ECONOMIC RANKING OF COPPER MINING PROJECTS AT EXPLORATION AND EARLY ENGINEERING STAGES

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ABSTRACT

Mining companies usually have several projects at different stages, from exploration targets to mines in production. Once the project has ended the advanced exploration stage, they proceed to an engineering stage (conceptual, prefeasibility and feasibility) with suitable studies to support the economic potential of each project that are added in the business development plan. Based on those studies, it is possible to rank the projects and make investment decisions about them. In contrast, for projects at exploration or early stages, available information and knowledge are weak, then there is more uncertainty about economic feasibility and prioritising of them is more complex.

In order for a mining project to successfully pass a mine operation, knowledge of several factors is required, such as: mineral resources, geological and geotechnical issues, energy and water supply, etc. This work presents a simple methodology for the economic prioritization of mining projects at early stages, which is based on the public information of copper deposits in Chile. Each deposit is characterized by their mineral resources, considering its tonnages and grades, for which their marginal distributions are modelled and then combined to define a bivariate density function of the grades and tonnages. From the bivariate density function, it is possible to obtain the probability of occurrence of a deposit with certain tonnage and grade. This allows comparing and contextualizing new deposits in size with respect current deposits and could be used to guide the investment strategy by supporting the decision-making process for the projects involved. The methodology is extensible to consider other factors beyond the resources: the depth of emplacement, coproducts, mineralization style and distance between deposits, among others.

In Chile, there are more than 586 million known tonnes of copper; Andina and Rio Blanco at Los Bronces are currently the largest districts in the world. The largest amount of copper is located in the Middle Miocene-Early Pliocene Metallogenic belt in the central Andes mountain range.

INTRODUCTION

Mining companies usually have several projects at different stages, from exploration targets to mines in production. Once the project has ended the advanced exploration stage, they pass to an engineering stage (scoping, prefeasibility and feasibility) with suitable studies to support the economic potential of each project, that are added in the business development plan. Based on those studies, it is possible to rank the projects and make investment decisions about them.

In contrast, for projects at exploration or early engineering stages there is less available information (samples, studies, knowledge, etc) that increases the uncertainty related to their economic feasibility, therefore it is complex at this point, to establish a profit/risk ranking of the projects.

In order for a mining project to successfully pass to a mine operation, knowledge of several factors is required, such as: mineral resources, contaminants, mineralization style, ore body geometry, accessibility, elevation, geotechnical issues, geometallurgic, metallurgical, process design, tailings disposal, equipment mining and process supplies, operational services, energy and water supplies, human capital, manpower, environmental condition (e.g: glacier location), social and governmental factors, political conditions, etc.

This work proposes a simple approach to ranking the prospect and projects in early stage, based on tonnage and copper grade of currently known deposits in different stages, from prospect to operation mine. The mineral resources information of mainly deposit in Chile was recopilated from public sources of the last 2 years as: annual report, financial statement, NI43 101 reports, CEO presentations, geological congress and public communications and data web.

The deposits has not differenced between “discovered” or “known”, i.e. has been fully delimited by exploration with others orebody called “open” where is possible to find more resources in certain directions [5].

METODOLOGY

Copper Mineral Resources Recollected Data

A list of main copper mineral resources has been completed with information of deposit in with characteristic different such as: prospect stage to mine operation, size, shape, region, age, mineralization type and geological context. Although the list is not include the all copper deposit of Chile, but are been included the more important copper resources today. A total 61 of deposit has been collected of which 46 are porphyry copper, Table 1. The minerals resources data include all the classifications measured, indicated and inferred.

Some prospects, the information of recourses have been reported like range of tonnages and copper grades in the official report, in these cases were considered the averages of each one.

The copper mineral resources of Division Salvador (Inca, Damiana and San Antonio) and Cluster Toki (Toki, Genoveva, Quetena and Opache) are publicly reported globally without details by deposits.

