents the logic for such situation.

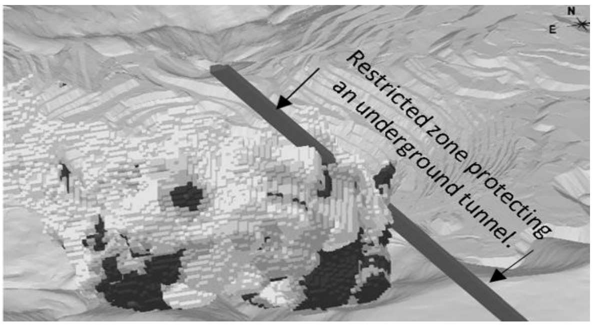

Fig. 3. A 3D subsurface view of a restricted volume, which transects the ore body

Based on the restrictions, the following scenarios are developed in the investigation:

- Case 1 with no mining restrictions;
- Case 2 with mining restrictions, caused by a safety buffer zone around the main conveyor belt tunnel.

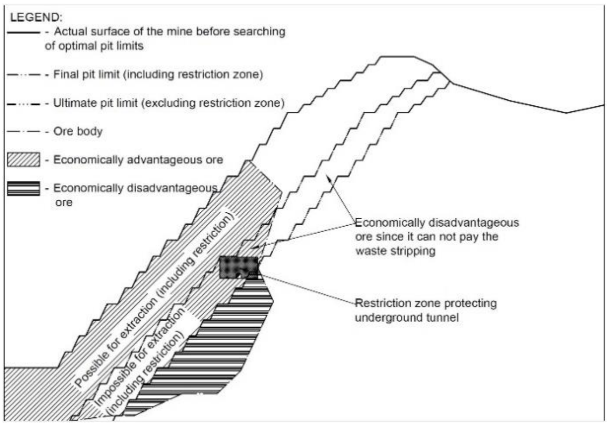

Fig. 4. The logic behind the 3D restriction of mining volumes. It secures an underground tunnel, which passes through the ore body

Three additional sub-cases for each case are considered. They represent pessimistic, realistic and optimistic commodity prices. The assumed sub-cases parameters are listed in Table 1.

Table 1. *Different studied options*

Definition of subvariants for searching of ultimate pit limits							
Parameters	Units	Implemented parameters and restrictions					
Number of main variants	-	№1			№2		
Type of main variants	-	Withouth 3D restriction			With 3D restriction		
Number of subvariant	-	№1.1	№1.2	№1.3	№2.1	№2.2	№2.3
Type of subvariant	-	Pessimistic	Realistic	Optimistic	Pessimistic	Realistic	Optimistic
Price Cu (Main component)	$/t	5000	6500	8000	5000	6500	8000
Price Au (Secondary component)	$/Oz	1700	1600	1500	1700	1600	1500
Cut-off grade	%	0.100	0.100	0.100	0.100	0.100	0.100
Used pit slope angles	-	According to the lithology					
Minimum dimensions of the pit bottom	m	60 x 180					

The considered models, along with their parameters and assumptions, are essential for designing an open pit optimum depth. The input data is not exhaustive. Including or excluding some data depends on each particular design.

Main functions and methods for ultimate pit depth estimation with MinePlan™3D

Calculation model

The Lerchs-Grossmann method, which is part of the economical module of MinePlan™3D, is used. This method always uses the logic for optimum pit extent, while maximising profit.

Main functions

A safety buffer zone is represented by a hard restriction. Mining and transportation costs are calculated for each mining bench.

The open pit bottom elevation restriction is used for each sub-case. The elevation is raised by +1 at 12 steps for each sub-case. Only the initial calculation is not restricted. Then it is numbered as 0th.

Methodology description for the ultimate open pit depth in MinePlan™3D

The ultimate pit depth estimation approach (all cases)

The open pit optimum depth estimation approach accounts for all mining processes and geometrical restrictions. This provides maximum profit, while the most economically usable ore is targeted.

