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Appraisal of Engineering Phases of a Mineral Asset: From Exploration to Mine Approval

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Abstract

It is well known that the most common methodology for evaluating a mineral asset is the NPV. Most of the mining companies employ this technique for evaluating the expected economic benefits provided by the exploration and exploitation of a mineral deposit. However, companies also wish to know how their assets are creating value through the several exploration and development phases. The purpose being to assess the progressive value of the mineral asset in agreement with the information and data cumulated through the different steps from exploration to project approval. This paper establishes the value of a copper mineral deposit through their successive phases from exploration to feasibility and approval using the options' binomial nodes framework. Results are applied to two copper negotiations for method validation.

Keywords

Mine Value, Exploration Phases, Binomial Nodes, Copper Deposits, Method Validation

1. Introduction

Since the 50's, economists like Jack L. Treynor, William Sharpe, and others introduced, independently and based in Harry Markowitz's previous works, the principles of the Net Present Value (NPV) to value capital assets based on the Capital Asset Pricing method (1964). Sharpe along with Markowitz and Merton Miller were awarded the Nobel Prize for their contributions to the theory of financial economics (1990).

However, the Capital Asset Pricing method does not constitute the real value of an asset. This is particularly true in the case of a strategic asset calling strategic, an asset which is neither found everywhere nor easily discovered. The estimated price can be viewed as a financial value; the real value is a subjective value

Any strategic asset, because of its characteristics, merits a prize at the moment of evaluating its economic returns. This prize depends on a time frame and the uncertainties through this time period both imposing variabilities affecting the price of the underlying asset. This underlying asset (copper metal, for example) is the real financial asset upon which the value of a product or derivative (copper asset, for example) is based upon.

In the 70's, Fisher Black and Myron Scholes (1973) [1], with the collaboration of Robert Merton, proposed a formula to value, at a selected point of time, the acquisition and the selling of an asset under uncertainties affecting its underlying asset. The method called "call option" is a financial contract that provides to the buyer the right, but not the obligation, to buy an asset of a selected present value (strike price) at a specific price (expiration price) within a specific time period. A call option contract increases the value of an asset when the price of the underlying asset has also increased.

Due to a continuously variation of a metal commodity price through time without reaching the zero-value, their relative prices can be suggested to be log-normally distributed and, as such, they can be transformed into a continuous normal distribution or a discrete and progressive sequence of binomial data.

Cox, Ross and Rubinstein (1976) [2] suggested a method to approximate the Black & Scholes formula considering the T time frame as a progressive sequence of binomial data. The valuation of a mine asset from the exploration to approval phases can be emulated through a compatible binomial nodes schema.

2. Mine Exploration and Development Evaluation Process

A mine development process can be configured by a series of progressive development phases that go from exploration to approval. Each of them is looking for the best scenario to try to reach the maximum value at the approval phase, where the project blessing is decided (**Figure 1**). The different paths to go from exploration to approval follow a sequence of discrete binomial data sequence.

Assume that the expected value of a mineral asset, within a time frame T, becomes E (point S). This estimated NPV value should evolve through all the mine development phases (exploration, scoping, pre feasibility) up to reaching the feasibility and approval phases progressively (point N). If the interest is focused on how we can increase this value, the logical step after reaching the E value at point N, would be to return back along the same previous path evaluating at each of the phases, the best course of action among all the possible alternate and available scenarios.

To evaluate these alternate scenarios at each phase several parameters have to be introduced such as: the volatility (v); the expected increase-step of the underlying asset (u); the expected decrease-step of the underlying asset (d), the probability of neutral risk, (p) which is the probability of possible future fair asset value adjusted for risk; the maximum value of the asset at the previous phase (Vmax) as a function of the expected value of that phase, and the minimum value of the asset at the phase (Vmin) equivalent to the lower value reached at the previous phase including 0.0), and the expenses (capex) used in the phase, CEX.

