Optimization of Open Pit Mining under Surpac and Whittle - Application to the Ruashi II and III Deposits

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Abstract: ***This study focuses on the optimization of pits, the search for a single project, the optimal long-term pit of the two mega-fragments of the Ruashi II and III deposit. The objective is to carry out several technical-economic analyses taking into account the changes in copper prices on the international market, in order to choose a pit that will be technically feasible and which will allow the company, to make the maximum of for the duration of the operation. To achieve this objective, the survey data on the study site allowed constructing the mineralized body and the model block, then an estimate of the total resources could be established. To obtain the optimum pit of the project, a first optimization from the technical point of view was carried out with the software Surpac, starting from the current costs on the market and while placing itself in unfavourable conditions, in order to give a scenario the most profitable as possible. The results showed that there are several possible technically optimal pits that can be carried out on the ground. These have been classified into three families. These families have been the subject of three different projects. The first pit family comprises all the pits for which the average copper price varies around $2 800/ton on the market. The second family comprises all the pits for which the average copper price varies between $3500 and $4200. The price that was chosen for this category is $3800; this is the average of the values. The third family includes all the pits, the price of which varies between $5 200 and $9 100. Here also, the average of the values worth $7000 was retained. With the whittle software, a second optimization procedure was carried out on an economic level, taking into account separately these three projects constituted. After several techno-economic analyses, the optimum pit of the second project realized at $3 800 was retained as an optimal pit in the long term. Thus, the starting cost to obtain the best pit of this deposit was set at $3 800/ton of copper. Then an analysis of the operating sequences could be carried out to have to orient the production to the most promising places. The best case is the fact of undermining all successive benches into three push-backs. And finally the mining reserves contained within the limits of the optimum long-term pit have been determined. At a cut-off content exceeding 0.3%, the pit retained contains a volume of 22 517 500 m3 and 48 549 986 tons of ore. The average copper content is estimated at 2.56% and an average cobalt content of 0.41%.***

Keywords: optimization, optimal pit, model block, mineralized body, resources

1. Introduction

The importance of mineral raw materials, particularly minerals, is no longer to be demonstrated, either for the consumer or producer countries. The highlighting of the new metal deposits became paramount and motivated the implementation of various techniques: geological surveys, estimation of reserves, technical-economic optimization, etc. In the case of conventional open-pit operations, the optimization of the trench, which aims to design a pit allowing both a very good recovery of the deposit and a cost of the extracted metal as low as possible, is one of the elements essential elements of the feasibility study [1]. This optimization is done using specific software. These calculate the pit which will be economically most profitable (i.e. whose net present value will be maximum) according to the data of the deposit (geometric envelope of the deposit, contents, distribution of contents within this envelope, ...), economic data (unit costs of extraction operations, costs of processing ore, price of metal,...) and technical data (maximum slopes ensuring stability of the pit, yield of plants, dilution during extraction,...). The best project to be chosen is the one that will significantly reduce the risk in mining and maximize the benefit over the life of the mine. To achieve concrete results, the Ruashi mine was chosen as a study site. The different studies will focus precisely on the two scales Ruashi II and III. Indeed, the approach of this study offers at the professional level or to mining companies, a new vision in the technical-economic analysis of mining projects. The problem is part of a finding observed in the mining field in general and in the Ruashi mine in particular. As a result, there are two fundamental questions, namely, what is the best pit of the Ruashi II and III project? And what is the best starting price in optimizing the pit of this deposit? Thus, it will be a question of doing a study on the optimization of pits, based on different technical-economic analyses and taking into account the changes in the prices of copper in the international market, in order to choose the best optimum pit of this project while setting the best starting price. That is to say a pit that will be technically feasible and that will allow the company to make the maximum profit in the long term. The first part of this study consists of a purely technical analysis with the optimization software Surpac® and the second part of the study is devoted to the purely economic analysis with whittle.

2. Material and Methodology

The data from the surveys conducted in Ruashi II and III will be used to create the mineralized body that represents the spatial limits of our deposit. They will be compiled into an Access database that can be used by the Surpac software. The purpose of this exercise will be to construct a correct geometry of the formations to be exploited. Which geometry will be used for qualitative and quantitative assessments of the materials contained in the area to be exploited in the suite. The mineralized zones will be determined on each drilling for a cut-off content of 0.3%, using copper as the main variable to separate the type of mineralization in order to observe the oxidized, mixed and sulphated parts well. From the mineralized intersections of the boreholes, different mineralized surfaces will be defined and joined between the sections to construct the solid of the mineralized body. After a certainty that the modeling of the geological layers of the mineralized zones passes through the solids, we will create a topographical surface starting from the data of surveys, to see the representation of the shape of our terrain after the realization of the various surveys. And finally, the mineralized body representing the wanted deposit will be created by the triangulation method of the surfaces of the mineralized passes digitalised on each section of surveys. A study of the variability of the copper content in the deposit will be carried out, thanks to the different data imported into the Surpac software. This information will allow us to carry out a variographic analysis of the copper values. And the variograms will be constructed from the original data to characterize the spatial continuity of the data set [2]. This geostatistical data will allow us to infer the parameters necessary for the distribution of these contents in the blocks that we will make through the inverse distance method to easily assess the total resources of the project. Next, we will calculate the resources contained within the project boundaries; to do this we will consider the mineralized body created with considerable precision thanks to the 321 surveys carried out, and taking into account the results obtained during geostatistical analyses and by the inverse distance method. We will create the model block by subdividing according to the different zones of mineralization, oxides, mixed and sulphated. Knowing the average size of the mesh on the ground, the size of the blocks will be defined, considering different cases to make an ideal choice of the best possible model block. We will assign to this model block, different attributes and classified materials according to different grades, which will allow to have an idea on the reserves of the deposit. An optimization on a purely technical aspect will be performed, using the software Surpac through its pit module optimize using as method of calculating the method $/unit. The pits will be generated using the technical-economic parameters of exploitation evaluated. Considering the current price of copper on the market and to which several discounts will be applied to see the behavior of the different pits. The different pits obtained will be grouped together in families which would constitute projects for a purely economical optimization much more advanced in the software whittle taking into account the variation of the metal price and the different costs on the market in order to choose the best optimal pit, which will be considered technically feasible and economically profitable in the long run. This optimization with whittle will be based on the total resources of our project that are supposed to be measured and indicated, and the selection of blocks was made by the marginal cut-off content. The simulation according to the current market conditions takes into account the costs obtained at the mine level. To choose the optimal long-term pit of this study, we will analyze separately the sensitivity of these optimal pits obtained in each project carried out. We will search among these pits, a pit that is technically feasible and economically profitable in the long run. An important aspect of the whittle software is its ability to provide information about the sensitivity of the project in relation to the different techno-economic parameters. This will allow us to see the variation of the VAN for each of the parameters chosen in the economic evaluation. In this study, we will vary the selected factors by ± 10% relative to the starting value in order to observe the impact on the NPV. If the variation is more than ± 25%, i.e. the impact is less significant and if not, the impact would be more significant and may affect the non-selection of the pit in question. Then we will make a comparative approach of the pits obtained in the software Surpac and in the software Whittle to see the behavior on a technical aspect, and then draw conclusions on the choice of best pit optimal for the long term. The best starting price will be set to get the pit technically feasible and economically profitable in the long run. We will have to propose the best possible scenario using the whittle software to properly sequence the mining to maximize revenue, and then push-backs are programmed to reach the ultimate pit. The contours of these pits will be exported from the whittle software to the Surpac software to properly evaluate the different quantities of materials that we will classify according to the different zones, oxidized, mixed and sulphated while taking into account the different proposed cuts. Thus, mining reserves taking into account mining recovery and dilution will be obtained as well as the volume and average copper content.

3. Results and discussions

3.1 Construction of the mineralized body by compilation and analysis of the survey type data

After compilation under access of Surpac and analysis of 321 surveys; we have the mineralized body.

