Journal of Mining Engineering and Research. 1 (2): 94-103. December, 2019 www.j-miner.com
doi:10.35624/jminer2019.01.10

Economic potential of new ore products in processing plant operations: A case study from midsize prospects, Atacama Chile.

Juan Daniel Silva
Mining Engineer, PhD in Geology. Professor at the Universidad Adolfo Ibáñez.

Patricio Toledo
Geologist, PhD in Geophysics. Professor at the Adolfo Ibáñez University.

Daniela Holzmann
Mining Engineer. Research Engineer at the Adolfo Ibáñez University.

ABSTRACT: This paper proposes a methodology to evaluate the economic potential of mining prospects with a 'multi-product' approach. The National Mining Company (ENAMI) is a Chilean producer traditionally engaged in copper, silver and gold production and commercialization. Using this methodology it has been possible to identify other commodities with greater geological, market and technological potential. Prospects studied were valued using economic-mining criteria such as the cut-off grade, marginal cut-off grade and equivalent grade. In this work, thirteen commodities were analyzed and seven of them stand out: molybdenum, lithium, iron, bismuth, tungsten, rare earths (REE) and titanium. For every commodity, it is essential to know the geological characteristics of the prospect, the mining and processing technologies, the purchase point closest to the prospect and the market for these commodities. The sources of information are public bodies specialized in these matters, such as the National Geology and Mining Service, SERNAGEOMIN; the Chilean Copper Commission, COCHILCO. Sixteen ENAMI prospects were valued based on the proposed methodology and six of them presented the greatest economic potential: Salado Norte, Cerro Negro, Pazota, Pastenes, Laura–Laurita and Carmen Sur.

KEYWORDS: Cut off grade, multiproduct treatment, midsize prospects.

1. INTRODUCTION: CUT-OFF GRADE

To determine if a project is profitable, there are several factors to consider; among them, a fundamental one is the cut-off grade (COG) of the ore.

The determination of the cut-off grade is defined by economic factors such as the price of the metals to be extracted, mining cost, processing cost, fixed costs, interest rate, etc.; and metallurgical factors, such as the type of product, the process, capacity, recovery of the ore, impurities, by-products, etc.

Nowadays, there are several complex mathematical models which allow to determine the optimal cut-off grade that maximizes the net present value of a mining project. However, this optimal cut-off grade is unique and variable in time, because it has associated costs that are also variable over time, such as price, mining costs, etc.

The cut-off grade of a deposit is the criterion normally used in the mining operation to discriminate between the mineral that is feasible to extract obtaining economic benefit from the deposit, and the waste one. Everything below this value is treated as waste, and anything above is considered usable ore. The COG is the grade where the income obtained by the product equals the costs of extracting it, which is known as the break-even point.

Within the framework of the cut-off grade, and based on the method that will be explained in detail later, a calculation of this indicator was developed for each prospect, which will be of great help to evaluate the potential of the prospect a priori and to elaborate the production plan in the future.

2. OBJECTIVES

2.1 General objective

To develop an analysis of the valuation criteria for the prospects studied in the Atacama Region, identifying economic cut-off grades of these prospects, based on the seven commodities of interest: Molybdenum, Lithium, Iron, Bismuth, Tungsten, Rare earths elements (REE) and Titanium.

2.2 Specific objectives

For the development and validation of this methodology, it is intended to:

- Define key concepts for the valuation of new ores in a processing plant.
- Study and define criteria to value mining prospects.
- Define the process for valuing prospects in order to prioritize them economically.

3 SCOPE

The proposed analysis shows the 'economic potential' that each prospect has according to the fulfillment of certain conditions that consider basic evaluation concepts such as the cut-off grade, marginal cut-off grade and equivalent grade, among others. It should be noted that the term 'economic potential' refers to the a priori potential that a prospect has, and it is in no case an assertion about whether the project is profitable in its entirety. It must be borne in mind that for this to happen, not only must the cut-off grade indicator be studied, but many other factors must also be considered when analyzing the profitability of the prospect; therefore, the concept used refers to an approximation of the economic potential of the project.

It should also be mentioned that the data and values entered in the different formulas are subject to changes over time; therefore, prospects that have a greater economic potential may also undergo modifications in the same way in the future.