Table 1: Copper mineral resources by deposit in Chile

Name Deposit	Mton	Cu grade	Metal Cu content	Deposit Classification	Belt geological	Stage	Source
Andina	16908	0.63	106.4	porphyry Cu	Middle Miocene – Early Pliocene	mine/feasibility	Annual Report 2008
Antakena (Madrugador y Elenita)	38	0.83	0.3	Strata-bound	Jurassic - Early cretaceous	prospect	NI43 101
Antucoya	590	0.38	2.2	Strata-bound	Jurassic - Early cretaceous	feasibility	Annual Report 2008 range
Aurora	7	1.24	0.1	Strata-bound	Paleocene	prospect	Annual Report 2008 range
Brujulina	65	0.59	0.4	exotic	Middle Miocene – Early Pliocene	prospect	Annual Report 2008 range
Candelaria	391	0.55	2.2	IOCG	Jurassic - Early cretaceous	mine	Annual Report 2008
Caracoles	1100	0.50	5.5	porphyry Cu-Au-Mo	Paleocene	prospect	Annual Report 2008
Caracoles	900	0.55	4.9	porphyry Cu	Paleocene	prospect	Annual Report 2008 range
Caserones	1350	0.33	4.5	porphyry Cu	Early - Middle Miocene	prefeasibility	EIA report
Casualidad Virgo	400	0.55	2.2	IOCG	Late Eocene – Early Oligocene	prospect	Annual Report 2008
Centinela	80	0.70	0.6	porphyry Cu	Paleocene	prospect	Annual Report 2008 range
Cerro Casale	1285	0.35	4.5	porphyry Cu-Au	Early - Middle Miocene	feasibility	Camus, F., 2005.
Cerro Colorado	372	0.63	2.3	porphyry Cu	Paleocene	mine	Annual Report 2008
Chimborazo	236	0.6	1.4	porphyry Cu	Paleocene	prospect	Long, K.R., 1995
Chuquicamata	6535	0.61	39.9	porphyry Cu	Late Eocene – Early Oligocene	mine/feasibility	Slides CEO
Cluster toki	2648	0.49	12.9	porphyry Cu	Late Eocene – Early Oligocene	scopy study	Slides CEO
Conchi	550	0.61	3.4	porphyry Cu	Middle Miocene – Early Pliocene	prospect	Annual Report 2008 range
El Abra	1120	0.45	5.0	porphyry Cu	Late Eocene – Early Oligocene	mine/prefeasibility	Annual Report 2008
El Morro	487	0.56	2.7	porphyry Cu-Au	Late Eocene – Early Oligocene	prospect	Slides CEO
El Soldado	71	0.56	0.4	Strata-bound	Late Eocene – Early Oligocene	mine	Annual Report 2008
El Telegrafo	1600	0.44	7.0	porphyry Cu-Au-Mo	Paleocene	prospect	Annual Report 2008
El Teniente	16898	0.55	93.6	porphyry Cu	Middle Miocene – Early Pliocene	mine/feasibility	Annual Report 2008
El Tesoro	287	0.57	1.6	exotic	Paleocene	mine	Annual Report 2008
Escondida	8913	0.63	56.2	porphyry Cu-Mo	Late Eocene – Early Oligocene	mine/feasibility	Annual Report 2008
Esperanza	1204	0.45	5.4	porphyry Cu-Au-Mo	Paleocene	construction	Annual Report 2008
Franke	73	0.70	0.5	IOCG	Jurassic - Early cretaceous	start up	NI43 101
Hypogene Project Andacollo	464	0.36	1.7	porphyry Cu-Au	Middle cretaceous	construction	Mineria Chilena
Inca de Oro	345	0.47	1.6	porphyry Cu-Au	Paleocene	prefeasibility	Annual Report 2008
Llano Paleocanal	115	0.46	0.5	exotic	Paleocene	prospect	Annual Report 2008 range
Lomas Bayas	287	0.27	0.8	porphyry Cu	Paleocene	mine	web site
Los Bronces	2472	0.39	9.6	porphyry Cu-Mo	Middle Miocene – Early Pliocene	mine/feasibility	Annual Report 2008
Los Pelambres	4860	0.56	27.2	porphyry Cu-Mo	Middle Miocene – Early Pliocene	mine	Annual Report 2008
Los Sulfatos	1200	1.46	17.5	porphyry Cu-Mo	Middle Miocene – Early Pliocene	prospect	web site
Mantos blancos	138	0.66	0.9	Strata-bound	Jurassic - Early cretaceous	mine	Annual Report 2008
Mantoverde	155	0.51	0.8	IOCG	Jurassic - Early cretaceous	mine/	Annual Report 2008
Michilla	62	1.46	0.9	Strata-bound	Jurassic - Early cretaceous	mine	Annual Report 2008
Mina Sur	23	0.49	0.1	exotic	Late Eocene – Early Oligocene	mine	Slides CEO
Minera Gaby	1195	0.37	4.4	porphyry Cu	Late Eocene – Early Oligocene	mine	Annual Report 2008
Mirador	28	0.72	0.2	porphyry Cu	Paleocene	prospect	Annual Report 2008 range
Miranda	600	0.45	2.7	porphyry Cu	Late Eocene – Early Oligocene	prospect	Geological Congress
MM Central	1310	0.96	12.6	porphyry Cu-Ag	Late Eocene – Early Oligocene	feasibility/construction	Geological Congress
MM Sur	47	1.48	0.7	porphyry Cu-Ag	Late Eocene – Early Oligocene	prospect	Slides CEO
MMN	214	0.87	1.9	porphyry Cu-Ag	Late Eocene – Early Oligocene	scopy study	Slides CEO
Mocha	250	0.5	1.3	porphyry Cu	Late Eocene – Early Oligocene	prospect	web site
Polo sur	375	0.46	1.7	porphyry Cu	Paleocene	prospect	Annual Report 2008 range
Putilla Galenosa	540	0.25	1.4	porphyry Cu	Jurassic - Early cretaceous	prospect	Annual Report 2005
Quebrada Blca	1030	0.50	5.2	porphyry copper	Late Eocene – Early Oligocene	mine/prospect	NI43 101
Relincho	521	0.45	2.3	porphyry Cu	Paleocene	prospect	NI43 101
Rencoret	20	1.11	0.2	Strata-bound	Paleocene	prospect	Annual Report 2008 range
Rosario	2664	0.89	23.7	porphyry Cu-Mo	Late Eocene – Early Oligocene	mine	Annual Report 2008
Rosario Oeste	746	1.06	7.9	porphyry Cu-Mo	Late Eocene – Early Oligocene	scopy study	Annual Report 2008
RT	7039	0.37	25.9	porphyry Cu	Late Eocene – Early Oligocene	mine/prefeasibility	Slides CEO
Salvador	2526	0.45	11.3	porphyry Cu	Late Eocene – Early Oligocene	mine/prefeasibility	Annual Report 2008
San Enrique Monolito	3000	0.70	21.0	porphyry Cu-Mo	Middle Miocene – Early Pliocene	prospect	web site
Sierra Gorda	2080	0.416	8.7	porphyry Cu-Mo	Paleocene	prospect	NI43 101
Spence	371	0.94	3.5	porphyry Cu	Paleocene	mine	Annual Report 2008
Telegrafo norte	400	0.41	1.6	porphyry Cu	Paleocene	prospect	Annual Report 2008 range
Telegrafo sur	900	0.46	4.1	porphyry Cu	Paleocene	prospect	Annual Report 2008 range
Ujina	1762	0.65	11.5	porphyry Cu-Mo	Late Eocene – Early Oligocene	mine	Annual Report 2008
Vizcachitas	1087	0.363	3.9	porphyry Cu-Mo	Middle Miocene – Early Pliocene	scopy study	NI43 101
Zaldivar	234	0.46	1.1	porphyry Cu	Late Eocene – Early Oligocene	mine	Annual Report 2008