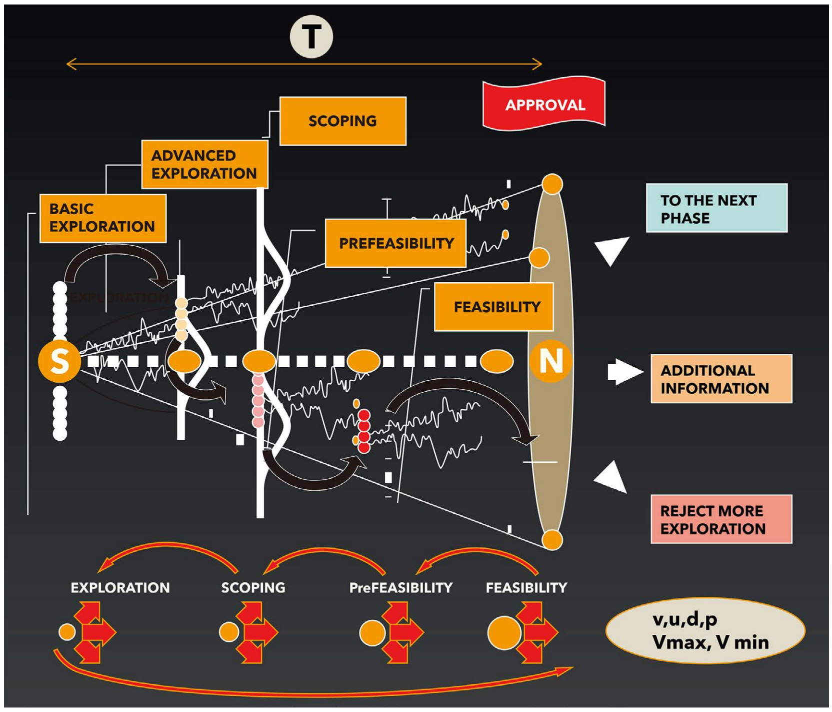

Figure 1. Sketch shows the different activity phases covering from exploration to approval (N). One way to look at the process is to estimate the project NPV at (S) and consider it as an irreversible process that evolves through time in accord with market conditions until reaching the point N. The alternative way is to return to (S), using the same path, but analysing at each of the phases the best option that it would have been possible to exercise under the circumstances occurring at each of the phases according to metal-price-volatility, costs, incomes, interest-free rate, expenses incurred, time-period, and other indicators, reaching again the point S with a new NPV higher that the original NPV. Options is a method to manage and respond to uncertainties, always looking at different scenarios, contrary to consider value creation as an irreversible and unique process.

The phase valuation should respond to the following algorithm

expected present value based on the previous phase value including Vmax and Vmin and the probability of passing from the previous to the next phase.	estimation of the neutral-risk probability p $\frac{(Vmax) \times rf - (Vmin)}{(Vmax - Vmin)}$	the expected NPV of this present phase includes its Vmax, Vmin, the neutral-risk probability, the phase period N in years, and the expenses E during the phase $[(Vmax) \times p - (Vmin) \times (1-p)]/rf^N - E$

3. Mine Exploration and Development Data

Assume to look a copper mine property to be developed in six phases (Figure 2).

Mine property development includes a sequence of phases where the *entrance* from one phase to the next depends on the successful economic *exit* of that phase. This means that the probability to become successful (from the first phase) at the end of the mine development process (to the final phase) becomes known only after all phases have been successfully completed.

To determine the probability of becoming successful in the transit from one phase to the following, a survey regarding Chile's mineral exploration data provided reliable data for successful mine development work from advanced exploration to mine approval.