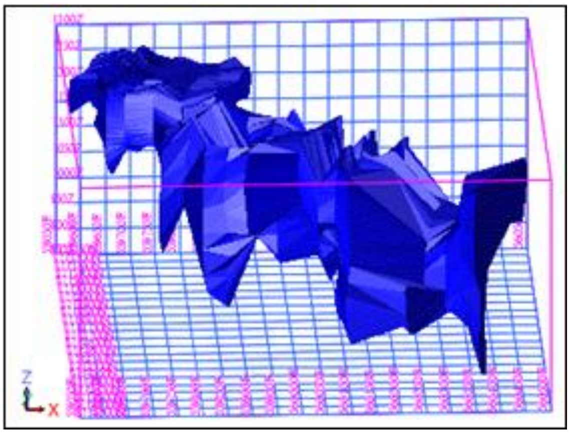

Figure 5: Ruashi II and III mineralized body in XZ plane

Table 1: Mineralized body results

Solid modeling object report			
Layer Name		Mineralized body	
Object		2	
Trisolation		2	
Validated		True	
Status		Solid	
Trisolation Extents			
X Minimum	559557.644	X Maximum	560461.977
Y Minimum	8714186.62	Y Maximum	8715218.18
Z Minimum	887.829	Z Maximum	1277.435
Surface area		1678790 m^2	
Volume		54990200 m^3	

3.2 Variographic analysis of copper content values

Variographic analysis gave the different directional variograms and the preferential variance has an azimuth of 135 °, a dip of 0 and a dip of 89.9038 °. The variographic study reveals the nugdo effect of 0.246437, a bearing of 1.095237. These values are acceptable, and the variance of the block is 0.65479. This geostatistical data will allow to infer the parameters necessary for the distribution of these contents in the blocks that we carried out through the inverse distance method to easily evaluate the total resources of our project.

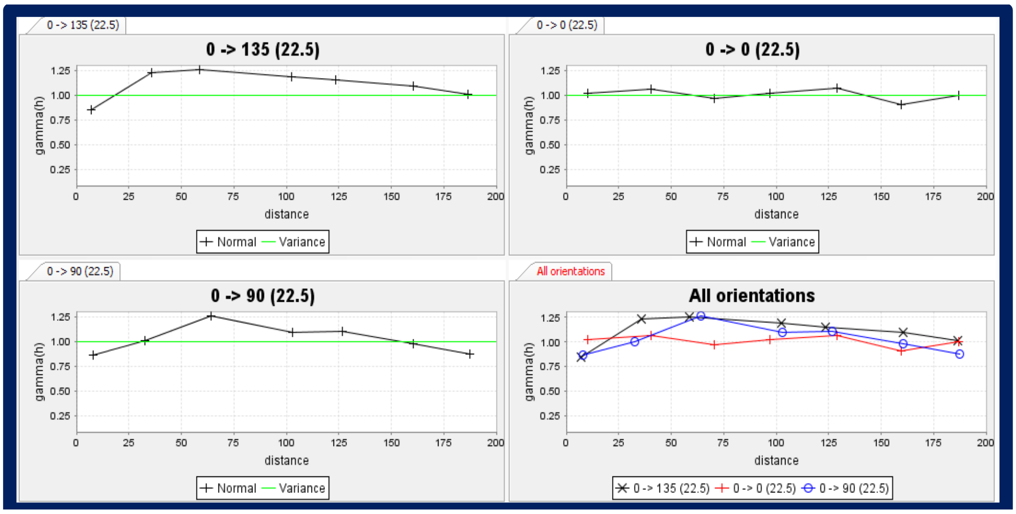

Figure 6: Results of all directional variograms

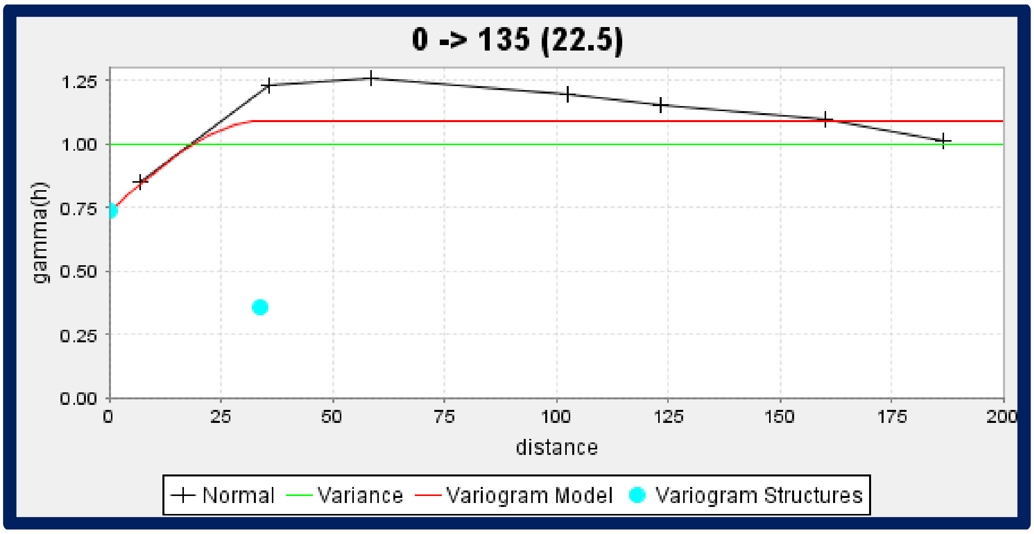

Figure 7: Model variogram after modeling

Table 2: Model variogram report after modelling

Variogram model	Spherical	
Experimental variogram type	Normalised	
Nugget	0,4905305	
	Sill	Range
Structure 1	0,8299153	39,570

For our study, the orientation variogram 22.5 degrees has the most important range.

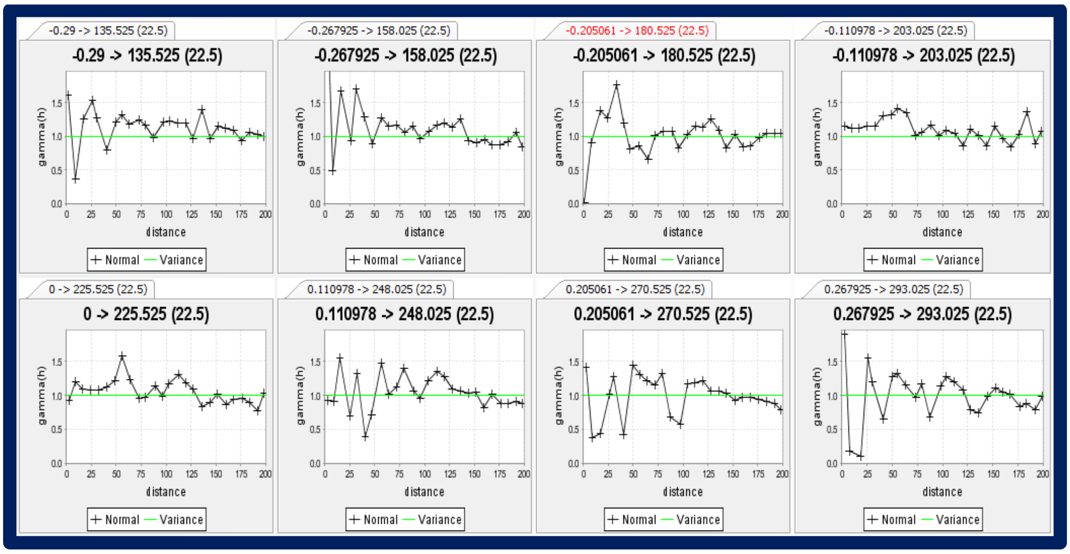

Figure 8: Various main axes of guidance 22.5

We notice, the third variogram for orientation 22.5 degrees seems to have a greater range and a lower variance, it is it that we will adjust as experimental variogram to have a considerable distance deviation.

Table 3: 2D anisotropic estimation report

Anisotropy Ellipse Parameters	
Orientation	Surpac ZXY LRL
Parameter	Value
Bearing	135
Plunge	0
Dip	89.9038
Anisotropy factors	
Parameter	Value
major / semi-major	1.5
major / minor	3
Anisotropy Ellipse Parameters	1.5/3