Copper Metal Content Approach

The metal copper content in the mineral deposit is frequently used for ranking of orebody or comparison between them. Therefore, this approach has an inconvenience or defect that is not provide an economic potential idea of the deposit, i.e. does not describe the quality of such concentration. For this is necessary to regard the tonnage and copper grade of each deposit to compare deposits in a first approach, because the same metal copper content does not guarantee the same economic feasibility. As example, the Figure1 presents a log-probability plot of metal copper content and shows two projects of the Codelco Norte district close to the same position. However, both deposits MM and Toki are clearly different in the economic evaluation. MM resources represent the very high portion of a porphyry deposit with apical high-grade breccias and Toki resources represent a low-grade disseminated ore characteristic of porphyries, wide and pervasive. Resources and Net present Value (NPV) for MM & Toki are compared in the Table 2.

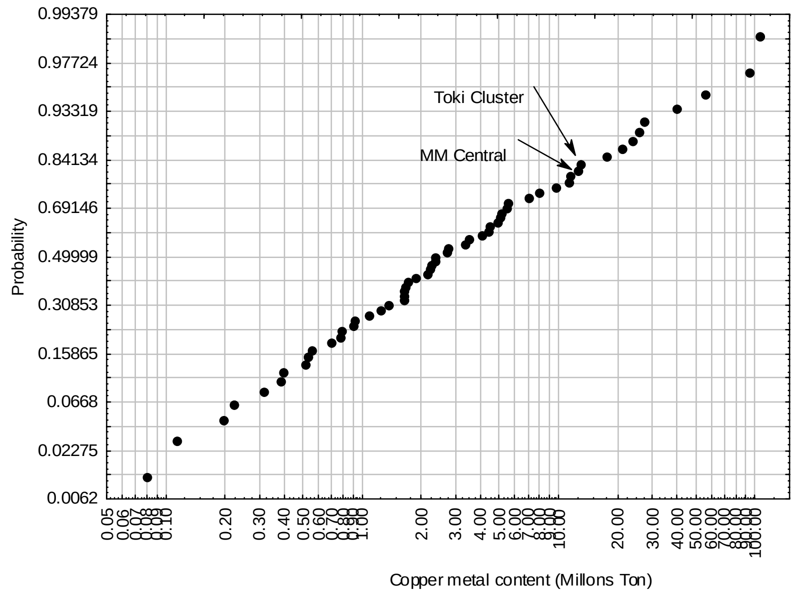

Figure 1: Metal copper content distribution in Chilean deposits

Table 2: Copper mineral resources and NPV of deposit in Chile

[redacted]

The spatial distribution of copper grade could depend on the behaviour of the disseminated stocks emplacement or concentrated in high grades mineralized bodies, product of the sources of metals where the mineralization pass through in veins or breccias for example.