Main study stages

For each sub-case, the optimum pit extent is calculated without taking into account the bottom restriction. The software independently estimates this. The estimated conceptual ultimate pit shell of Sub-case 1.1 is shown in Fig. 5.

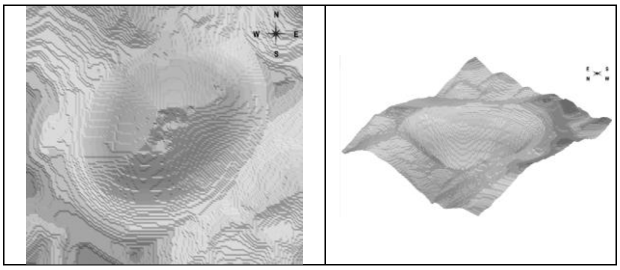

Fig. 5. A plan view and a 3D rendition of a conceptual shell in MinePlan™3D (no bottom restrictions)

Bench plan views of the ultimate pit bottom extent are shown in Fig. 6.

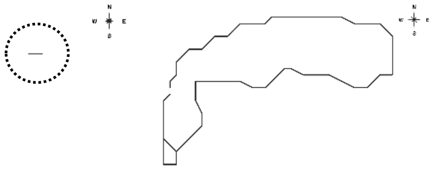

Fig. 6. Plan view in MinePlan™3D of the conceptual bottom extent: left – pit bottom, arbitrary elevation = 0; right – bottom delineation at +3 elevation

The initial no-restriction calculation of the bottom is shown on the left side of the figure. The restricted bottom (+3) is presented on the right.

The optimum open pit shell of Sub-case 1.1 (table1) can be seen in Fig. 7 and Fig. 8 (arbitrary cross-sectional examples, perpendicular to each other).

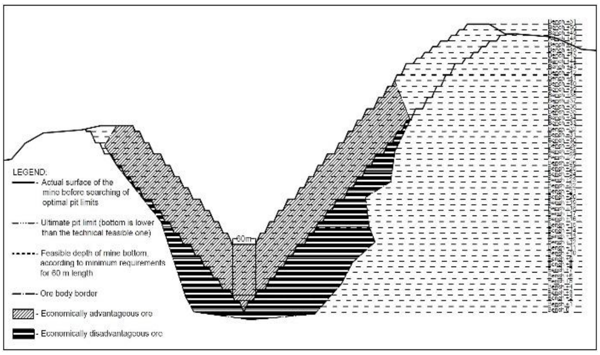

Fig. 7. Example of an optimum push-back cross-section

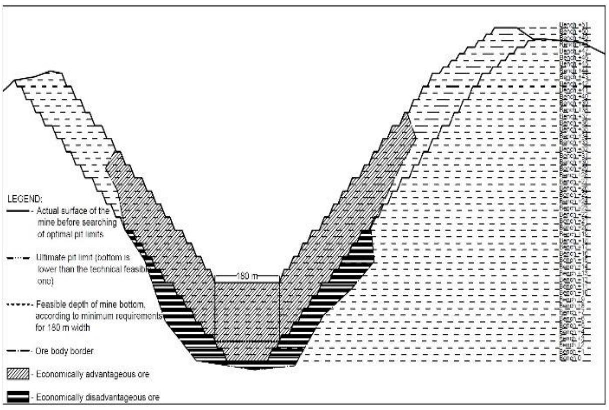

Fig. 8. Complementary example at 90˚ to the one in Fig. 7

The software, if there are not any restrictions, always delineates economically profitable ore, which is located beneath the level of the bottom (+3). The latter is defined after applying the minimum bottom extent restriction.

Thus, the restricted lowest pit bottom extent is applied for the bench, located above the calculated initial optimum pit bottom level. After that, the estimated pit bottom level (with the extent restriction) is raised in twelve steps (from +1 to +12).