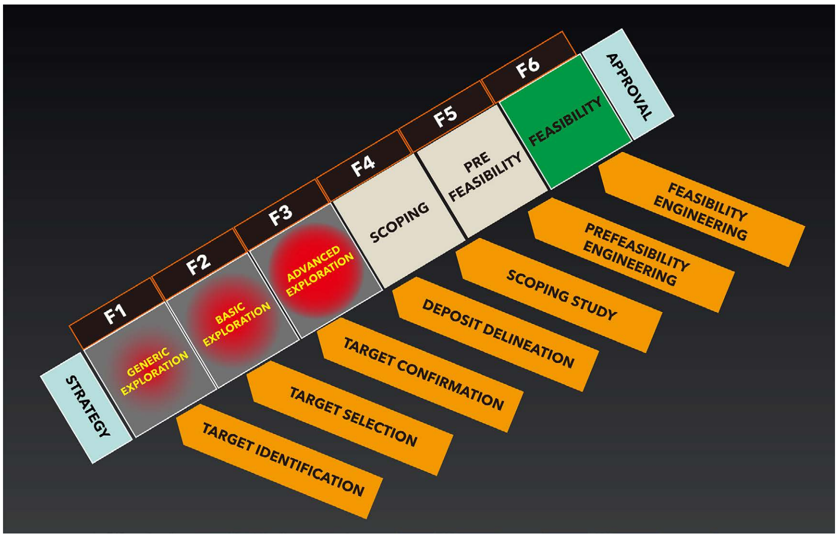

Figure 2. Mine property development strategy: Generic Exploration; Basic Exploration; Advanced Exploration, Scoping, PreFeasibility, Feasibility.

Based on data of Figure 3, the probabilities of passing from one engineering level to another is illustrated in Table 1.

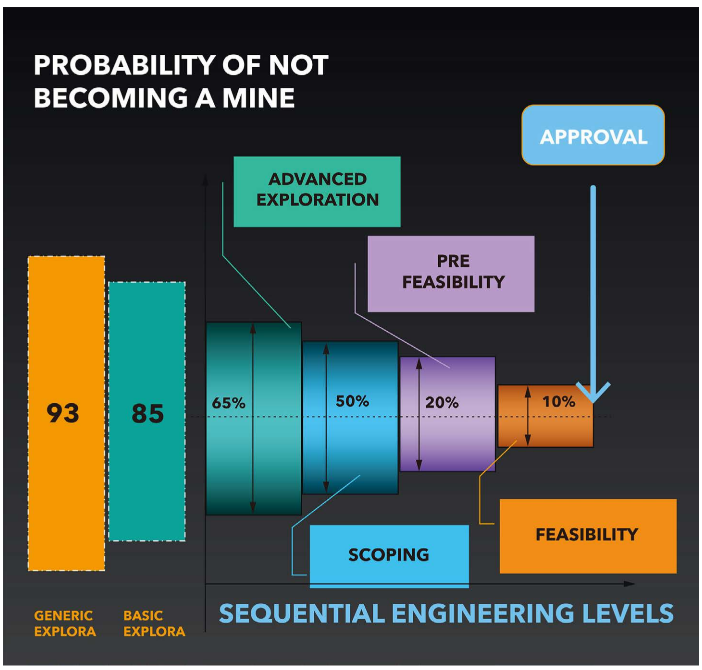

Figure 3. Probabilities of not becoming a mine from a mine development strategy covering the transit from Generic Exploration to Feasibility Engineering. This figure shows the probabilities of not reaching the Approval decision for construction. For generic and basic exploration, data from the pharmaceutical industry were taken.

Table 1. Probability of passing from one engineering level to the next one capital expenses.

From	to	Probability of successful transit	Capital Expenses (000 US$)
Generic Exploration	Basic Exploration	47	2.000 2000
Basic Exploration	Advanced Exploration	43	3.000 5000
Advanced Exploration	Scoping	70	5.000 10,000
Scoping	PreFeasibility	63	7.000 17,000
PreFeasibility	Feasibility	88	9.000 26,000
Feasibility	Approval	90	15.000 41,000

Finally, an estimate of phase period in years is shown in Table 2.

Table 2. Time of exploration and development activities in years.

Phase	Time (years)	Phase	Time (years)
Generic Exploration	1	Scoping	2
Generic Exploration	2	PreFeasibility	1
Generic Exploration	1	Feasibility	1

Assume a medium size copper mine with the following parameters (Table 3).

Table 3. Estimates of mine property data and value (for Operations Costs: OBSERVATORIO DE COSTOS COCHILCO 2022 vs 2021 https://www.cochilco.cl/Listado%20Temtico/Observatorio%20de%20Costos%20(Presentacio%CC%81n)%20Octubre%202022.pdf).