ANALYSIS AND RESULTS

Tonnages and Grades – Ranking of Prospect

The deposits presented in the Table 1 are used to plot the tonnage and average copper grade, Figure 3. The lack of relation between both variables suggests that the tonnages of ore and grades average of the deposits are independent.

The deposit Chuquicamata and Radomiro Tomic (RT) were represented separately and in conjunction because of the geological point of view are same or continuous orebody, but they have different development projects for the future (underground mine versus open pit respectively).

Andina, Teniente, Chuquicamata-RT and Escondida are by far the largest copper resources deposits. Rio Blanco at Los Bronces (Andina, Los Bronces, Los Sulfatos and San Enrique Monolito) as a mining district currently represents the greatest concentration of copper in the world; however not all the resource can be ore reserves, due several factors.

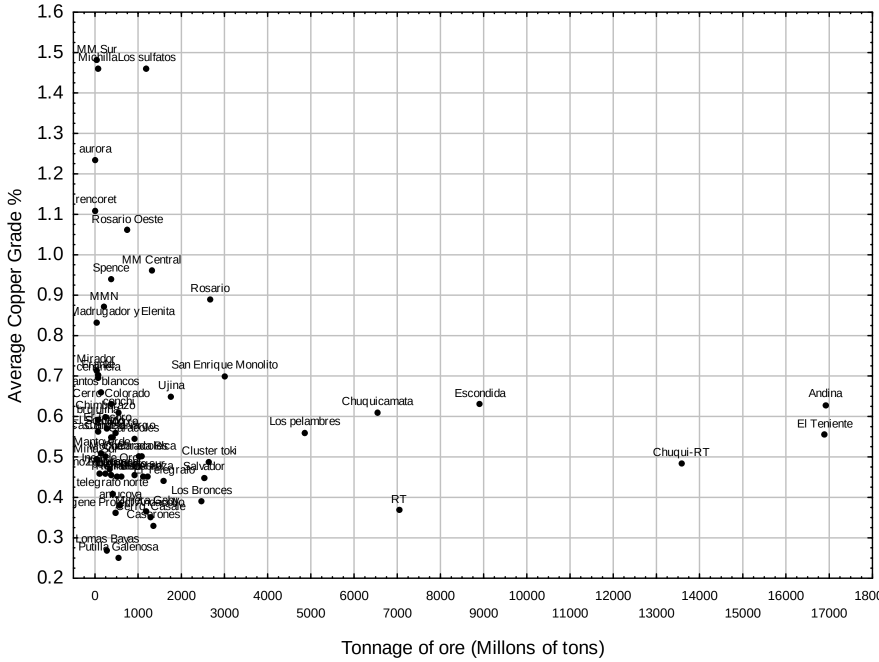

Figure 2: Tonnage versus average copper grade of ore deposit in Chile

Modelling the distributions

Two approaches were developed an empirical one where it assumed that the frequencies of tonnages and average copper grade represent their probabilities and other that model of probability density function is fit a probability density function to the data. For the tonnage an exponential distribution was used and a lognormal distribution for copper grades, shown in Figure 3.

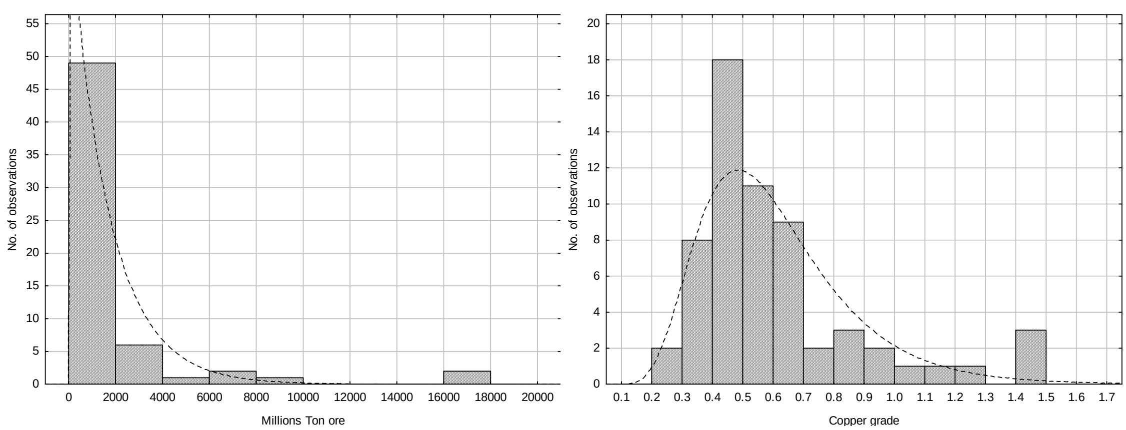

Figure 3: Histogram and fitting distribution for tonnage (right) and copper grades (left)

For the tonnage, the probability of a deposit being larger than x tonnage is given by the expression:

$$P(X > x) = Exp(-x/1692) \quad (1)$$

Where X stands for a random variable related to the tonnage expressed in million tonne (Mton) of ore.