Finally, it should be considered that the mining, processing, treatment, refining and commercialization costs are estimated data because there is no public or specific information about this point; hence, other studies of greater detail are needed in order to complete the remaining values with valid information.

4 METHODOLOGY

Before explaining the methodology, it is necessary, first, to define certain fundamental concepts that will help to better understand it.

4.1 Key concepts for valuation

4.1.1 Definition of resources and reserves

A mineral resource is defined as a concentration or occurrence of natural, solid, inorganic or fossilized organic material in or on the Earth's crust, in such form, quantity and quality, that there are reasonable prospects for eventual economic extraction. The location, tonnages, quantity of elements or ores of interest, geological characteristics, and the continuity of the mineralization is estimated, known or interpreted from specific geological, metallurgical and technological evidence (CCCRRM, 2015).

These mineral resources can be identified and estimated through exploration, recognition, and sampling. According to the existing level of confidence, resources can be classified as Measured, Indicated, and Inferred.

A mineral reserve is defined as the part of the Measured or Indicated Mineral Resource that is economically extractable according to a productive, environmental, economic, and financial scenario derived from a mining plan and in whose evaluation all the modifying factors have been considered (mining, metallurgical, economic, financial, commercial, legal, environmental, infrastructure, social and governmental). Mineral Reserves include losses and dilutions with adjacent material surrounding that part of the Mineral Resource and which contaminates it due to mining extraction. As the Mining Resource, Mining Reserves can be categorized into Proved Reserves and Probable Reserves, where the former has a higher level of confidence (CCCRRM, 2015).

4.2 Criteria for valuing the prospects

At present, reserve classification systems used, are based on geological confidence and economic viability.

For this purpose, there are different geological resources classification systems in the literature, which are used by applying qualitative and quantitative variables. These variables are used to determine the level of recognition of geological. There are two main methods for categorizing ores.

4.2.1 Traditional or classic criteria

Which uses the following criteria:

- Geological continuity.
- Density of the exploration grid.
- Interpolation against extrapolation.
- Technological considerations
- Data quality.

4.2.2 Geo-statistical criteria

Which uses the following criteria:

- Range of the variogram: it allows to quantify the level of correlation between the samples located in a certain mineralized zone. The degree of this correlation is commonly used to classify resources and reserves.
- Kriging variance: Kriging allows to obtain the estimation of the value of a block and the error of this estimate.

4.3 Valuation standards

There are minimum standards for public reports of ore exploration results, mineral resources and ore reserves, which are established in the JORC Code (Stephenson, 2001).

This Australian code provides a mandatory system for the classification of the results previously mentioned according to the levels of confidence in geological knowledge and technical and economic considerations in public reports.

The purpose of preparing public reports in accordance with the JORC code is to inform investors or potential investors and their advisors; and they include, among other things, annual and quarterly company reports, press releases, information memoranda, technical documents, website postings and public presentations of Exploration results, Mineral resources and Mineral reserves estimates.

4.4 Cut-off grade (COG)

It is defined as the lowest grade that mineralized body can have so that when extracted, economic benefit is obtained. The material that contains commodities of interest above the cut-off grade is sent to the plant to be processed, the rest is considered waste and sent to dumps (Rendu, 2014).

4.4.1 Break-even cut-off grades

There are various ways to calculate a COG, in Formula 1, the break-even cut-off grade G is defined as:

$$G = \frac{C_M + C_P + C_T * d}{R(P - S)}, \qquad [1]$$

where*:*

C_M Mining cost, USD/ton

C_P Processing cost, USD/ton

C_T Transport cost, function of distance from the nearest purchase point, USD/(ton*km).

P Ore price, USD/ton

S Refining cost, USD/ton

R Ore recovery

d Distance km

The numerator of the formula is the mining cost, which includes drilling, blasting, loading and transport; the processing cost that considers the metallurgical processes through which the ore has to pass to be a marketable product; and finally the cost of transportation of the finished product from the plant to the nearest point of purchase. This is defined as the distance in kilometers multiplied by an average factor set to 0.3 USD/km /ton, considering the available information provided by ENAMI.