Estimates of Mine Property data and value			
Mine Property data		Mine Property value	
Annual production (tCu)	78,000	Profit per lbCu (US$/lbCu)	1.00
Life of mine (years)	25	lbCu/tCu	2204.6
Cu price (US$/lbCu)	3.5	Annual Profit (MUS$)	172
Operations Cost (US$/lbCu)	2.5		
Recovery %	80	PV [$172 \times (1 - e^{-2.5})/0.10$]	1579
Capex MUS$	1105	NPV (MUS$)	474
Market rate %	10		

4. Mine Exploration and Development Valuation

Now, the first phase valuation algorithm starts considering the approval phase to determine the value at the feasibility phase (Tables 4-6).

Table 4. This table starts from the NPV which can be used as the Value for a selling-buying process and follows the phase valuation algorithm explained above. Specifically, Table 4 provides the value at the Feasibility phase (372 MUS$) starting from a current value set up at an Approval instance (474 MUS$).

EXPECTED VALUE OF PRESENT PHASE (MUS$)	PROBABILTY OF OCCURRENCE BETWEEN CONSECUTIVE PHASES	PHASE TIME	EXPENSES (MUS$)	EXPECTED VALUE PREVIOUS PHASE (MUS$)
700 474 0	0.90	1	15	{[0.58 × 700 + 0.42 × 0]/1.05} - 15
(474 × 0.90)/1.10 387	[387 × 1.05 - 0]/[700 - 0] 0.58			372
VALUE OF CURRENT PHASE	PROBABILITY OF NEUTRAL RISK	IN YEARS	IN MUS$	VALUE OF PREVIOUS PHASE

Table 5. This table starts from the last phase value calculated (372 MUS$) and follows the phase valuation algorithm explained above. Specifically, Table 5 provides the value at the Pre-Feasibility phase (289 MUS$) starting from the already calculated Feasibility value (372 MUS$).

EXPECTED VALUE OF PRESENT PHASE (MUS$)	PROBABILTY OF OCCURRENCE BETWEEN CONSECUTIVE PHASES	PHASE TIME	EXPENSES (MUS$)	EXPECTED VALUE PREVIOUS PHASE (MUS$)
666 372 0	0.88	1	9	{[0.47 × 666 +0.53 × 0]/1.05} - 9
(372 × 0.88)/1.10 298	[298 × 1.05 - 0]/[666 - 0] 0.47			289
VALUE OF CURRENT PHASE	PROBABILITY OF NEUTRAL RISK	IN YEARS	IN MUS$	VALUE OF PREVIOUS PHASE

Table 6. This table starts from the last phase value calculated (289 MUS$) and follows the phase valuation algorithm explained above. Specifically, Table 6 provides the value at the Scoping phase (152 MUS$) starting from the already calculated Pre-Feasibility value (289 MUS$).

EXPECTED VALUE OF PRESENT PHASE (MUS$)	PROBABILTY OF OCCURRENCE BETWEEN CONSECUTIVE PHASES	PHASE TIME	EXPENSES (MUS$)	EXPECTED VALUE PREVIOUS PHASE (MUS$)
604 289 0	0.70	2	7	$\{[0.29 \times 604 + 0.71 \times 0]/1.05^2\} - 7$
$(289 \times 0.70)/1.10^2$ 167	[167 × 1.05 - 0]/[604 - 0] 0.29			152
VALUE OF CURRENT PHASE	PROBABILITY OF NEUTRAL RISK	IN YEARS	IN MUS$	VALUE OF PREVIOUS PHASE

After the entire back analysis of the mine development sequence going from approval down to generic exploration, the following results are obtained (Table 7, Figure 4).

Table 7. Column I identifies the mine development phase; Column II Shows the mine property value at different development phases; Column III shows the value of one-lbCu-in the ground at each phase.