For the grades, the probabilities of an Oligocene deposit have grades greater than is given by the expression:

$$P(Y > y) = 1 - \phi(\frac{Ln(y) + 0.571}{.391}) \quad (2)$$

Where Y stands for a random variable related to grades expressed in percentage and ϕ is the standard normal cumulative distribution function.

Using both expressions and assuming independence between X and Y, it is possible to derive the probability of a deposit have grades greater than X and tonnage larger than Y is given by the combined probability function:

$$P(X > x, Y > y) = P(X > x)P(Y > y) = Exp(-x/1692) * (1 - \phi(\frac{Ln(y) + 0.571}{.391})) \quad (3)$$

Based on the combined probability the copper mineral resources of deposits were sorted descending, Table 3. Also has been calculated the empirical probability. The order of the deposit makes senses; however evidence some limitation to compare mass and concentrated deposits for example: MM Sur is a deposit characterized for presence of high grade breccias bodies separated by host rock weakly mineralized with the copper porphyry in deep, it shows a high ranking. The ranking shows a group of deposits with tonnage greater than 2000 million tonne of ore and copper grade greater than 0.5 that have probability lower than 5%.

Table 3: Ranking of Copper mineral resources of deposits in Chile

Name Deposit	Mton Ore	Cu grade	Metal Cu content	Empirical Probability			Fitting Probability Model			
				Tonnage (a)	Cu grade (b)	combinated (a)*(b)	Tonnage (c)	Cu grade (d)	combinated (c)*(d)	Ranking
Andina	16908	0.63	106.4	1.61%	32.26%	0.5%	0.0%	39.2%	0.0%	1
El Teniente	16898	0.55	93.6	3.23%	46.77%	1.5%	0.0%	52.0%	0.0%	2
Escondida	8913	0.63	56.2	4.84%	29.03%	1.4%	0.5%	39.0%	0.2%	3
Los Sulfatos	1200	1.46	17.5	30.65%	4.84%	1.5%	49.2%	0.8%	0.4%	4
MM Sur	47	1.48	0.7	90.32%	1.61%	1.5%	97.3%	0.7%	0.7%	5
Michilla	62	1.46	0.9	88.71%	3.23%	2.9%	96.4%	0.8%	0.7%	6
Chuquicamata	6535	0.61	39.9	8.06%	33.87%	2.7%	2.1%	42.2%	0.9%	7
RT	7039	0.37	25.9	6.45%	87.10%	5.6%	1.6%	86.4%	1.3%	8
Aurora	7	1.24	0.1	98.39%	6.45%	6.3%	99.6%	2.3%	2.3%	9
Rosario	2664	0.89	23.7	12.90%	14.52%	1.9%	20.7%	12.3%	2.5%	10
Los Pelambres	4860	0.56	27.2	9.68%	43.55%	4.2%	5.6%	50.9%	2.9%	11
Rosario Oeste	746	1.06	7.9	43.55%	9.68%	4.2%	64.3%	5.4%	3.5%	12
MM Central	1310	0.96	12.6	25.81%	11.29%	2.9%	46.1%	8.8%	4.0%	13
Rencoret	20	1.11	0.2	96.77%	8.06%	7.8%	98.8%	4.2%	4.2%	14
San Enrique Monolito	3000	0.70	21.0	11.29%	22.58%	2.5%	17.0%	29.2%	5.0%	15
Spence	371	0.94	3.5	64.52%	12.90%	8.3%	80.3%	9.7%	7.8%	16
MMN	214	0.87	1.9	75.81%	16.13%	12.2%	88.1%	13.5%	11.9%	17
Ujina	1762	0.65	11.5	20.97%	27.42%	5.7%	35.3%	36.0%	12.7%	18
Cluster toki	2648	0.49	12.9	14.52%	61.29%	8.9%	20.9%	64.7%	13.5%	19
Antakena (Madrugador y Elenita)	38	0.83	0.3	91.94%	17.74%	16.3%	97.8%	16.1%	15.7%	20
Salvador	2526	0.45	11.3	16.13%	77.42%	12.5%	22.5%	72.1%	16.2%	21
Los Bronces	2472	0.39	9.6	17.74%	83.87%	14.9%	23.2%	82.8%	19.2%	22
Sierra Gorda	2080	0.416	8.7	19.35%	80.65%	15.6%	29.2%	78.3%	22.9%	23