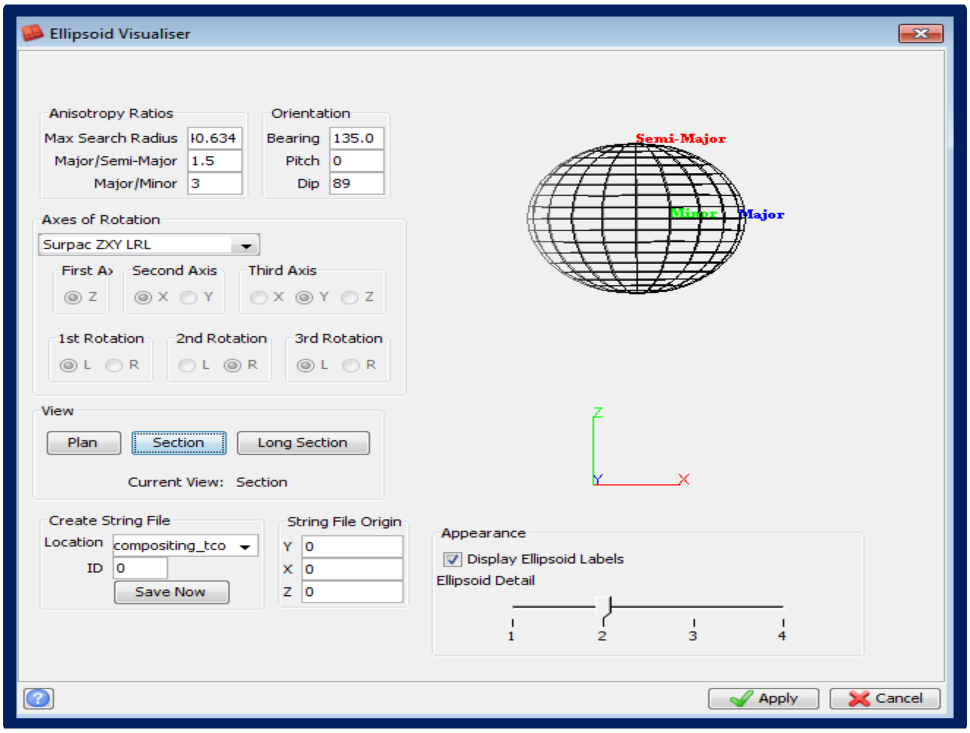

Figure 9: Variographic analysis results

Table 4: Inverse distance parameter

PARAMETERS OF THE ORDINARY KRIGING	
ANGLES OF ROTATION	
First Axis	18.5
Second Axis	-0.2
Third Axis	89.9
ANISOTROPY FACTORS	
Semi_major axis	1
Minor axis	1
OTHER INTERPOLATION PARAMETERS	
Max search distance of major axis	40.634
Max vertical search distance	999
Maximum number of informing samples	15
Minimum number of informing samples	3
ANALYSE VARIOGRAPHIQUE	
VARIOGRAM MODEL	Spherical
Cumulative sill	1.095237
Nugget effect	0.246437
BLOCK VARIANCE	0.65479

3.3 Estimation of resources

We created the model block. The dimensions of the block model are limited in X, Y, and Z coordinates of our block model from the limits of the X, Y, Z survey lot on the prospected area.

Table 5: Limit coordinates of the Ruashi II and III block model

DIMENSIONS			
	X	Y	Z
Max coordinates	561 100	8 715 290	1300
Min coordinates	560 200	8 713 740	850

To be more exact in our estimation, we considered it good to test various sizes of blocks to obtain a better calibrated block size for our deposit by comparing the tonnages of measured and indicated resources. Three cases were selected:

Resources Calculated for block sizes of 10 × 10 × 10
Resources calculated for blocks sizes of 5 × 5 × 5
Resources calculated for block sizes of 2.5 × 2.5 × 2.5

After the study of these three cases, the choice of the best block size must take into account the long-term criterion that is that of the reality of mining operations. The study shows us that, with a larger block size of 10 × 10 × 10 dimensions, we can be led to greater vagueness in the measurement of resources, and to exaggerated dilution problems during operation. With a smaller block size of dimensions 2.5 × 2.5 × 2.5 will arise a problem of the more important operating costs related to operational problems. And in addition to that the estimation methods do not show a better performance when the blocks are divided into small units. The objective is to define a model block that will highlight the quality of the evaluation and especially the quality of the optimization to come. We validate the size of blocks of dimensions 5 × 5 × 5. which give us reasonable cubings of resources in the category of measured resources and is operationally in relation to the types of equipment used in the mine. This size also allows us to minimize dilution.

Table 6: Total resources for a model block with 5 X 5 x 5 blocks

Total Resources				
Zone	**Volume**	**Tons**	**Tcu**	**Tco**
Oxydes	13 742 125	29 017 869	1.72	0.44
Mixtes	17 159 500	36 914 274	2.37	0.28
Sulfures	11 963 875	25 715 255	2.59	0.24
Total	42865500	91647397	2.23	0.32

The different attributes assigned to the model block are:

Table 7: The different attributes assigned to the model block

Bloc centroïd		
Y = 8714636,268	X = 560006,87	Z = 1230,63
Bloc size		
Y = 5	X = 5	Z = 5
Attributs	**Value**	**Description**
material_class	High_grade	Classification des teneurs par matériaux
rock_type		Type de roche
Sg	1,97089	Densité de la roche
tco	1,06	Teneur du cobalt
tcu	6,03	Teneur du cuivre
zones	oxyde	bloc oxide

And to properly arrange the work in the mine, we classified the ores in different classes of cut-off grades namely: marginal blocks – (the blocks assimilated to the sterile: grades between 0.3 and 0.9%); Low low grade blocks (blocks of low grades: grades between 0.9 and 1.9%); Low grade blocks (blocks of average grades: grades between 1.9 and 2.5%); Medium grade blocks (high grades: grades between 2.5 and 3.5%); High grade blocks (blocks of very high grades: grades above 3.5%). As minerals are very diverse with several varieties of minerals. We have divided the blocks into three zones according to the different domains obtained. The oxidized blocks of the Ruashi mine are mainly in the form of carbonate, malachite (CuCO3, Cu (OH) 2, azurite (2CuCO3, Cu (OH) 2), cuprite (Cu2O), etc. Oxidized ores are often present in the upper parts of the deposits, areas of significant alteration. These blocks depart from level 1270 to the vicinity of level 1170; The mixed blocks of this deposit are often annexed to sulphides because of their dolomitic predominance. Mixed blocks start in the vicinity of level 1180 up to level 1130; The sulphide zone, which represents the large part of the deposit in the form of chalcopyrite (CuFeS2) and bornite (Cu5FeS4), begins at the vicinity of the level 1140 m up to the level 850 m. Finally, the estimate of reserves was made by inverse distance in taking copper as the main variable and we present a synthesis of the results that ranges from 850 m to 1300 m, for a cut-off content of 0.3 copper as the main variable of this project.

Table 8: Total resources contained within the limits of our project

TOTAL RESOURCES					
Zone	Class Teneur	Volume	Tons	Tcu	Tco
Oxydes	High_grade	1624125	3517018	6.32	0.59
Oxydes	medium_grade	621750	1360287	2.97	0.53
Oxydes	Low_grade	1133750	2326214	2.21	0.39
Oxydes	Low_low_grade	3993625	8622799	1.32	0.47
Oxydes	Marginal	6368875	13191550	0.55	0.37
Sub Total		13742125	29017869	1.72	0.44

Mixtes	High_grade	3691125	8139708	6.27	0.46
Mixtes	medium_grade	1287250	2801512	2.95	0.33
Mixtes	Low_grade	1567250	3218907	2.21	0.32
Mixtes	Low_low_grade	4819250	10241408	1.36	0.25
Mixtes	marginal	5794625	12512739	0.56	0.16
Sub Total		17159500	36914274	2.37	0.28
Sulfures	High_grade	3349625	7313777	5.69	0.39
Sulfures	medium_grade	1137000	2558890	2.92	0.33
Sulfures	Low_grade	1068375	2344342	2.2	0.31
Sulfures	Low_low_grade	2917750	6374887	1.34	0.18
Sulfures	marginal	3491125	7123358	0.55	0.1
Sub Total		11963875	25715255	2.59	0.24
Grand Total		42865500	91647397	2.23	0.32

3.4 Technical optimization with pit optimize from Surpac

Because the model block does not necessarily have to contain blocks of the same size; and that each type of ore type has its own extraction cost, content and processing cost. We have techno-economical parameters to generate the pits.

1) Geotechnical data

In Surpac, the maximum angles are limited to the azimuths of the cardinal points (N-S-E-W-NE-NW-SE-SW). The slopes depend on the type of rock which gives an opportunity to bypass the definitions by geometric zones. This allows to assign a different maximum slope to these blocks according to their ' rock_type ' attribute, and to obtain different slopes according to the depths.

Table 9: The slopes considered for optimization

SLOPES									
Rock Type	-								
Rock Type	Default	North	North-east	East	South-east	South	South-west	West	North-west
Default	45	45	45	45	45	45	45	45	45

2) Economic data

The economic data are the most sensitive values determining the shape of the final pit and the cut-off grades of the ore. There are several problems when estimating the cost of processing extraction and the selling price of metal. The default starting value to be used is $7 000/ton of copper, the current market price. The price on which several discounts will be applied to observe the behavior of the different pits obtained.

a. Extraction cost ($/m^3)

The extraction cost is defined for each type of sterile rock or ore. From where we originally defined what kind of rock is sterile and ore. The pit optimize will examine each block and determine according to the selling price if it is ore or sterile.

Table 10: Copper prices considered for optimization, and different data at mine level

Sale Price Curves:				
Ore Type	Sale Price	Grade Cutoff	Default Sg	Recovery (%)
1	70	0.3	2.23	86

Table 11: Different mine data for waste rock

Waste Mining Costs:			
Rock Type	Reference Elevation	Mining Cost ($/volume)	Haulage Cost ($/volume)
Default	850	15	1

Table 12: Different mining data for minerals

Ore Mining Costs:			
Rock Type	Reference Elevation	Mining Cost ($/volume)	Haulage Cost ($/volume)
Default	850	43	1.5

b. Processing costs ($/t)

The content alone allows to eliminate from the calculation, the blocks that do not contain enough metal to be considered ore. Pit optimising Surpac will not even calculate their value, and will consider them by default as sterile. When a block contains, for example, 60% ore at 65%, the software will calculate the overall content since a block can contain only one type of rock, thus about 40%. If this content makes the processing profitable (depending on the calculation of the software) then the block will be processed. This can be a big drawback.