It must be considered that the mining cost and the processing cost are variable throughout the life of the mine since the transport distances of the extracted material are variable and the ore processing in the plant varies depending on the ore by which it is fed; this is caused by the depth which it is being mined, so for both costs the best possible estimate must be used.

The cut-off grade of the final pit or Mine COG is given by:

$$G_M = \frac{C_M + C_P}{R(P - S)}, \qquad [2]$$

that is, it does not count transportation. And the Processing cut-off grade or Mill COG is given by:

$$G_P = \frac{C_P}{R(P - S)}, \qquad [3]$$

that is, it does not count mine costs.

Formula 2 ensures that no material is exploited from the mine, unless all the direct cost associated with obtaining and marketing the ore is recovered. Formula 3 is used once the blocks destined for mining have been selected with the first equation in order to reach the highest grade ore blocks, independently of the mining expenses incurred (Lane, 1988) (Rendu, 2014).

4.4.2 Marginal cut-off grade

Also known as the operational grade, it is defined as that which is below the cut-off grade, but over waste. In this case, the marginal material is not taken to the dumps, but stored for the option to process it in the future. This grade is used for by-products. Therefore the Operational COG is given by the Formula 4:

$$G_O = \frac{30\%\ C_P}{R(P - S)}, \qquad [4]$$

The calculation of the marginal cut-off grade is practically the same as in the processing cut-off grade, but the mining and transport costs are equal to zero because they are paid by the main ore. Besides, the by-product processing cost is 30% of the main product processing cost.

4.4.3 Equivalent grade

This concept includes the main product and the by-products so that, using a calculation mechanism, the grades of the by-products are converted into the equivalent of the main product (Rendu, 2014), as shown in Formula 5:

$$G_E = G_1 + G_2 f_2 + G_3 f_3 + \cdots, \qquad [5]$$

with:

$$f_n = \frac{R_n(P_n - S_n)}{R_1(P_1 - S_1)}, n = 1,2,3,\cdots,$$

and:

G_E Equivalent grade of polymetallic ore
G_n *n-th* ore mean grade
G_1 main ore mean grade
P_n *n-th* ore price, USD/ton
S_n *n-th* ore refining cost, USD/ton
R_n *n-th* ore recovery

4.5 Valuation process

It is worth mentioning that the information reviewed and collected comes from ENAMI, which has 43 prospects in the Atacama Region (Silva, et al., 2016).Then, a study was carried out to create a method for ranking the 15 ores of interest, resulting in 7 selected ores (Silva, et al., 2017). Figure 1 details the process used to value these prospects.

Identifying the type of deposit: First, a prospect is selected and its type of deposit is identified.

Deposits vary greatly in shape, size, ore content, economic value and origin. Consequently, it is difficult for all of these factors to fit in their own category, so the type of classification used will depend on the following predominant factors (Silva, et al., 2017). The porphyry category grouped the deposits with characteristics of volcanic and granitic rocks and different sub-classifications of porphyries (Camus & Dilles, 2001); the iron-oxide-copper-gold (IOCG) classification included deposits in the iron metallogenic belt in the third region (Oyarzun, et al., 2003), (Sillitoe, 2003); salt flats included brine deposits (Houston, et al., 2011); and rare earths included those composed of lanthanides (Rhodes & Oreskes, 1999). This classification grouped the 43 initial prospects as show in Table 1.

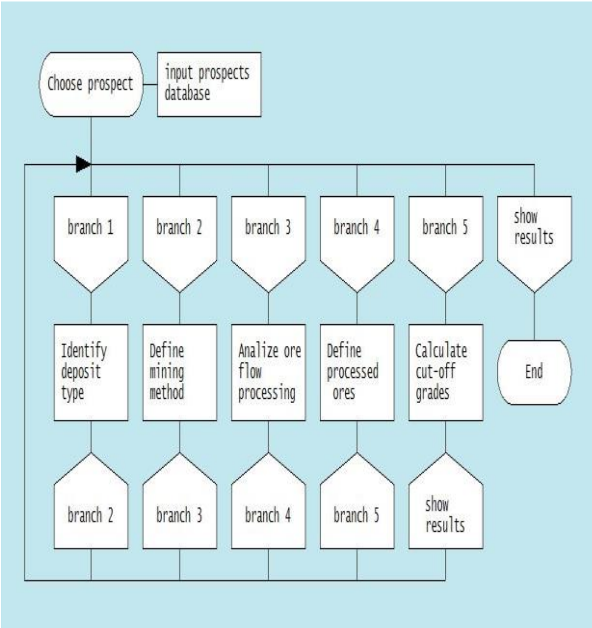

Figure 1. Prospect valuation process (Silva, et al., 2017).