The optimum open pit shell of Sub-case 1.1 (table 1) is illustrated with similar cross-sections in Fig. 9 and Fig. 10. There, the mining process restriction of minimum bottom extent is arbitrarily denoted as level +4 (the fifth calculation of Sub-case 1.1).

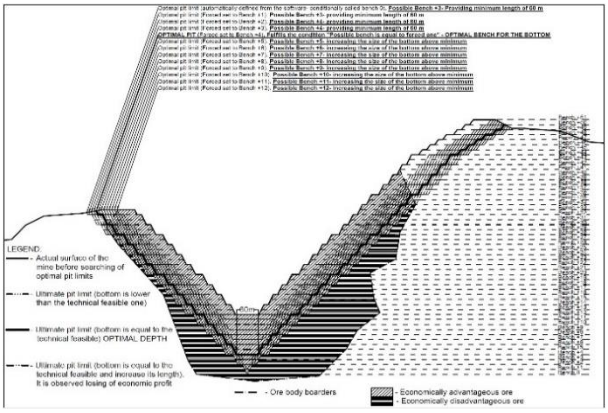

Fig. 9. Example of a cross-section, representing the final open pit geometry, calculated with different bottom’s elevations

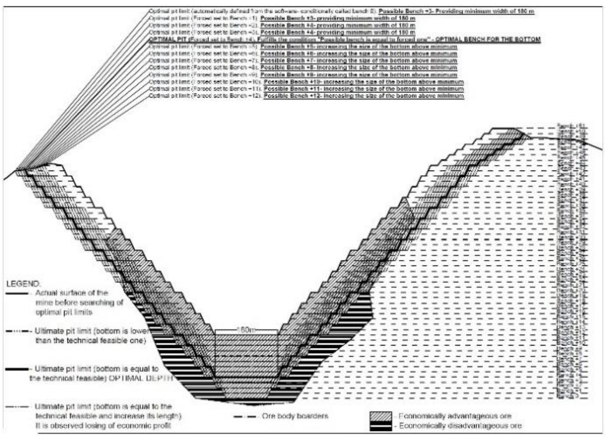

Fig. 10. Complimentary example at 90˚ to the one in Fig. 9

Discussion and conclusions

Discussion

The profit variation and discretised economically profitable ore is visible on the figures shown here. All calculated sub-cases show that the profit is stable for several pit bottom elevation steps, performed in the first part of the calculation. Continuing with the raised cases of the elevation of the open pit bottom, the profit and delineated economical ore reserves drastically decrease. The intersection point (breaking point) between the flat and steep sections of the profit line defines the optimum elevation of the pit bottom and ultimate open pit extent (tables 2, 3, 4, 5, 6, and 7, and the corresponding figures 11, 12, 13, 14, 15, and 16).

Table 2. *Parametric results for Sub-case 1.1*

Main variant №1 (withouth restriction). Subvariant №1.1							
Parameters	Cut-off grade	Variation of the market condition	Tones of ore (according to Optim. Variant +4)	Profit (according to Optim. Variant +4)	Stripping ratio	Forced bench	Bench, providing minimum dimensions of the bottom
Units	%, Cu	-	%	%	t/t	Bench	Bench
No restriction for the bottom	0.100	Pessimistic	104.4%	101.9%	0.30	0	+3
With forced restriction zone			102.8%	101.8%	0.30	+1	+3
			102.1%	101.6%	0.30	+2	+3
			101.2%	101.0%	0.30	+3	+4
			100.0%	**100.0%**	**0.31**	**+4**	**+4**
			97.4%	98.5%	0.31	+5	+5
			91.3%	96.4%	0.28	+6	+6
			88.5%	93.3%	0.29	+7	+7
			82.5%	88.6%	0.29	+8	+8
			73.1%	82.2%	0.26	+9	+9
			67.3%	73.7%	0.27	+10	+10
			58.1%	62.5%	0.28	+11	+11
			47.5%	48.5%	0.23	+12	+12