Table 13: Different data at the processing plant

Milling Cost Curves:			
Ore Type	Grade Value	Mill Recovery (%)	Cost ($/mass)
1	2.5	90	25

c. Metal price ($/t)

The price of metal is given in $/ton. It does not vary depending on the time. Pit optimize will handle and optimize pits containing several metals. We will set different prices for different types of ore (if these are in different blocks), containing the same metal in the deposit.

Table 14: Copper prices since 2008

Average annual copper price between 2008 and 2018	
Years	**Copper price ($/kg)**
2018	6,9894
2017	6,1687
2016	4,8648
2015	5,4892
2014	6,8607
2013	7,324
2012	7,9478
2011	8,8285
2010	7,5509
2009	5,1075
2008	6,7656
Average	**6,7179**

Different discounts

The discount percentage is that percentage that is subtracted from the selling price, and as a result, a different optimal pit is produced from the sales price obtained. The Convention that pit optimize uses when it specifies this percentage of discounts is that the positive number reduces the sales price of the ore by percentage, while the negative numbers increase the selling price of the ore by that percentage.

Table 15: different copper price discounts for optimization

Discount Factor	Original Sale Price	Discount Value $/unit	New Sale Price $/unit
-30	70	21	91
-20	70	14	84
-10	70	7	77
0	70	0	70
10	70	-7	63
25	70	-17.5	52.5
40	70	-28	42
45	70	-31.5	38.5
50	70	-35	35
60	70	-42	28

Pit generation

The pits are generated for all the technical-economic parameters of exploitation, evaluated. The optimal pits from the technical point of view offered by pit optimize from Surpac, using the $/unit method are generated by the technical optimization in the XZ plane and in the XY plane. We present in the table below the volumes directly proportional to the amount of metal extracted from the plant, for each proposed pit.

Table 16: pits optimization results with pit optimize

Pit optimization						
Output	Discount	Volume	Value	Blocs considérés	Blocs positifs	Pourcentage
pit-30-30.dtm	-30	115 992 500	8 920 569 714	42 107 793	262 282	0.62
pit-20-20.dtm	-20	111 502 875	7 897 689 802	11 109 935	231 919	2.09
pit-10-10.dtm	-10	108 940 875	6 895 364 865	11 074 018	219 237	1.98
pit00.dtm	0	103 786 625	5 909 182 116	11 053 522	206 710	1.87
pit1010.dtm	10	99 550 000	4 943 116 002	11 012 288	193 957	1.76
pit2525.dtm	25	86 899 750	3 543 151 455	10 978 395	178 044	1.62
pit4040.dtm	40	58 844 875	2 204 769 443	10 877 193	148 059	1.36
pit4545.dtm	45	56 269 750	1 835 088 349	10 652 754	113 512	1.07
pit5050.dtm	50	53 089 125	1 479 423 136	10 632 153	105 157	0.99
pit6060.dtm	60	33 693 125	845 736 056	10 606 708	84 790	0.8

These results show that there are indeed several possible projects, technically optimal and likely to be the economic optimum in the sense of maximization of profit for the parameters chosen. The knowledge of all these projects will allow us to intervene when choosing the optimum pit of other criteria than maximizing profit or profit because Surpac does not give us the power to choose the optimum pit for a project. Observing the results of table 16, we note that on a technical aspect the net value of resources is high for the largest pit and small for the smallest pit, which would mean that the best pit would be the one that takes the maximum any amount of waste rock that should be extracted. This idea is to be checked taking into account the different parameters such as sensitivity analysis. The generation of these pits obtained provides us with a guide for the continuation of the work, it gives us an idea for the sequencing of the future exploitation that allows the change of the ultimate project during the exploitation when the price of metal varies and that the project initially selected is no longer optimal. Among all these technically optimal pits obtained, which respect different constraints, some are always better than others. The idea advanced in this study is to make profitable even the smallest technically optimal pit and to emerge a maximum amount of metal, in order to obtain a maximum profit in case of variation of the price of metal on the market. The Surpac software does not provide much precision on the best pit to consider from an economic point of view, but we notice that it has given us three families of pits technically optimal or feasible taking into account the variation of the price of the copper metal course on the market. These three families will allow us to do a much more advanced study in the whittle software in the form of different projects taking into account the variation of the metal price and the different costs on the market. The first project will consist of the families of the pits taking into account the projects for which the metal course varies around $2800 per ton on the market. The second project will consist of the second family of pits grouping the technically optimum projects for which the metal course varies between $3500 to $4200, from where we take an average of $3800 as the reference price in Whittle. The study of the third project will consist of the third family of pits concern all technically optimum projects for a metal course which varies between $5250 to $9100 per ton of copper on the market. This takes us to an average of $7000 per ton.

3.5 Techno-economical optimization with whittle

The data required for the determination of the optimal pits of our deposit are in the form of a model block for which we have information on the position and the content of the ore. Attributes are the properties to use when optimizing processes in the whittle software. At this point we add the attributes for the construction of the economic model of the blocks.

Table 17: Site rehabilitation costs (Ruashi Mining)

Rehabilitation costs	
Rehab costs	0.16 $/t

Table 18: Costs of mineralurgic processing

Processing costs	
Processing costs	**25 $/t**

Table 19: Cost of placing on the market (Ruashi Mining)

Selling costs	
Selling costs	2000 $/t

Table 1: Starting extraction costs

Starting extraction costs	
Mining costs	6.75 $/m^3

The contents of the model block are exported from Surpac to whittle. The parameter file containing the technical parameters, the essential economic information and the ranges of income factors necessary for optimization has been set up in the whittle software.

Table 21: Summary of optimization parameters

Optimization settings	
Mining cost per ton	6.75 $
Processing cost per ton	25 $
Price of copper	2800 $, 3800 $, 7000 $
Selling cost	2000 $
Capital cost	100 000 000 $
Discount rate	0.1
Mining recovery	0.86
Mining dilution	0.15
Revenue factor range	0.3 to 2 at 0.02 steps
Overall pit slope angle	36 °

a) First project: family of pits with the price of copper at $2800 per ton

Optimization at $2800 per ton generated 19 candidate pits covering the range of income factor values from 0.3 to 2.

Table 22: Results of pit optimization

Optimization pit summary				
Pit	Maximum Rev Ftr	Rock Tons	Ore Tons	Strip Ratio
1	1	338216	147772	1.29
2	1	549780	225150	1.44
3	1	757003	320081	1.37
4	1	1198140	506539	1.37
5	1	2675110	1026816	1.61
6	1	3695832	1432316	1.58
7	1	4863724	2100667	1.32
8	1	7431318	2984227	1.49
9	1	26441226	6748589	2.92
10	1	49620447	13130851	2.78
11	1	63693759	17666349	2.61
12	1	78179881	22321425	2.5
13	1	94671519	26759431	2.54
14	2	113063130	32259912	2.5
15	2	117706282	34963549	2.37
16	2	128791988	38263953	2.37
17	2	133307228	40096728	2.32
18	2	147924182	44153709	2.35
19	2	193425658	50881053	2.8

The optimization process has selected a combination of resource blocks that can provide us with the largest VAN. The pit shell of the resultant pit represents the optimum pit according to the criteria used. It is this optimal pit that will then be retained for the next study. We notice that the pit most profitable pit is the ninth pit.