Table 1. Mining prospects according to the type of deposit (Silva, et al., 2016)

Deposit type	#
Porphyries	16
IOCG	10
Unidentified	12
Brine (Salt flats)	3
REE	1
Skarn	1

Defining the mining method: After the type of deposit of the selected prospect is determined, the most appropriate mining method for this prospect is evaluated, where there are two major classifications: methods of surface mining and methods of underground mining

(Whittle & Wharton, 1995). Within these methods, there are some important ones, for example, Open pit and Quarry, on the one hand; and on the other hand, Room and Pillar, Sublevel Stoping, Shrinkage Stoping, Cut and Fill, among others. For choosing the method, a series of aspects affecting the prospect or deposit must be taken into account, such as:

- Spatial characteristics: size, shape, arrangement, depth.
- Geological conditions: drainage, mineralogy, chemical composition, structures, planes of weakness and hydrology.
- Geotechnical considerations: elastic properties, state of stress, other physical properties.
- Economic considerations: reserves, production rates, mine life, productivity.
- Technological factors.
- Environmental factors.

As it can be seen, there are many factors to consider when deciding which mining method to choose; however, the spatial characteristics (body geometry) and the competence of the rock are essential to determine the convenience of one method over another. It is worth mentioning that in cases where the deposit can be mined, either by surface or underground methods, the decision must be made based on the economic benefit obtained in each case.

Analyzing the ore processing flow: a qualitative diagram focused on the treatment of several commodities recovered from tailings and concentrates from a copper sulfide treatment plant is shown Figure 2 (Silva, et al., 2017), (Habashi, 2017).