PHASE I	MINE PROPERTY VALUE II	VALUE OF ONE lbCu IN THE GROUND III
Approval	474	11.0
Feasibility	372	8.7
Pre Feasibility	289	6.3
Scoping	152	3.5
Advanced Exploration	82	1.9
Basic Exploration	25	0.6
Generic Exploration	9	0.2

The 78.000 tCu per year during the 25 year-life means a total production of 4299 M lbCu (=78,000 × 2206.4 × 25) so the value of one-lbCu in the ground appears in column III as the mineral deposit goes from exploration to approval.

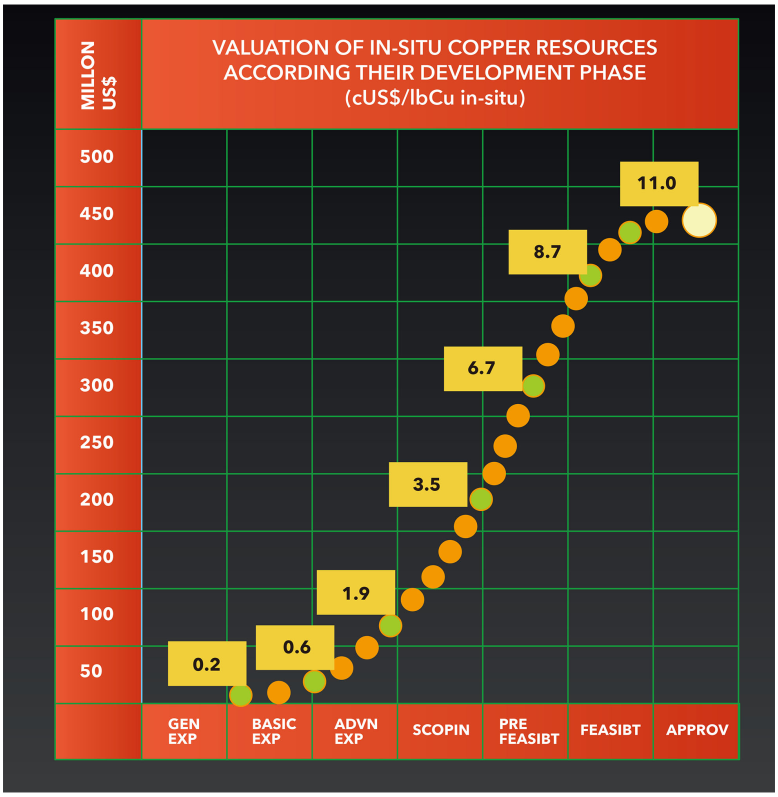

Figure 4. Value creation of a mineral property subject to exploration and mine development. Figure shows the value of *in-situ* copper resources according their development phase (cUS$/lbCu *in-situ*).

In addition, there is a sort of one-to-one relation between the mine property development phases and the *categorization* of mineral resources and reserves. The CRIRSCO code rules a series of guidelines for both the mine development phasing and the categorization of mineral resources and reserves. Figure 5 outlines their relations allowing to derive the value of mineral resources and mineral reserves such as Figure 6 shows.