Table 23: Economic assessment of the pit during $2800

Economic assessment of the pit during $2800							
Pit	Open pit cashflow $ disc	Open pit cashflow	Open pit cashflow	ton input	Waste best ton	Mine life years	Internal rate of
1	9532736	9532736	9532736	213321	124894	0.11851	97.54
2	16963373	16963373	16963373	339251	210529	0.18847	174.52
3	23352084	23352084	23352084	453622	303383	0.25201	241.62
4	33406060	33406060	33406060	706172	491970	0.39232	350.59
5	54342455	54342455	54342455	1427892	1247220	0.79327	593.95
6	64175043	64175043	64175043	1906902	1788932	1.05939	657.18
7	74685515	74685515	74685515	2569419	2294309	1.42745	545.14
8	84282987	84282987	84282987	3373757	4057566	1.87431	464.33
9	85446219	85446219	85446219	6747586	19693677	3.74866	122.32
10	61868080	61868080	61868080	11182021	38438490	6.21223	23.71
11	41798017	41798017	41798017	13343063	50350778	7.41281	8.11
12	16600712	16600712	16600712	15119052	63060928	8.39947	0
13	-11985384	-11985384	-11985384	16749266	77922370	9.30515	0
14	-47746931	-47746931	-47746931	18742928	94320339	10.41274	0
15	-57193075	-57193075	-57193075	19161420	98545003	10.64523	0
16	-79615762	-79615762	-79615762	20068507	108723650	11.14917	0
17	-88699146	-88699146	-88699146	20311247	112996162	11.28403	0
18	-118050334	-118050334	-118050334	21016238	126908155	11.67569	0
19	-206571954	-206571954	-206571954	23268003	170157903	12.92667	0

The frame of the pit no. 9 was chosen as the optimal of the series of pits generated in Whittle during the optimization at $2800 per ton, because it is it that maximizes the cash flow among all the candidate pits generated. To perform this study well, according to the optimum pit selected at $2800 per ton. We varied separately the different base prices, the extraction costs, the processing costs and the marketing costs while keeping the price of copper on the market constant, the figure of the basic scenario for the copper price ranged from – 25% to 25 to check the effect of variations on the VAN. The result shows that the variation in extractions and processing costs have too much influence on profitability. The variation in sensitivity is evident in the price of the metal. This project requires a good operating sequence and is valid for large variations of the metal course. We note that the net present value of $75 850 207 is reasonable for this project, this pit maximizes profit within 3.75 years. This project has an internal rate of return of 122.32, the discount rate that cancels the net present value of the series of financial flows is exorbitant, which explains a payback period of 1.53 years.

Table 24: Results of the profitability analysis in whittle

Pit summary for pit 10	
Movement	**Tons**
Ore	6 747 586
Waste reject	19 296 147
Waste other	397 530
Total	26 441 263
Measures	
NPV	75 850 207
Life (year)	3.75
Payback (year)	1.53
Payback ratio	0.41
IRR%	122.32

These figures show us that the project carried out at $2800 per ton are good or flattering, but in view of the size of the deposit. The internal rate of return is very high, which means that we have been too selective. This project will leave a lot of ore in the basement. While the assigned objective is to take as much ore as possible while remaining in a profit margin. To make the choice of the only optimal long-term pit in this project, we thought to compare, the results obtained in Surpac and those of whittle. That is, we will need the pit that does not deviate from the pit obtained with the same basic parameters of that obtained in the software Surpac. We combined the two pits obtained and we find that the pit coming out in Whittle is smaller than that obtained in the software Surpac. This may well be explained by the Surpac providing us with a technically feasible pit and that the whittle software gives us a pit view on the economic point or profitability. In observing the cumulation proposed by the table below, the figures are really reasonable. For 4 years, 19 693 677 tons of waste rock for 6 747 586 tons of ore.

Table 25: accumulation of sterile ore from the pit realized at 2800

Accumulation of sterile ore		
Cumulative ore ton	Cumulatve waste ton	Period
1800000	10034350	1
3600000	16226449	2
5400000	18993685	3
6747586	19693677	4

The optimum pit obtained at a copper metal price of $2800 per ton considering the current costs in the market is technically feasible, but profitability is too low by seeing the size of the deposit as it is done over a short period of time. This means that this pit cannot be retained for the long term because the purpose of having a pit technically feasible and which gives us maximum benefit over a long time is not achieved.

b) Second project: pit family with the price of copper at $3800 per ton

The optimization generated 21 candidate pits covering the range of income factor values from 0.3 to 2.

Table 26: Result of the pit optimization carried out at $3800

Optimization pit summary				
Pit	Rev Ftr	Rock Tons	Ore Tons	Strip Ratio
1	1	307354	124959	1.46
2	1	752016	254335	1.96
3	1	1779652	529325	2.36
4	1	3648386	1100173	2.32
5	1	4614024	1519055	2.04
6	1	7866867	2449405	2.21
7	1	29687025	5515024	4.38
8	1	47998527	9272152	4.18
9	1	59285470	11801422	4.02
10	1	82519691	15644517	4.27
11	1	106595957	22110087	3.82
12	1	127106234	29441935	3.32
13	1	139227520	34107414	3.08
14	1	211091719	44365074	3.76
15	1	234499103	49008034	3.78
16	2	248330931	51988264	3.78
17	2	260209696	54882166	3.74
18	2	272695837	58106836	3.69
19	2	277235907	61517685	3.51
20	2	293647943	64487432	3.55
21	2	294390763	66451964	3.43

The whittle optimization process selects a combination of resource blocks that may be exposed to provide the largest VAN in an open pit for a given set of design, operation, and assumptions. The pit shell of the resultant pit represents the optimum pit according to the criteria used. It is this optimal pit that will then be used to prepare the detailed mining plan.

Table 27: Economic assessment of the pit during $3800

Economic evaluation during $3800 per tone							
Pit	Open pit cashflow $ disc	Open pit cashflow	Open pit cashflow	ton input	Waste best ton	Mine life years	Internal rate of
1	13868242	13868242	13868242	197020	110335	0.24627	144.35
2	31983997	31983997	31983997	400360	351657	0.50045	340.35
3	62067207	50443493	62019244	979780	799874	1.22472	520.52
4	101151029	107767200	99361681	1947520	1700870	2.4344	428.55
5	116923618	122762672	113417872	2576218	2037810	3.22027	381.11
6	146665343	171710344	138571444	3938295	3928576	4.92287	315.36
7	204995203	314658784	178897728	8872251	20814809	11.28473	157.12
8	226920607	251606246	177723238	13158497	34840096	16.8366	104.54
9	233970515	453244614	172580408	15211879	44073657	19.40333	85.31
10	238729165	129874364	145395594	18424856	64094932	23.59751	50.33
11	238958349	499654865	109029773	22115547	84480546	28.3534	31.78
12	238119057	7857066	84428555	24685285	102421119	32.00898	23.99
13	237430569	497799631	70599274	25776196	113451514	33.91825	20.76
14	233218315	402730251	-2801366	30616889	180475105	44.50666	9.69
15	232579698	359896742	-25966680	31814752	202684653	47.22476	7.47
16	232267025	320360165	-37335979	32388809	215942443	48.69532	6.49

17	232011661	306559507	-46816371	32785945	227424085	49.91698	5.72
18	231758211	270014042	-55953778	33206492	239489700	51.48204	4.98
19	231672721	252799596	-59595922	33298346	243937926	51.80878	4.71
20	231372274	199328418	-70065014	33753961	259894375	53.63234	3.85
21	231358160	197151669	-70754636	33759877	260631282	53.71488	3.8

The frame of the n ° 11 pit was chosen as the optimal of the series of pits generated in Whittle during the optimization at $3800 per ton, because it is it that maximizes the cash flow. The same sensitivity analysis was performed for the optimum pit obtained at $3800 per ton. We can ensure that for a metal course of $3 800/ton, the effect of changes in the various extractions and processing costs, do not have too much influence on profitability. Then we tried to play lightly with the cost of copper, while remaining within the previously established family margin, i.e. between $3500 and $4200. We made a change of 10% of the copper course, we find that the variation in sensitivity is more significant on the course of the metal. The price of copper may vary beyond ± 25%. This means that this project is valid for large variations of the metal course. In the lower or higher prices, it is optimal. This reasoning explains that this pit can be considered as an optimal pit in the long term. The net present value of 194 666 299 is reasonable for a profit in an unfavourable condition when it is known that over the past ten years the copper price has not reached this figure. This project has an internal rate of return of 45.58, the discount rate that cancels the net present value of the series of financial flows is also positive, which assures us that our project is viable. The recovery time is 4.42 years as summarized in the table below.

Table 28: Result of the pit's profitability analysis during $3800

Pit summary for pit 11	
Movement	**Tons**
Ore	22115547
Waste reject	83559785
Waste other	920761
Total	106596093
Measures	
NPV	194666299
Life (year)	15.21
Payback (year)	4.42
Payback ratio	0.29
IRR%	45.58

These figures show that the project at $3800 per ton is reasonable for a mining project in view of the size of the deposit. This study validates the project from a realistic economic point of view as did the first analysis. To make the choice of the only optimal long-term pit in this project, we thought to compare, the results obtained in Surpac and those of whittle. That is, we will need the pit that does not deviate from the pit obtained with the same basic parameters of that obtained previously in the software Surpac. By combining the results obtained in Whittle with those obtained in Surpac for the optimum pit obtained at $3800 per ton, the result shows that the two pits are identical. Despite the multiple variations in costs. We can say that $3800 is the best price to do the long-term optimization of this project.