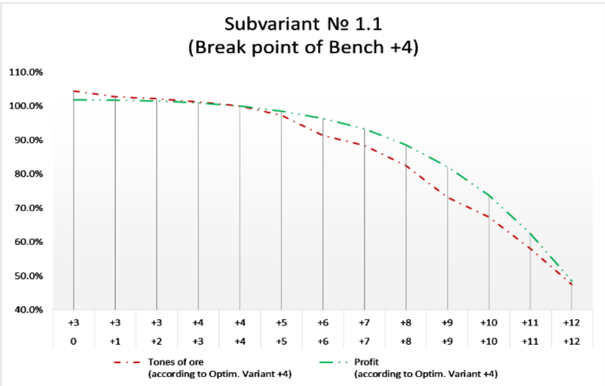

Fig. 11. Sub-case 1.1 with a breaking point at level +4

Table 3. *Parametric results for Sub-case 1.2*

Main variant №1 (withouth restriction). Subvariant №1.2							
Parameters	Cut-off grade	Variation of the market condition	Tones of ore (according to Optim. Variant +1)	Profit (according to Optim. Variant +1)	Stripping ratio	Forced bench	Bench, providing minimum dimensions of the bottom
Units	%, Cu	-	%	%	t/t	Bench	Bench
No restriction for the bottom	0.100	Realistic	105.7%	101.4%	0.54	-4	-2
With forced restriction zone			105.6%	101.4%	0.54	-3	-1
			105.0%	101.2%	0.54	-2	-1
			102.4%	101.0%	0.54	-1	0
			101.1%	100.7%	0.54	0	+1
			100.0%	**100.0%**	**0.55**	**+1**	**+1**
			97.4%	99.0%	0.54	+2	+2
			95.1%	97.6%	0.55	+3	+3
			92.9%	95.8%	0.56	+4	+4
			89.5%	93.6%	0.54	+5	+5
			86.0%	90.6%	0.54	+6	+6
			80.7%	86.5%	0.55	+7	+7
			73.7%	81.3%	0.50	+8	+8

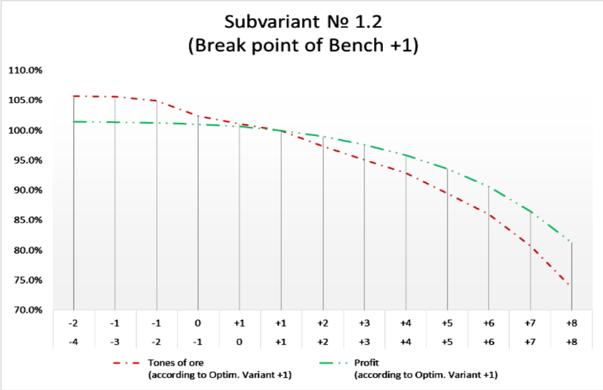

Fig. 12. Sub-case 1.2 with a breaking point at level +1

Table 4. *Parametric results for Sub-case 1.3*

Main variant №1 (withouth restriction). Subvariant №1.3							
Parameters	Cut-off grade	Variation of the market condition	Tones of ore (according to Optim. Variant -2)	Profit (according to Optim. Variant -2)	Stripping ratio	Forced bench	Bench, providing minimum dimensions of the bottom
Units	%, Cu	-	%	%	t/t	Bench	Bench
No restriction for the bottom	0.100	Optimistic	100.8%	100.5%	0.96	-5	-3
With forced restriction zone			100.8%	100.5%	0.96	-4	-3
			100.6%	100.3%	0.96	-3	-2
			100.0%	**100.0%**	**0.97**	**-2**	**-2**
			98.9%	99.5%	0.97	-1	-1
			97.9%	98.6%	0.98	0	0
			96.2%	97.5%	0.99	+1	+1
			89.3%	95.9%	0.93	+2	+2
			87.8%	94.0%	0.95	+3	+3
			84.2%	91.7%	0.95	+4	+4
			77.4%	89.0%	0.81	+5	+5
			73.4%	85.6%	0.80	+6	+6
			69.2%	81.2%	0.81	+7	+7