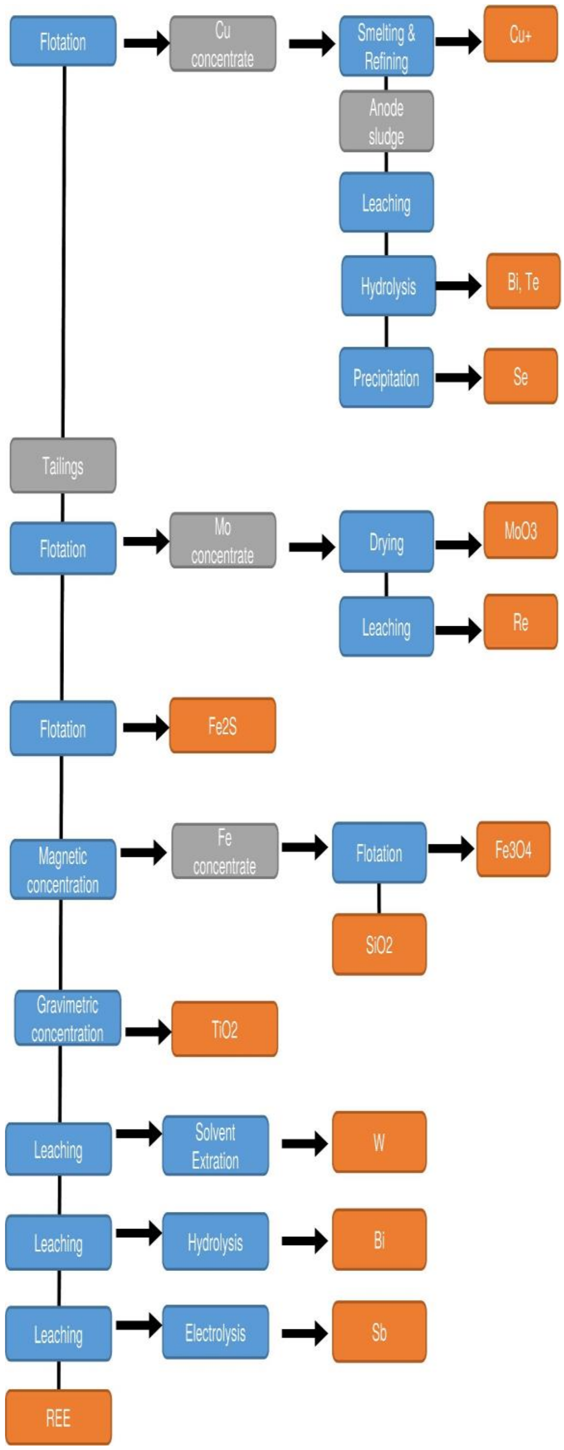

Figure 2. Qualitative diagram for a technological process for the recovery of metals from tailings and copper concentrates (Silva, et al., 2017), (Habashi, 2017).

The tailings that come from copper concentrate can be treated through a flotation and drying process to obtain, first, molybdenum trioxide (MoO_3). On the other hand, flotation residue can be floated to obtain pyrite and both molybdenum trioxide and pyrite might be leached to produce rhenium, the tailings can separate iron by magnetic concentration; then, waste can generate silica (SiO_2) by reverse flotation, and produce titanium oxide (TiO_2) by gravimetric concentration. The current coming from tailings produced by several stages of leaching allows to obtain tungsten and bismuth by solvent extraction and hydrolysis respectively. Finally, concentrates of rare earth oxides and antimony can be obtained with the final resources through successive stages of leaching and electrolysis.

On the other hand, bismuth and Tungsten can also be obtained by treating copper by fusion and electrorefining, producing anodic sludge passed through a process of leaching and hydrolysis, this process also can yield tellurium. Finally, a precipitation stage ends with selenium.

Figure 3 shows a diagram of the treatment to obtain rare earths. The treatment to obtain them involves, in the first place, a process of crushing and grinding; next, flotation, then filtering, leaching, calcination and purification.

Defining ores to be processed: In this stage of the valuation process, it is necessary to define which ores of the prospect are going to be processed according to the processing flow shown in the previous stage, that is, this flow will show which ores can be recovered and through what treatment. Also, in this stage, it is necessary to identify which ore will be considered the main one, and which will be by-products. To define this, the criterion used was based on the income Formula 6 (Lane, 1964):

$$I_n = G_n(P_n - S_n)R_n, \;\; n = 1,2,\cdots. \qquad [6]$$

By calculating the income of each ore of a particular prospect, the ore that brings the greatest economic benefit was determined, so it was chosen as the main ore or product.