Table 29: Accumulation of sterile pit ores during $3800

Accumulation of sterile ore		
Cumulative ore ton	Cumulatve waste ton	Period (année)
622676	8377324	1
1410455	16589545	2
2296057	24703943	3
3312272	32687728	4
4451523	40548477	5
5749010	48250990	6
7340150	55659850	7
9140150	61816971	8
10940150	66689330	9
12740150	70661465	10
14540150	74349149	11
16340150	77991671	12
18140150	80770755	13
19940150	82621489	14
21740150	84243105	15
22115547	84480546	16

Hence this pit will be chosen as the optimal long-term pit for this project because it has been technically feasible in Surpac and economically profitable in Whittle. This makes it the optimal pit sought.

c) Third project: pit family with the price of copper at $7000 per ton

We conducted a study similar to the other two, for an average base metal course of $7000 per ton of copper on the market, keeping all other costs identical. The optimization generated 45 candidate pits with the whittle software covering the range of income factor values from 0.3 to 2 as shown in the tableaux45 and 46 below.

Table 30: Result of the pit optimization carried out at $7000

Optimization pit summary				
Pit	Maximum Rev Ftr	Rock Tons	Ore Tons	Stri Ratio
1	0	124366	66656	0.87
2	0	255267	122961	1.08
3	0	468809	191193	1.45
4	0	549780	225844	1.43
5	0	757003	317289	1.39
6	0	1010084	419435	1.41
7	0	1677106	647676	1.59
8	0	1930207	745829	1.59
9	0	3118891	1193055	1.61
10	0	3954893	1522594	1.6
11	0	4719238	1844574	1.56
12	0	4932581	2091131	1.36
13	0	7065840	2788788	1.53
14	0	7794649	3130429	1.49
15	0	8617677	3511391	1.45
16	0	9891018	3943391	1.51
17	0	30088180	7431243	2.05
18	0	33117175	8413399	2.94
19	1	48370918	12169639	2.97
20	1	49497879	12960465	2.82
21	1	57709831	15248870	2.78
22	1	63084260	17158434	2.68
23	1	69445193	19113660	2.63

Table 31: Result of pit optimization at $7000 (cont'd)

Optimization pit summary				
Pit	Maximum Rev Ftr	Rock Tons	Ore Tons	Strip Ratio
24	1	78705567	21816729	2.61
25	1	89344167	24045914	2.72
26	1	94862360	25995736	2.65
27	1	110230245	30480141	2.62
28	1	116479063	32568864	2.58
29	1	118455910	34199904	2.46
30	1	127747807	37109565	2.44
31	1	132502500	38786187	2.42
32	1	134578103	40333816	2.34
33	1	192652630	48884398	2.94
34	1	197402705	51209407	2.85
35	1	218050773	57964795	2.76
36	1	243033089	63724464	2.81
37	1	256033233	69435613	2.69
38	1	270520096	72832619	2.71
39	1	276540791	75194509	2.68
40	2	287344162	77805720	2.69
41	2	296500309	80265165	2.69
42	2	300889718	82113517	2.66
43	2	306940091	83656519	2.67
44	2	308460780	84519188	2.65
45	2	309811827	85638480	2.62

The whittle software has offered us several nested pits, and we have to choose the pit that maximizes the income, like the optimum pit of this project. And it is she who will serve us the various analyses for the continuation. The tables below give us the various elements that will serve us in the choice of the optimum pit.

Table 32: Economic assessment of the pit during $7000

Economic evaluation during $7000 per ton							
Pit	Open pit cashflow $ disc	Open pit cashflow	Open pit cashflow	ton input	Waste best ton	Mine life years	Internal rate of
1	30527380	30527380	30527380	104405	19962	0.058	307.52
2	59429408	59429408	59429408	196233	59034	0.10902	601.54
3	99609965	99609965	99609965	367535	101272	0.20419	1017.63
4	112931710	112931710	112931710	423313	126467	0.23517	1157.18
5	144810496	144810496	144810496	568818	188187	0.31601	1495.44
6	177877875	177877875	177877875	752634	257452	0.41813	1855.16
7	254717572	254717572	254717572	1266628	410478	0.70368	2730.8
8	274036180	274036180	274036180	1414551	515657	0.78586	2961.27
9	384492686	383576467	383576467	2322326	796567	1.29018	2911.18
10	451563202	447631662	447631662	2967834	987059	1.6488	2607.94
11	500613578	493541618	493541618	3495886	1223356	1.94216	2461.14
12	517848260	509908870	509908870	3698118	1234468	2.05451	2416.47
13	621897568	603391801	603391801	5006971	2058876	2.78165	2044.75
14	655573285	632206164	632206164	5558903	2235749	3.08828	1951.9
15	688272112	660054286	660054286	6094007	2523673	3.38556	1830.47
16	730583688	694621011	694621011	6880366	3010658	3.82243	1755.69
17	1071366625	953330765	953330765	15595180	14493034	8.66399	1071.15
18	1109022341	976344930	976344930	16895213	16222011	9.38623	1043.35
19	1254965621	1040953007	1040953007	23270449	25100534	12.92803	887.84
20	1263493104	1042620562	1042620562	23741435	25756514	13.18969	880.5
21	1314231265	1061353211	1061353211	26533205	31176692	14.74067	846.42
22	1338904137	1057368843	1057368843	28366603	34717738	15.75922	821.75
23	1362703491	1053789386	1053789386	30351586	39093693	16.86199	791.14

Table 33: Economic assessment of the pit during $7000 (cont'd)

Economic evaluation during $7000 per ton							
Pit	Open pit cashflow $ disc	Open pit cashflow	Open pit cashflow	ton input	Waste best ton	Mine life years	Internal rate of
24	1390363769	1048245979	1048245979	32989144	45716514	18.3273	751.6
25	1412035123	1039357173	1039357173	35071374	54272909	19.58262	705.76
26	1421804618	1026765074	1026765074	36493171	58369305	20.3725	676.24
27	1442972895	993034130	993034130	40859631	69370744	23.03372	620.33
28	1449501737	978068774	978068774	42379134	74100068	23.87789	575.25
29	1451150850	974655825	974655825	42846835	75609218	24.13772	565.02
30	1457039019	950462229	950462229	44778680	82969293	25.24638	507.76
31	1459256373	935511934	935511934	45667741	86834939	25.7403	472.43
32	1460059954	926984652	926984652	46291079	88287204	26.0866	466.74
33	1462076709	790443326	790443326	54931225	137721650	33.99252	331.75
34	1462447818	773938305	773938305	55568329	141834635	34.42434	315.69
35	1462913976	709793706	709793706	57972901	160078160	36.87444	263.28
36	1462099366	636610734	636610734	60210067	182823351	39.80927	196.64
37	1461579312	602318740	602318740	61340768	194692810	40.93885	177.08
38	1460901482	565900866	565900866	62526312	207994147	42.5485	160.56
39	1460553746	554919870	554919870	62992115	213549050	43.21747	153.95
40	1459971439	524366860	524366860	63624880	223719679	44.41785	140.25
41	1459433000	507198726	507198726	64080090	232420627	45.4352	134.34
42	1459151112	499576827	499576827	64363121	236527009	45.92291	130.89

43	1458804821	480317671	480317671	64771067	242169452	46.59518	123.63
44	1458708358	477493991	477493991	64900996	243560215	46.76414	123.04
45	1458619566	471944661	471944661	65066864	244745399	46.91426	120.63

The pit shell n ° 35 is chosen as the optimum pit of the series of pits generated in Whittle during the optimization at $7000 per ton, because it is it that maximizes the cash flow in this category. The same sensitivity analysis for the optimum pit obtained at $7000 per ton. We have varied the extractions costs, processing costs and marketing costs while keeping the price of copper on the market constant, the figure of the basic scenario for the price of copper has ranged from – 25% to 25% to verify the effect of change NS on the VAN. The result shows that, we can ensure that for a metal course of $7000 per ton, the effect of changes in the various extractions and processing costs, do not have too much influence on profitability. By varying the price of metal in the range $5250 to $9100, we find that the project does not show any sensitivity compared to the copper course. This means that we can exploit all the deposit without large selection, which is detrimental to a mining operation. That is to say that we were very optimistic or that we overestimated the project. This analysis already gives us an idea of the choice of the best pit of the project, because it is not valid for the long term, the risk being too high in case of falling of the metal price on the market. We note that the net present value of $1 462 913 976 is too high, this pit maximizes profit in a period of 34 years. This project has an internal rate of return of 263.28, the discount rate that cancels the net present value of the series of financial flows is too high, which explains a payback period of less than one year as summarized in the table below:

Table 34: Result of the analysis of the profitability of the pit realized at $7000

Pit summary for pit 35	
Movement	Tons
Ore	57 972 901
Waste reject	158 651 938
Waste other	1 426 222
Total	218 051 061
Measures	
NPV	1 462 913 976
Life (year)	34
Payback (year)	0.46
Payback ratio	0.01
IRR%	263.28

These exorbitant figures show us that the project carried out at $7000 per ton was overestimated in view of the size of the deposit. And this reflection joins the results of the sensitivity analysis. This project is not valid for the long term since the change in the price of metal in the market has no impact on the project, which is wrong. We are going to perform a comparison of the results as in the other two previous cases. By combining the results obtained in Whittle with those obtained in the software Surpac for the optimum pit obtained at $7000 per ton, we find that the two pits are not identical. Despite the multiple cost variations made for the different costs of this family, the whittle pit is largely above that found in Surpac. This means that, economically, profitability is very high. This is due to the fact that the price of metal of $7000 price as the basis of the project is largely above the current operating costs in the market. We can also point out in table 50, the accumulation of sterile ore obtained in Whittle shows that a lot of waste is to be removed to arrive at an average quantity of ores. This is due to the fact that the pit has an accentuated lateral extension. Making a choice on a technical level compared to the other two pits is unacceptable.