Mirador	28	0.72	0.2	93.55%	19.35%	18.1%	98.4%	27.4%	26.9%	24
Franke	73	0.70	0.5	83.87%	20.97%	17.6%	95.8%	29.1%	27.8%	25
Centinela	80	0.70	0.6	82.26%	24.19%	19.9%	95.4%	29.8%	28.4%	26
El Telegrafo	1600	0.44	7.0	22.58%	79.03%	17.8%	38.8%	73.8%	28.7%	27
Conchi	550	0.61	3.4	48.39%	35.48%	17.2%	72.2%	42.2%	30.5%	28
Cerro Colorado	372	0.63	2.3	62.90%	30.65%	19.3%	80.3%	39.0%	31.3%	29
Caracoles	900	0.55	4.9	41.94%	58.06%	24.3%	58.7%	53.7%	31.5%	30
Mantos blancos	138	0.66	0.9	79.03%	25.81%	20.4%	92.2%	34.6%	31.8%	31
Caracoles	1100	0.50	5.5	35.48%	51.61%	18.3%	52.2%	62.2%	32.5%	32
Quebrada Blca	1030	0.50	5.2	38.71%	54.84%	21.2%	54.4%	62.2%	33.9%	33
Esperanza	1204	0.45	5.4	29.03%	74.19%	21.5%	49.1%	71.9%	35.3%	34
El Abra	1120	0.45	5.0	33.87%	75.81%	25.7%	51.6%	71.9%	37.1%	35
El Morro	487	0.56	2.7	53.23%	45.16%	24.0%	75.0%	50.9%	38.2%	36
Chimborazo	236	0.6	1.4	72.58%	37.10%	26.9%	87.0%	43.9%	38.2%	37
Caserones	1350	0.33	4.5	24.19%	95.16%	23.0%	45.0%	91.5%	41.2%	38
El Tesoro	287	0.57	1.6	69.35%	40.32%	28.0%	84.4%	49.1%	41.4%	39
Cerro Casale	1285	0.35	4.5	27.42%	93.55%	25.7%	46.8%	88.9%	41.6%	40
Casualidad Virgo	400	0.55	2.2	58.06%	48.39%	28.1%	78.9%	52.7%	41.6%	41
Telegrafo sur	900	0.46	4.1	40.32%	67.74%	27.3%	58.7%	71.0%	41.7%	42
Candelaria	391	0.55	2.2	59.68%	50.00%	29.8%	79.4%	52.7%	41.8%	43
Minera Gaby	1195	0.37	4.4	32.26%	88.71%	28.6%	49.3%	86.8%	42.8%	44
Brujulina	65	0.59	0.4	87.10%	38.71%	33.7%	96.2%	45.6%	43.9%	45
Vizcachitas	1087	0.363	3.9	37.10%	90.32%	33.5%	52.6%	87.1%	45.8%	46
El Soldado	71	0.56	0.4	85.48%	41.94%	35.8%	95.9%	50.4%	48.3%	47
Miranda	600	0.45	2.7	45.16%	72.58%	32.8%	70.1%	71.9%	50.5%	48
Relincho	521	0.45	2.3	51.61%	70.97%	36.6%	73.5%	71.9%	52.9%	49
Mocha	250	0.5	1.3	70.97%	56.45%	40.1%	86.3%	62.2%	53.7%	50
Mantoverde	155	0.51	0.8	77.42%	53.23%	41.2%	91.3%	60.3%	55.0%	51
Inca de Oro	345	0.47	1.6	66.13%	62.90%	41.6%	81.5%	68.1%	55.5%	52
Polo sur	375	0.46	1.7	61.29%	69.35%	42.5%	80.1%	71.0%	56.9%	53
Antucoya	590	0.38	2.2	46.77%	85.48%	40.0%	70.5%	84.4%	59.6%	54
Zaldivar	234	0.46	1.1	74.19%	64.52%	47.9%	87.1%	70.0%	61.0%	55
Telegrafo norte	400	0.41	1.6	56.45%	82.26%	46.4%	78.9%	79.4%	62.6%	56
Mina Sur	23	0.49	0.1	95.16%	59.68%	56.8%	98.6%	63.6%	62.7%	57
Llano Paleocanal	115	0.46	0.5	80.65%	66.13%	53.3%	93.4%	70.0%	65.4%	58
Hypogene Project Andacollo	464	0.36	1.7	54.84%	91.94%	50.4%	76.0%	87.5%	66.5%	59
Putilla Galenosa	540	0.25	1.4	50.00%	98.39%	49.2%	72.7%	98.1%	71.3%	60
Lomas Bayas	287	0.27	0.8	67.74%	96.77%	65.6%	84.4%	97.0%	81.9%	61

This ranking allows comparing and contextualizing a new deposit in size in relation to current deposits. This combined probability could be interpreted like the undiscovered deposit has a tonnage and copper grader greater than certain values.

Metallogenic Belts

Chile is located along the subduction zone between Nazca plate and the South American plate. The collision between plates has generated magmatic and volcanic belts in time, which may generate mineral deposits depending on several variables. .