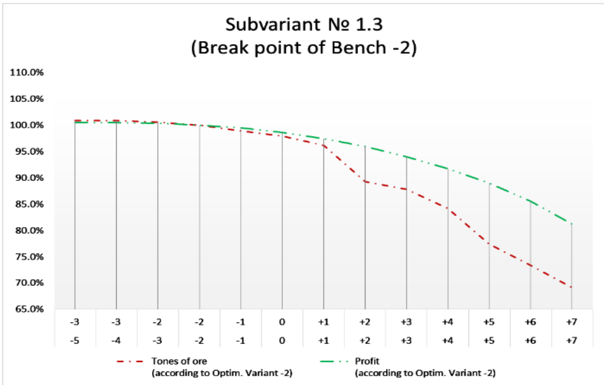

Fig. 13. Sub-case 1.3 with a breaking point at level -2

Table 5. *Parametric results for Sub-case 2.1*

Main variant №2 (with restriction). Subvariant №2.1							
Parameters	Cut-off grade	Variation of the market condition	Tones of ore (according to Optim. Variant +4)	Profit (according to Optim. Variant +4)	Stripping ratio	Forced bench	Bench, providing minimum dimensions of the bottom
Units	%, Cu	-	%	%	t/t	Bench	Bench
No restriction for the bottom	0.100	Pessimistic	104.0%	101.4%	0.13	0	+3
With forced restriction zone			102.1%	101.3%	0.12	+1	+3
			101.5%	101.1%	0.12	+2	+4
			100.9%	100.7%	0.12	+3	+4
			100.0%	**100.0%**	**0.12**	**+4**	**+4**
			96.5%	99.0%	0.12	+5	+5
			94.0%	97.3%	0.12	+6	+6
			90.8%	94.6%	0.12	+7	+7
			84.5%	90.5%	0.11	+8	+8
			77.8%	84.5%	0.11	+9	+9
			70.9%	76.1%	0.11	+10	+10
			60.3%	64.7%	0.10	+11	+11
			51.9%	50.0%	0.11	+12	+12

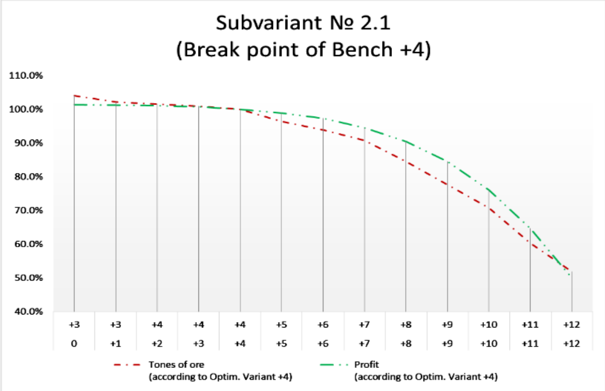

Fig. 14. Sub-case 2.1 with a breaking point at level +4

Table 6. *Parametric results for Sub-case 2.2*

Main variant №2 (with restriction). Subvariant №2.2							
Parameters	Cut-off grade	Variation of the market condition	Tones of ore (according to Optim. Variant +1)	Profit (according to Optim. Variant +1)	Stripping ratio	Forced bench	Bench, providing minimum dimensions of the bottom
Units	%, Cu	-	%	%	t/t	Bench	Bench
No restriction for the bottom	0.100	Realistic	105.5%	101.1%	0.32	-4	-1
With forced restriction zone			105.3%	101.1%	0.32	-3	0
			102.6%	101.0%	0.31	-2	0
			102.3%	100.8%	0.31	-1	0
			101.1%	100.5%	0.31	0	+1
			100.0%	**100.0%**	**0.31**	**+1**	**+1**
			97.7%	99.2%	0.31	+2	+2
			95.6%	98.3%	0.31	+3	+3
			93.4%	97.0%	0.31	+4	+4
			91.5%	95.3%	0.32	+5	+5
			87.7%	92.8%	0.31	+6	+6
			82.3%	89.3%	0.31	+7	+7
			76.6%	84.5%	0.27	+8	+8