Table 35: Accumulation of sterile ore from the pit realized at $7000

Accumulation of sterile ore					
Cumulative ore ton	Cumulative waste ton	Period	Cumulative ore ton	Cumulatve waste ton	Period
1202607	7797393	1	30334105	114173815	18
2588703	15411297	2	32134105	118337037	19
3991512	23008488	3	33934105	122307892	20
5525861	30474139	4	35734105	126263118	21
7091162	37908838	5	37534105	129987010	22
8771350	45228650	6	39334105	133511703	23
10534105	52465895	7	41134105	136945616	24
12334105	59283206	8	42934105	140071919	25
14134105	65748325	9	44734105	142987595	26
15934105	72020356	10	46534105	145763689	27
17734105	78202927	11	48334105	148524061	28
19534105	84294879	12	50134105	151192090	29
21334105	89927632	13	51934105	153737024	30
23134105	95343068	14	53734105	156018887	31
24934105	100483166	15	55534105	158021138	32
26734105	105232032	16	57334105	159684068	33
28534105	109825934	17	57972901	160078160	34

The results show that the optimum pit obtained at a copper metal price of $7000 is economically profitable but technically not feasible and then exceeds the limits assigned by the first study. If we go beyond the limit, we will have to expand the mine, which leads to a lot of waste rock. Based on the results obtained in the various analyses above, we find that the first project carried out at $2800 has a good economic sensitivity in the short term. And the technical study shows us that the project is feasible, but profitability is not continual until the end of this project. The project carried out at $7000 is however that profitability is long term but that the project is not technically feasible because the extension of the pit is too accentuated and exceeds the optimum limits of the technical optimum. The consequence is that one is obliged to take a lot of sterile and to go much deeper, which can bring stability problems. From where we chose the optimum pit of the project carried out at $3800 per ton, as the optimum pit of the long-term project of this study, since according to the analyses carried out above, it is economically profitable and technically feasible over the long end. This means that for this Ruashi II and III deposit the techno-economic parameters are optimal for a reference metal course of $3800 per ton.

3.6 Sequence of operations

The optimum pit of our chosen project, the deposit to exploit takes a definitive form. That is, a closed volume defined by an external envelope that is our optimal pit. The table below gives a default sequencing proposed by whittle.

Table 36: gross cash flow proposed by whittle

Period	ton input	Waste ton	Strip ratio	Grade input TCU	Open pit cashflow $	Open pit cashflow $ disc
1	622676	8377324	13.45	3.889	-16458465	-14962241
2	787779	8212221	10.42	3.971	3505181	2896844
3	885603	8114397	9.16	4.049	8643148	6493725
4	1016214	7983786	7.86	3.778	9711219	6632893
5	1139252	7860748	6.9	3.592	10878185	6754497
6	1297487	7702513	5.94	3.741	19720433	11131670
7	1591140	7408860	4.66	4.005	36897878	18934446
8	1800000	6157121	3.42	4.15	52237265	24369070
9	1800000	4872359	2.71	4.021	51793590	21965538
10	1800000	3972136	2.21	3.845	49184598	18962792
11	1800000	3687683	2.05	3.904	51617801	18091724
12	1800000	3642523	2.02	4.341	64411658	20523539
13	1800000	2779084	1.54	4.556	73350697	21247084
14	1800000	1850734	1.03	4.587	77075591	20296412
15	1800000	1621616	0.9	4.361	70720060	16929820
16	375397	237441	0.63	4.783	17464101	4098485

Thus, the problem is to determine in which order the production of the mine is to be linked to maximize the cash flows generated during the first years of operation, and what strategy to take to saturate the processing plant at its rate and avoid peaks of the stripping ratio during the lifetime of the deposit. The whittle software can calculate using the Lerchs and Grossmann algorithm the best possible scenarios for the proper management of this chosen pit. Whittle studies two scenarios: the worst case would be to undermine all sections of the first bench starting with that of the smallest pit, then to undermine the sections of the second bench and so on. That means we're not going to get the ore first. Incomes begin to be considerable only towards the end of the mine's life; the best case would be to undermine all successive benches of the smallest pit then to undermine successive benches of the second pit and so on. That means we're going to get the ore as fast as we can. Once a sequence of operations is determined according to the two cases mentioned, it is possible to orient the production to the places that seem the most promising and it is known from the outset that the net present value of the project will be somewhere between the worst case and the best case. Sequencing is based on the principle of dominance, meaning that one solution dominates another, or that it is better than another if it provides a better profit and a smaller volume.

Table 2: Cash flow proposé par séquence des push-backs

Period	ton input	Waste ton	Strip ratio	Grade input TCU	Open pit cashflow $	Open pit cashflow $ disc
Push back 1						
1	1414878	7585122	5.36	4.234	27981381	25437619
2	1800000	6360468	3.53	4.235	54714633	45218704
3	1800000	3889836	2.16	4.249	62785066	47171349
4	1800000	2183796	1.21	4.877	85879321	58656732
5	1800000	752816	0.42	5.137	97489518	60533321
Push back 2						
6	479454	8520546	17.77	6.255	6519454	3680061
7	931336	8068664	8.66	3.249	-926881	-475637
8	1800000	4293968	2.39	3.808	47942913	22365723
9	1800000	1772212	0.98	3.905	58311245	24729660
10	1745829	7254171	4.16	4.242	45326836	17475457
Push back 3						
11	333410	8666590	25.99	1.993	-25431887	-8913722
12	664416	8335584	12.55	2.407	-18225594	-5807236
13	1426538	7573462	5.31	2.77	-612289	-177358
14	1800000	6378840	3.54	3.893	41378244	10896185
15	1800000	2318193	1.29	4.182	63140560	15115348
16	719687	526278	0.73	4.881	34480425	7945705

The industrial value of a mining project is primarily based on its ore reserves. It is imperative to inventory and quantify the materials contained in the operating project. These are the recoverable reserves of the ore and the sterile contained in the operating project. The mining reserves concern the parts of the deposits subject to economic constraints. The optimum pit was determined using the whittle software, and then we divided our operating sequence into 3 push-backs to reach the optimum pit. The valuation of the mining reserves contained within the limits of the pit is carried out under the software Geovia Surpac, at the cut-off content used by the company of 0.3% copper content. We will make an estimate for each push back, by determining the different areas and different grades of cuts.

Table 38: Quantity of materials in the push-back1

PUSH BACK MATERIALS 1					
Zone	**Class Teneur**	**Volume**	**Tons**	**Tcu**	**Tco**
Oxyde	High_grade	873000	1892134	7.55	0.57
Oxyde	Medium_grade	375000	832195	2.94	0.58
Oxyde	Low_grade	349000	760313	2.16	0.43
Oxyde	Low_low_grade	1630000	3538435	1.28	0.55
Oxyde	Marginal	2226000	4736625	0.58	0.5
Oxyde	Waste	4660500	9434425	0.07	0.15
Sub Total		10113500	21194128	1.2	0.35
Mixte	High_grade	1308000	2848833	7.53	0.51
Mixte	Medium_grade	349000	784639	2.96	0.35
Mixte	Low_grade	294000	666343	2.19	0.31
Mixte	Low_low_grade	581000	1246557	1.39	0.39
Mixte	Marginal	366000	814405	0.56	0.4
Mixte	Waste	299000	588437	0.06	0.04
Sub Total		3197000	6949213	3.93	0.39
Grand Total		**13310500**	**28143341**	**1.86**	**0.36**

Total mineral reserves are valued at 8 351 000 m3 for a tonnage of 18 120 479 tons of ore. The total quantity of waste rock is quantified at 4 959 500 m3 for a tonnage of 10 022 862 tons.