The metallogenic belt provides a spatial temporal context for the occurrence of mineral deposits. The principal metallogenic belts [2, 4] in Chile (Figure 4) are:

- Jurassic - Early cretaceous***:*** this belt includes the copper veins in plutons and strata bound copper deposits located mainly in the Coastal Cordillera of northern Chile. Some examples are: Michilla and Mantos Blancos. It is related to a succession of porphyritic stocks and dikes that were emplaced within Jurassic andesitic volcanics.
- Middle cretaceous: includes copper, iron, apatite, gold, silver and manganese veins, as well copper skarn, large iron deposit and certain strata bound deposits and scarce copper porphyries like for example: Andacollo.
- Paleocene: this belt includes gold, silver and copper veins, as well copper breccias and porphyry: Sierra Gorda, Lomas Bayas and Spence (district Sierra Gorda).
- Late Eocene – Early Oligocene: large porphyry copper in northern Chile. For example: the districts of Chuquicamata, Escondida and Collahuasi.
- Early - Middle Miocene: Maricunga belt associated to emplacement of gold deposits and porphyry copper-gold.
- Middle Miocene – Early Pliocene: the porphyry copper deposits of central Chile as: Andina, Teniente, Los Bronces and Los Pelambres.

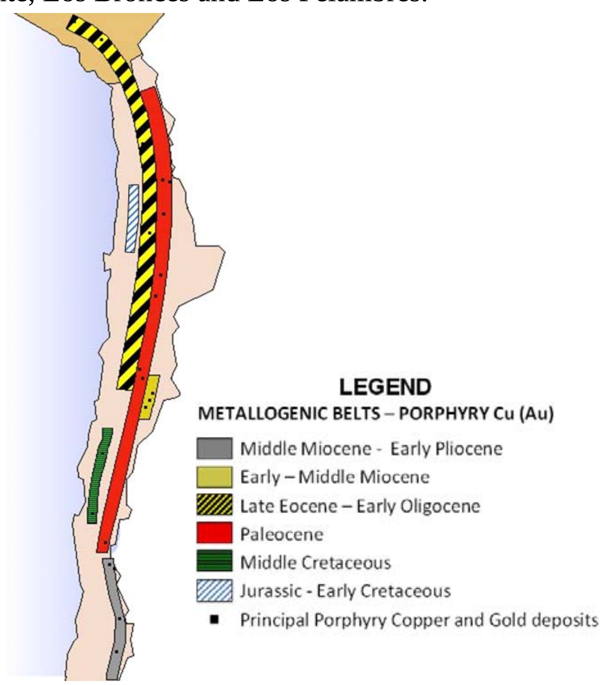

Figure 4: Metallogenic Belts - copper deposit in Chile. Adapted of Sernageomin [4]

The basic statistics by class of geological belt is shown Table 4. The belts with more metal copper content are Late Eocene – Early Oligocene and Middle Miocene – Early Pliocene (Figure 5), therefore is remarkable, in the last the average size deposit is more than double that in Late Eocene – Early Oligocene. Then the deposit of Middle Miocene – Early Pliocene, located in Chile Central, are more massive and concentrated than rest of belt, being from of point of view of the exploration more attractive.

Table 4: Copper mineral resources by metallogenic belt

Belt geological	Deposit Number	Average Tonnage Mton	Average Cu %	Metal Cu content Mton
Jurassic - Early cretaceous	8	248	0.46	9.2
Middle cretaceous	1	464	0.36	1.7
Paleocene	20	561	0.48	54.2
Late Eocene – Early Oligocene	21	1896	0.58	229.4
Early - Middle Miocene	2	1318	0.34	9.0
Middle Miocene – Early Pliocene	9	5227	0.60	283.0
Grand Total	**61**	**1691**	**0.57**	**586.4**

The list of recollected deposit sums 586 million tonnes of copper in current known resources in Chile at least.

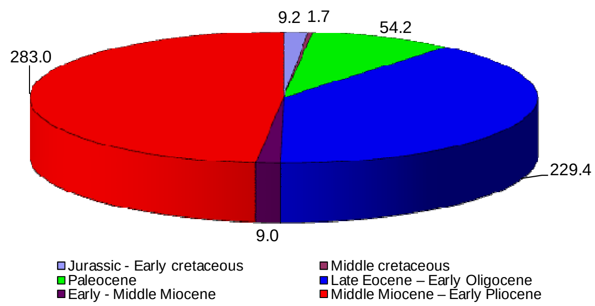

Figure 5: Metal copper content separated by Metallogenic Belts - Copper deposit in Chile

Broad Copper Deposit Classification

The common types of Chilean copper deposits are:

Porphyry copper

These content mainly copper and associated with molybdenum, gold, silver, and other elements. In general are centered in stock cylindrical porphyry, at least 100 meters from diameter km that correspond to porphyric apophysis above granitic plutons domes. The stocks are result of overprinting intrusive fluids associated with certain types of molten igneous rocks called magma. Also the host rocks are frequently altered with mineralized. The mineralization is presents in stockworks with multidirectional veins of sulphides and presence of quartz-sulphide with potassic – silicate alteration. Sericitic alteration defined by quartz, sericite and pyrite is commonly overimposed in all or part of potassic zone and in many cases produce remotion of total or partial metal [2]. A proportion part of the world copper production comes from types of porphyry copper deposits.