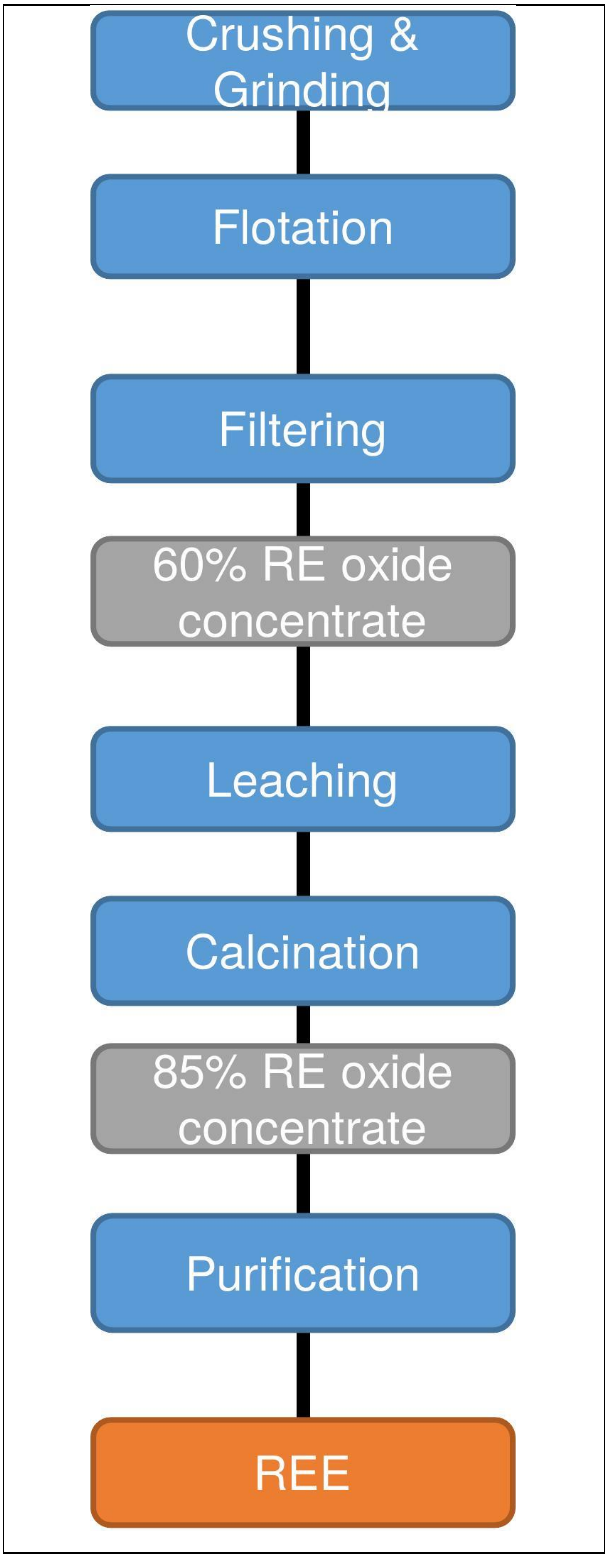

Figure 3. Diagram to treat rare earth (Silva, et al., 2017)

Also, for this choice, the following considerations must be taken into account:

- Processing flow: This flow allows us to recognize which ores are those that come out of the treatment flow first, that is, the ores that do not need many processes. These are candidates to be the main ore because they are processed and sold quickly.

- Average grade: is the concentration of the ore present in the mineralized material of a deposit. This average grade is an indicator to define the main ore because if the average grade of the ore is high, the ore is able to pay its mining costs on its own.
- Price of the ore: This is another indicator that should be considered when choosing the main ore because the higher the price, the greater the capacity to cover its mining and processing cost by itself.

Calculating cut-off grades: After defining the main ore and by-product, cut-off grades are calculated, entering values of mining Cost, processing cost, distance, prices, recovery, treatment, refining and commercialization price, among others, into the appropriate cut-off grade formulas. For the main ore, the cut-off grade is used, and for the by-products, the marginal cut-off grade is used.

Two cut-off grades will be defined: a minimum and a maximum one because the mining method to be used cannot be determined precisely, so the maximum cut-off grade is calculated with the most expensive method, whereas the minimum one, with the cheapest.

Additionally, the equivalent grade is calculated for prospects that have more than one ore.

Presentation of the results: Finally, with the cut-off grades, together with the equivalent grade or the average grade, calculated in the previous step, a brief analysis of the prospect is made.

5 OUTCOMES

This part will show the application of the valuation process of the prospects made in the previous point. It will be applied to each of the 16 prospects that present the ores of interest.

5.1 Data collection

Table 2 shows the 16 prospects, with their blurred coordinates, names, type of deposit and ores that they present.

For the mining costs of the different exploitation methods, an average of each method was considered, as shown in Table

Table 2 Prospect main characteristics (Silva, et al., 2016)

	name	deposit type	coordinates									REE			
			long	lat	Cu	Bi	Fe	Mo	Li	Ti	W	Ce	Y	Sc	La
1	Agua del Sol	Porphyry	-X0.0	-Y6.8			x								
2	Salado Norte	Porphyry	-X0.4	-Y6.3	x		x								
3	Tres Puntas	Porphyry	-X0.0	-Y6.9		x	x	x	x	x	x	x	x	x	x
4	Cerro Negro	Porphyry	-X0.5	-Y8.0	x		x								
5	Pazota	Porphyry	-X0.2	-Y6.4	x		x								
6	Las Pintadas	Porphyry	-X0.3	-Y7.6		x	x	x	x	x	x	x	x	x	x
8	Pastenes	IOCG	-X0.1	-Y6.0	x		x								
9	Laura-Laurita	IOCG	-X0.3	-Y6.5	x		x								
10	Superior	IOCG	-X0.3	-Y6.2									x		
11	Carmen Sur	IOCG	-X0.2	-Y6.4	x		x								
12	Cuprum	Porphyry	-X0.1	-Y6.4			x	x	x	x		x			x
13	Cuprum Alfa 6-7	IOCG/Porphyry	-X0.1	-Y6.4			x	x	x	x		x	x	x	x
14	Cuprum 2 alfa 5	IOCG/Porphyry	-X0.2	-Y6.3			x			x		x	x	x	x
15	Florita	IOCG	-X0.1	-Y6.3			x	x	x	x		x	x	x	x
16	Santo Domingo	IOCG	-X9.7	-Y6.7								x	x		x