Table 39: Quantity of materials in the push-back2

PUSH BACK MINIERES RESERVES 2					
Zone	**Class Teneur**	**Volume**	**Tons**	**Tcu**	**Tco**
Oxyde	High_grade	200000	424439	4.72	0.78
Oxyde	Medium_grade	97000	216540	2.93	0.54
Oxyde	Low_grade	111000	254015	2.18	0.51
Oxyde	Low_low_grade	358000	806627	1.37	0.41
Oxyde	marginal	756500	1585884	0.55	0.52
Oxyde	waste	2294000	4729547	0.03	0.04
Sub Total		3816500	8017052	0.64	0.24
Mixte	High_grade	1229000	2785900	5.78	0.37
Mixte	Medium_grade	357000	789673	3	0.29
Mixte	Low_grade	280000	634283	2.2	0.23
Mixte	Low_low_grade	582000	1252029	1.39	0.25

Mixte	marginal	624000	1449949	0.59	0.27
Mixte	waste	1249000	2528504	0.03	0.02
Sub Total		4321000	9440338	2.32	0.22
Sulfure	High_grade	168000	408599	6.04	0.21
Sulfure	Medium_grade	45000	103906	3.07	0.16
Sulfure	Low_grade	13000	28136	2.13	0.15
Sulfure	Low_low_grade	25000	51882	1.42	0.08
Sulfure	marginal	51000	126665	0.62	0.03
Sulfure	waste	33000	64522	0.01	0
Sub Total		335000	783710	3.72	0.14
Grand Total		**8472500**	**18241100**	**1.62**	**0.23**

Total mineral reserves are valued at 4 896 500 m3 for a tonnage of 10 918 527 tons of ore. The total quantity of waste rock is quantified at 3 576 000 m3 for a tonnage of 7 322 573 tons.

Table 40: Quantity of materials in the push-back3

PUSH BACK 3					
Zone	**Class Teneur**	**Volume**	**Tons**	**Tcu**	**Tco**
Oxyde	High_grade	12000	23450	5.19	0.22
Oxyde	Medium_grade	5000	10664	3.37	0.05
Oxyde	Low_grade	13000	26631	2.17	0.12
Oxyde	Low_low_grade	58000	119880	1.2	0.18
Oxyde	marginal	106000	213739	0.49	0.06
Oxyde	Waste	476000	964338	0.03	0.01
Sub Total		670000	1358702	0.36	0.04
Mixte	High_grade	481000	1062602	5.2	0.43
Mixte	Medium_grade	175000	384510	2.96	0.27
Mixte	Low_grade	177000	361209	2.22	0.23
Mixte	Low_low_grade	576000	1258345	1.42	0.23
Mixte	Marginal	639000	1392850	0.55	0.36
Mixte	Waste	1790000	3511164	0.02	0
Sub Total		3838000	7970679	1.27	0.18
Sulfure	High_grade	570000	1284230	6.17	0.44
Sulfure	Medium_grade	108000	250360	2.9	0.45
Sulfure	Low_grade	70000	160856	2.19	0.46
Sulfure	Low_low_grade	105000	224330	1.41	0.14
Sulfure	Marginal	134000	301049	0.6	0.12
Sulfure	Waste	610000	1173765	0.01	0
Sub Total		1597000	3394591	2.8	0.24
Grand Total		**6105000**	**12723972**	**1.58**	**0.18**

Total mineral reserves are valued at 3 229 000 m3 for a tonnage of 7 074 705 tons of ore. The total quantity of waste rock is quantified at 2 876 000 m3 for a tonnage of 5 649 267 tons. The measured mineral reserves contained in our project were determined at a cut-off content exceeding 0.3%, the cut-off content at the mine. These total reserves are presented in the table below.

Table 42: Total mining reserves

TOTAL MINING RESERVES				
Zone	**Volume**	**Tons**	**Tcu**	**Tco**
oxyde	11408500	24149239	1.85	0.49
mixte	9767000	21350643	3.12	0.34
sulfure	1342000	3050103	4.27	0.32
Grand Total	**22517500**	**48549986**	**2.56**	**0.41**

The optimum long-term pit will provide us 22 517 500 m3 and 48 549 986 tons of ore. The average copper content is estimated to be 2.56 and an average cobalt content of 0.41.

4. Conclusion

This study focused on the optimization of pits, the search for the optimal long-term pit for the profitability of the Ruashi II and Ruashi III scales of the Ruashi mine. These two scales are exploited by the company Ruashi Mining located 15 km from the post Office of the city of Lubumbashi, in the Democratic Republic of Congo. The goal was to look for a single project, the optimal long-term pit, the pit that will be technically feasible and economically profitable to maximize the benefit over the lifetime of the mine. To achieve this goal, several data were collected within the company Ruashi Mining. The geological data base which contained several information on the different surveys carried out in recent years on the study site, the geotechnical data, the economic data such as the different extraction costs, the costs of processing at the factory, the costs of placing on the market in order to get our results as accurately as possible. To achieve the best results, the work began with the Organization of the data, creating a database from all the information to our possession on the polls in order to show the distribution of the mineralization in our deposit . We created the solid using the Surpac software that represents the Ruashi II and III mineralized body. Then to make a good estimate of the resources of the deposit, a study of the variability of the copper content was carried out, defining its distribution through different statistical and geostatistical studies and the method of interpolation chosen to achieve good results was the inverse distance method. These results served as interpolations parameters for estimating total resources. For the construction of the model block, some simulations have been done to obtain a model block that reflects the reality of the terrain, failing that which we have not had at the company level. To be more exact in our estimation, the size of the blocks has undergone different variations. In the choice of the best block the observation carried out is that with large blocks, we can be led to a greater vagueness in the measurement of resources on the ground, the vagueness linked much more to problems of exaggerated dilution during the operation. And with much smaller blocks, we can be led to a problem of more important operating costs related to operational problems. The model block chosen is the one whose size is 5 × 5 × 5 because it gives us a reasonable cubage on average of the three. At the exit of this study, the total mineral resources contained within the limits of our project are estimated at 42 865 500 m3 for a tonnage of 91 647 397 t, with a mean weight content of 2.23% in copper and 0.32% cobalt. Then a first optimization was made with the software Surpac. Starting from the current costs on the market, while placing ourselves in the most unfavourable conditions possible in order to give a scenario as profitable as possible, sheltering any possible fluctuation of the copper price on the market. The price of the starting copper in the software Surpac pit optimize was the current course of $7000 per ton on the market, to which we applied several discount. The results showed that there are several possible technically optimal projects that can be carried out on the ground. But these results have not allowed to fix an optimal pit, because with Surpac it is the pit that takes the most ore that automatically gives the great benefit. This is what to check with the whittle software in the economic study. The generation of these pits with the software Surpac served as a guide, since it grouped all these pits into three families. This gave the idea to create three types of projects starting from the different families of the pits for the continuation of the study. The first project brings together all the pits for which the average copper price varies in the market around $2800 per ton. The second project consists of the pit family for which the average copper price varies between $3500 and $4200. The price chosen is $3800 price as average. And for the third family project, it gathers all the pits whose price varies between $5200 and $9100. The average was retained at $7000 for this category. With the whittle software, a second optimization could be carried out on a more economical aspect, taking into account separately these three projects constituted. Several analyses were carried out to make the choice of the best pit, the one that maximizes profit while remaining technically feasible. The optimum pit of the second project carried out at $3800 was retained as the optimum long-term pit for this study, and the starting cost for obtaining the best pit of this deposit was fixed at $3800 per ton of copper. This means that for this Ruashi II and III deposit, the techno-economic parameters are optimal for a reference metal course of $3800 per ton. Then an operational sequence analysis was carried out to orient the production to the places that seem to be the most promising. The best case would be to undermine all successive benches of the smallest pit and then undermine the successive benches of the second pit and so on. That means we're going to get the ore as fast as we can. The distribution of the sequence was made by the principle of dominance and three push-backs were retained, and a finding not to be overlooked was observed. The net present value rose from $194 366 299 to $313 851 912. And finally, the amount of materials to extract in each push back has been determined. For the push-back, we have a volume of 8 351 000 m3 for a tonnage of 18 120 479 tons of ore. And the total quantity of the waste rock is quantified at 4 959 500 m3 for a tonnage of 10 022 862 tons. For the push-back 2, a volume of 4 896 500 m3 for a tonnage of 10 918 527 tons of ore. The total amount of waste rock is quantified at 3 576 000 m3 for a tonnage of 7 322 573 tons. For the push-back 3, a volume of 3 229 000 m3 for a tonnage of 7 074 705 tons of ore. The total quantity of waste rock is quantified at 2 876 000 m3 for a tonnage of 5 649 267 tons. And finally the mining reserves contained within the limits of the optimum long-term pit. These measured reserves contained in the project were determined at a cut-off content exceeding 0.3%, the pit contains a volume of 22 517 500 m3 and 48 549 986 tons of ore. The average copper content is estimated at 2.56% and an average cobalt content of 0.41%.

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