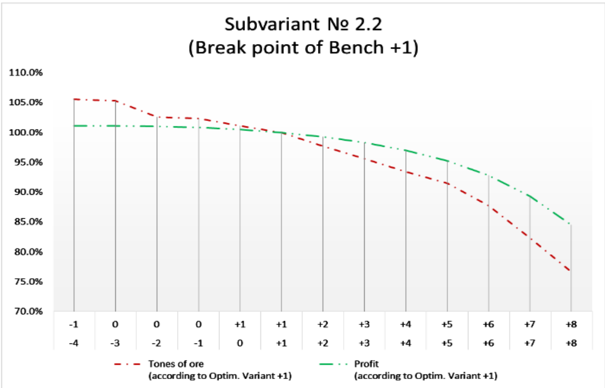

Fig. 15. Sub-case 2.2 with a breaking point at level +1

Table 7. *Parametric results for Sub-case 2.3*

Main variant №2 (with restriction). Subvariant №2.3							
Parameters	Cut-off grade	Variation of the market condition	Tones of ore (according to Optim. Variant 0)	Profit (according to Optim. Variant 0)	Stripping ratio	Forced bench	Bench, providing minimum dimensions of the bottom
Units	%, Cu	-	%	%	t/t	Bench	Bench
No restriction for the bottom	0.100	Optimistic	103.4%	101.8%	0.60	-5	-2
With forced restriction zone			103.3%	101.7%	0.60	-4	-2
			103.0%	101.6%	0.60	-3	-1
			102.7%	101.3%	0.60	-2	-1
			100.9%	100.8%	0.60	-1	0
			100.0%	**100.0%**	**0.60**	**0**	**0**
			96.8%	99.1%	0.59	+1	+1
			95.1%	97.9%	0.60	+2	+2
			91.8%	96.5%	0.60	+3	+3
			89.9%	94.6%	0.61	+4	+4
			86.0%	92.3%	0.59	+5	+5
			81.0%	89.3%	0.57	+6	+6
			76.7%	85.3%	0.56	+7	+7

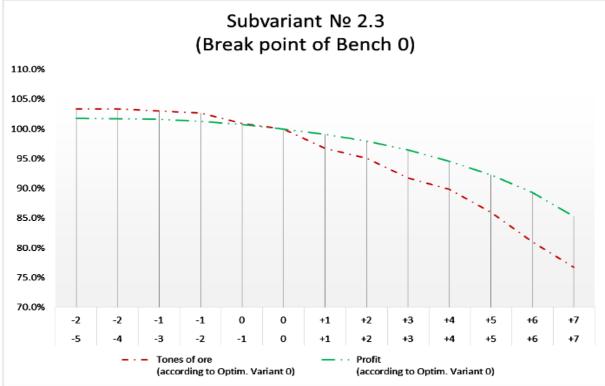

Fig. 16. Sub-case 2.3 with a breaking point at level 0

The cross section of Case 1.1 in Figure 17 suggests that the estimated initial shell, with elevation 0, does not satisfy the minimum open pit bottom extent restriction. The shell which satisfies the requirement has elevation +3. However, the optimum pit shell is with elevation of +4, as otherwise ore is locked between 0 and +3.