Table 3 Mining cost of exploitation methods (Silva, et al., 2017)

Mining Cost	Underground						Open pit	
	Block Caving	Sublevel Caving	Sublevel Stoping	Room & Pillar	Shrinkage Stoping	Cut & Fill	Min	Max
USD/t	8	15	25	30	45	70	2	6

5.2 Proposed analysis

After applying the method created to value the prospects with their grades, the analysis carried out to value these prospects is described:

5.2.1 Equivalent grade versus cut-off grades

For prospects with more than one ore, the equivalent grade was used. This indicates the grade of the prospect considering all its ores with their average grades. The criterion is the following:

Equivalent grade < Minimum cut-off grade

The prospect is not economically feasible.

Minimum cut-off grade < Equivalent grade < Maximum cut-off grade

The prospect will be feasible depending on the scenario, that is, it will depend on the mining method chosen. If the cut-off grade is lower than the equivalent grade, the prospect is economically feasible, otherwise, it is not.

Maximum cut-off grade < Equivalent grade

No matter what mining method is chosen, this prospect will be economically feasible in all cases.

6 CONCLUSIONS

Table 4 summarizes the most relevant results of the present study.

The 16 prospects studied in this report were selected in a previous study, where a ranking of minerals by-products was made, from which 7 commodities of interest stand out, and they were the filtered to select the prospects that presented them (Silva, et al., 2017). However, to know if the prospect has economic potential, it needs to be valued, and an indicator to show this is the cut-off grade. For this reason, the valuation process created was based on the calculation of these grades.

As a result of the analysis made for each prospect, according to the criteria described, it is concluded that 6 prospects are economically feasible, which are:

1) Salado Norte

2) Cerro Negro

3) Pazota

4) Pastenes

5) Laura – Laurita

6) Carmen Sur

The remaining prospects, with the values available today, are not prospects that bring any economic benefit if their minerals are extracted and processed.

It must be taken into account that, when working with costs and prices, the cut-off grade will never be a stable indicator over time, due to the variability of these data, so it is necessary to constantly update the values.

It is important to note that the costs of processing, treatment, refining and commercialization are estimates, and perhaps some of them are away from the actual value because there is no public information; this is why the collaboration of entities involved in the matter is needed in order to complete the remaining values with valid information.

Table 4 Summary table with the results of the study

name	deposit type	method	main product	by-products	# products	distance km	min COG %	max COG %	equivalent grade %	main product grade %	by-products grade %
Agua del Sol	Porphyry	OP	Fe		1	50	0.685185	0.759259	0.000003	0.000003	
Salado Norte	Porphyry	OP	Cu	Fe	2	13	0.003155	0.003861	0.006657	0.005400	0.001257
Tres Puntas	Porphyry	UG, OP	Sc	Mo, Fe Ti, W, Bi, Ce, Y, La, Li	9	62	0.002903	0.007766	0.001183	0.000550	0.000633
Cerro Negro	Porphyry	OP	Cu	Fe	2	64	0.005853	0.006558	0.009246	0.006700	0.002546
Pazota	Porphyry	OP	Cu	Fe	2	40	0.004583	0.005288	0.025088	0.020900	0.004188
Las Pintadas	Porphyry	UG, OP	Sc	Mo, Fe, Ti, W, Bi, Ce, Y, La, Li	9	18	0.001959	0.006822	0.000978	0.000710	0.000268
Pastenes	IOCG	OP	Cu	Fe	2	45	0.004848	0.005553	0.017380	0.015000	0.002380
Laura-Laurita	IOCG	UG, OP	Cu	Fe	2	13	0.003155	0.003861	0.009266	0.008300	0.000966
Superior	IOCG	OP	Y		1	21	0.003730	0.004257	0.109900	0.109900	
Carmen Sur	IOCG	OP	Cu	Fe	2	40	0.004583	0.005288	0.012904	0.011000	0.001904
Cuprum	Porphyry	UG, OP	Fe	Mo, Ti, Ce, La, Li	5	40	0.629630	0.703704	0.099244	0.083800	0.015444
Cuprum Alfa 6-7	IOCG/Porphyry	UG, OP	Sc	Mo, Fe, Ti, Ce, Y, La, Li	7	18	0.001959	0.006822	0.001526	0.001060	0.000466
Cuprum 2 alfa 5	IOCG/Porphyry	UG, OP	Sc	Mo, Ti, Ce, Y, La, Li	6	40	0.001859	0.007294	0.000765	0.000697	0.000068
Florita	IOCG	UG, OP	Sc	Mo, Fe, Ti, Ce, Y, La, Li	7	40	0.002431	0.040835	0.001228	0.000940	0.000288
Santo Domingo	IOCG	OP	Y	La, Ce	3	70	0.005667	0.006194	0.014157	0.004918	0.009239