Iron Oxides Copper and Gold (IOCG)

With Olympic Dam arises the conceptual posit model IOCG. In Chile, Candelaria, Manto Verde and San Antonio have been classified as it. The igneous rocks that host iron deposit could continue the hydrothermal evolution with availability of copper and gold is subject to paragenetic additional come to sulphides later of copper and gold [3]. These ore deposits of the Coastal Mountains have been emplaced in several pulses. Lower Cretaceous plutonic complexes and magnetite-apatite and iron oxide copper gold [2].

Strata-bound deposits or Chilean manto-type

The strata-bound deposits of copper with silver associated are hosted in volcanic rock. These deposits are at least one magnitude order smaller than the porphyry copper. Currently is possible to associate the copper mineralization to emplacement intrusive in volcanic sequence. Strata-bound deposits are volcanic rock and veins intrusive of the mid to upper Jurassic in the coast mountains of the Antofagasta region and early cretacic in central Chile [2].

The porphyry copper have as average of 2190 Mton of ore and 0.57 percent copper grade, table 5. The others type deposits have tonnage in the range 6.5 Mton to 440 Mton.

Table 5: Copper mineral resources by metallogenic belt

	Mton							Cu grade							Metal Cu content						
Deposit Classification	Average	N	Std.Dev.	Min.	Max	P. 10	P. 90	Average	N	Std.Dev.	Min.	Max	P. 10	P. 90	Average	N	Std.Dev.	Min.	Max	P. 10	P. 90
- Porphyry Cu	2190	46	3684	28	16908	234	6535	0.57	46	0.17	0.25	1.48	0.36	0.94	12.5	46	21.9	0.2	106.4	1.1	27.2
- Strata-bound	132	7	206	7	590			0.55	7	0.30	0.38	1.46			0.7	7	0.7	0.1	2.2		
- Exotic	122	4	116	23	287			0.54	4	0.05	0.46	0.59			0.7	4	0.7	0.1	1.6		
- IOCG	255	4	166	73	400			0.55	4	0.04	0.51	0.70			1.4	4	0.9	0.5	2.2		
All Grps	1691	61	3311	7	16908	62	3000	0.57	61	0.17	0.25	1.48	0.37	0.96	9.6	61	19.6	0.1	106.4	0.4	23.7

DISCUSSION

For this work the *current mineral resources* based on public information were used, however it is necessary to consider the complete or global resources (pre mining) of the deposit i.e. the resources already mined, residuals such as tailings and current resources, especially for the giant ore deposits. Current and global resources approaches are supplementary because:

- The current resources show the mining scenario, potentialities by copper industry and asset accounting of the copper for Chilean state.
- The global resources describe and quantify copper resources deposit in Chile from a historical perspective and provide an exploration-geology scenario of Chilean copper deposits. This may be used as input data in the construction of predictive models for the estimation of the potential undiscovered deposit.

Variables such depth of emplacement, cover rock or overburden of the deposits are key factors in the economic feasibility of the deposits, therefore should be consider along copper grades and tonnage to ranking the deposits. Once these variables are incorporated and the profitable/non-profitable known deposits will be possible to generate bands in the scatter plot of Figure 3 of economic project and uneconomic project.

The currently prospect in Chile presents low copper grades values, which generates opportunities to think in the future exploitation and reprocessing old tailings.

This bivariate approach, data sources used and global resources (pre mining) approach could be incorporated in the future study about undiscovered deposit, like it done by joint way Geological Surveys of Argentina, Chile, Colombia, Peru and United States [1]. Also cosimulation geostatistics in metallogenic belts could be considered in future studies of undiscovered deposits as a way to integrate different information sources such as: location of deposits, geological maps and discarded zones.

CONCLUSIONS

This work presents a quick and simple approach for the economic prioritization of mining projects at early stages, based on the public available information of *current mineral resources* about copper deposits in Chile. It could assist in helping the board of directors to support exploration expenses providing an index for decisions: when to cease exploration or to continue such effort, allowing for comparing and contextualizing a new deposit in size in relation to current deposits.

These tools may also applicable not only to such variables as grades and tonnage, but also to depth of emplacement, coproducts (molybdenum, silver and gold), mineralization style (oxides, sulphides) and distance between deposits, among others.

In Chile, there are more than 586 million known tonnes of copper, with Andina and Rio Blanco at Los Bronces currently being the largest deposit and district, respectively, in the world. The largest amount copper is located in the Middle Miocene-Early Pliocene Metallogenic belt in the central Andes mountain range.

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