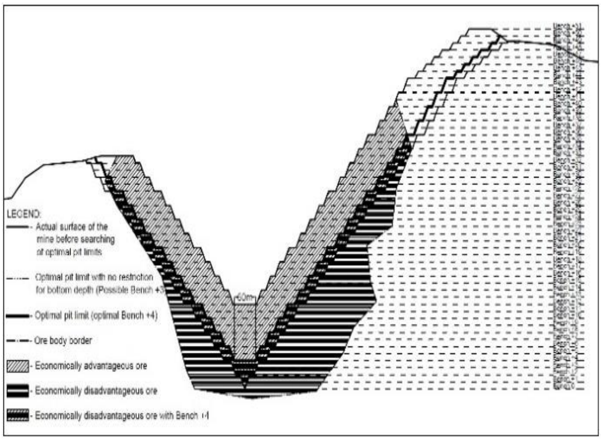

Fig. 17. An example of a cross-section (Sub-case 1.1) showing the initial bottom with level 0, the optional level +3, and the optimum level +4

An economic comparison (Fig. 17) between the calculated initial and optimum pit bottom elevations is given in Table 8.

Table 8. *Economic comparison by applying a discount rate*

Estimation according to Discount cash flow method (NPV)					
Subvariant	Cut-off grade, Cu%	Variation of the market condition	Profit from $ to % in first search vatiant, where the bottom is restricted to the feasible one(blocked ore, which is not possible to be extracted)	Profit from $ to % according to variant with defined optimal pit bottom (Break point)	Differences between first(blocking ore) and Optimal case
№1.1	0.100	Pessimistic	Ore blocked between Bench 0 to Bench +3	Bench +4	-0.21%
			100.0%	100.2%	
№1.2	0.100	Realistic	Ore blocked between Bench -4 to Bench -2	Bench +1	-1.07%
			100.0%	101.1%	
№1.3	0.100	Optimistic	Ore blocked between Bench -5 to Bench -3	Bench -2	-0.06%
			100.0%	100.1%	
№2.1	0.100	Pessimistic	Ore blocked between Bench 0 to Bench 3	Bench +4	-0.02%
			100.0%	100.0%	
№2.2	0.100	Realistic	Ore blocked between Bench -4 to Bench -1	Bench +1	-0.88%
			100.0%	100.9%	
№2.3	0.100	Optimistic	Ore blocked between Bench -5 to Bench -2	Bench 0	-0.03%
			100.0%	100.0%	

The table is completed for all sub-cases:

- Firstly, no restrictions on the bottom level are applied.
- Later, the open pit shell is determined by the breaking

point, at which the searched and optimum bottom levels are equal.

- Then, the ore which is impossible to extract is estimated. One such case is Sub-case 1.1 with the ore locked between levels 0 and +3.
- Finally, the optimum pit shell extent, which satisfies all mining process and geometrical restrictions with a maximum profit, is determined.

The economic estimate is performed by the MSVALP tool in MSEP. A discount rate of 10% is applied in order to estimate NPV (Net Present Value). The estimation assumes the equal annual profit, the extracted ore, and the overburden.

The purpose of the estimation is to define if the optimal pit shell is more economically profitable compared to the initial calculation, by applying a discount rate.

The results in Table 8 suggest that the estimated profit with the initial pit shell is smaller than the one with the optimum pit configuration. This observation is valid for all cases.

The strip ratio remains almost equal for all sub-cases in each case; hence, it can be considered as an optimum one. The calculated strip ratio shows the optimum overburden amount, necessary for the extraction of a unit of ore. That is valid at the application of the open cast mining method and all process restrictions applied. Optimum and ultimate strip ratios are dependent on economic conditions and mining process parameters. Otherwise, strip ratios define the maximum profit at final/perspective pit shells.

Conclusions

The calculation of the optimum open pit shell depth end extend can be relatively accurate if the methods described here are used. The defined pit optimum design guarantees maximum profit, accounting for the economic conditions, geotechnical parameters, and mining process restrictions.

A maximum profit from future open pit shell designs could not be achieved without a detailed analysis of the ultimate open pit shell. Moreover, the impact on the profit, caused by parameters variations and mining process restrictions, shall be estimated on a pre-feasibility study level.

The computer software for mine planning and design is a great tool for mining engineers. However, the user's expertise is of major importance for a reliable design.

References

„HxGN MinePlan3D", „MineSightEconomicPlanner HELP files", v. 4.0