UG: Sublevel Stoping, Room & Pillar; Shinkrage Stoping; Cut & Fill
OP: Open Pit

ACKNOWLEDGEMENTS

We want to thank ENAMI, for providing us with the information to perform this work, and Corporation de Fomento (CORFO) for funding this work.

REFERENCES

Camus, F. & Dilles, J. H., 2001. A special issue devoted to porphyry copper deposits of northern Chile. *Economic Geology,* Volume 96, pp. 233-237.

CCCRRM, 2015. *Código para informar sobre los resultados de exploración de recursos minerales y reservas minerales,* s.l.: Comisión Minera.

CIM, 2014. *National instrument 43-101 – standards of disclosure for mineral project,* s.l.: s.n.

Habashi, F., 2017. *Principles of extractive metallurgy.* s.l.:Routledge.

Houston, J. et al., 2011. The evaluation of brine prospects and the requirement for modifications to filing standards. *Economic Geology,* Volume 106, pp. 1225-1239.

Lane, K. F., 1964. Choosing the optimum cut-off grade Q. *Colorado School of Mines,* Volume 59, p. 811.

Lane, K. F., 1988. *The economic definition of ore: cut-off grades in theory and practice.* s.l.:Mining Journal Books London.

Oyarzun, R., Oyarzun, J., Ménard, J. J. & Lillo, J., 2003. The Cretaceous iron belt of northern Chile: role of oceanic plates, a superplume event, and a major shear zone. *Mineralium Deposita,* Volume 38, pp. 640-646.

Rendu, J.-M., 2014. *An introduction to cut-off grade estimation.* s.l.:Society for mining metallurgy.

Rhodes, A. L. & Oreskes, N., 1999. Geology and rare earth element (REE) geochemistry of magnetite deposits at El Laco, Chile. In: B. J. Skinner, ed. *Geology and Ore Deposits of the Central Andes.* s.l.:Society of Economic Geologists Special Publication, pp. 299-332.

Sillitoe, R. H., 2003. Iron oxide-copper-gold deposits: an Andean view. *Mineralium Deposita,* Volume 38, pp. 787-812.

Silva, J. et al., 2017. *Identificación de procesos y tecnologías disponibles en el mercado para tratamiento de minerales diferentes a cobre, oro y plata,* Santiago: Universidad Adolfo Ibáñez.

Silva, J., Toledo, P., Poblete, J. & Sanhueza, C., 2017. *Informe técnico-económico de explotación y tratamiento de nuevos minerales,* Santiago: Universidad Adolfo Ibáñez.

Silva, J., Toledo, P., Tapia, J. & Sanhueza, C., 2016. *Informe técnico de minerales,* Santiago: Universidad Adolfo Ibáñez.

Stephenson, P. R., 2001. The JORC code. *Applied Earth Science,* Volume 110, pp. 121-125.

Whittle, J. & Wharton, C., 1995. Optimising cut-off grades. *Mining Magazine,* Volume 173, pp. 287-9.