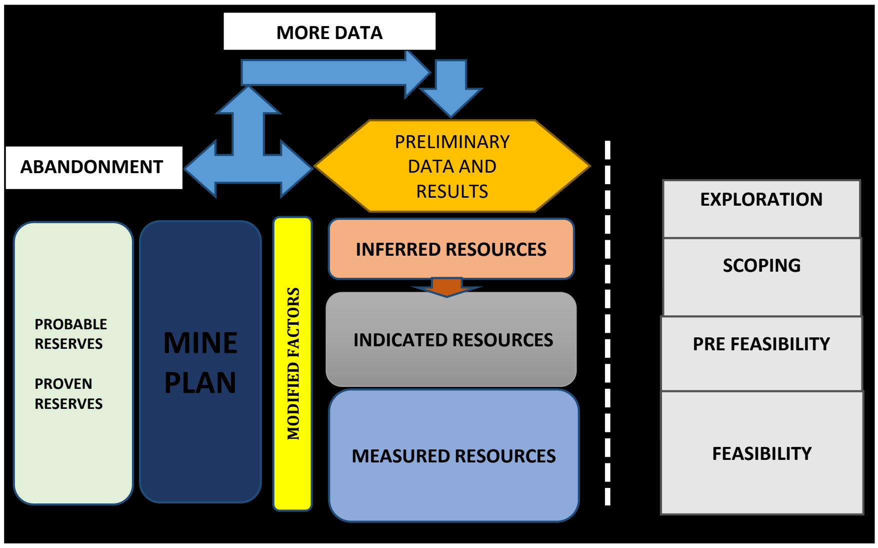

Figure 5. CRIRSCO's mineral resources and reserves categorization and mine development phasing guidelines.

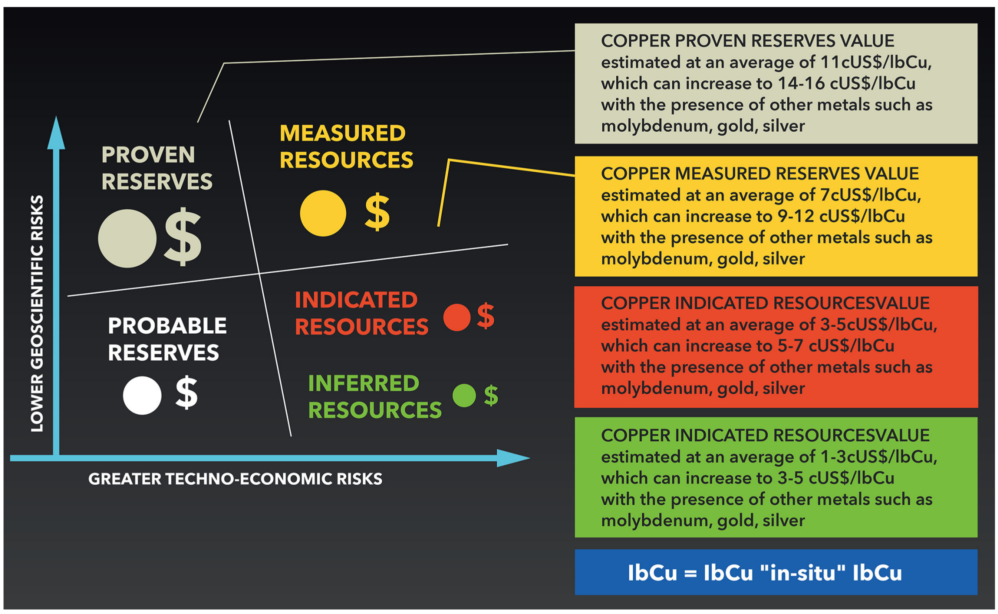

Figure 6. Estimated "*in-situ*" value per lbCu unit.

5. Validation

To validate the estimated values, two mine properties recently negotiated will be analysed: Acquisition of the Eva copper mine in South Africa (7/10/2022) by South African's Harmony Gold, and the acquisition of a portion of Sierra Gorda (22/02/2022) by South 32 in Chile. Data and Table 8 come from Companies' public information.

Table 8. Table on mineral resources & reserves given at the South 32 investor presentation.

TYPE	Classification	Tonnes (Kt)	Cu (%)	Au (g/t)	Mo (%)	Cu (t)	Au (kg)	Mo(t)
	Mineral Resources							
	Mineral Resources							
SULPHIDE	Measured	200,503	0.41	0.07	0.03	818,053	13,835	58,146
	Indicated	683,135	0.40	0.06	0.02	2,712,045	40,305	129,796
	Measured + Indicated	**883,638**	0.40	0.06	0.02	3,530,098	54,140	187,942
	Inferred	46,036	0.35	0.04	0.01	161,127	1749	2762
	Total Mineral Resource	**929,674**	0.40	0.06	0.02	**3,691,225**	**55,889**	**190,704**
OXIDE	Measured	13,241	0.38			50,579		
	Indicated	39,052	0.33			129,262	3,691,225	
	Measured + Indicated	**52,292**	0.34			**179,841**	181,244	
	Inferred	540	0.26			1403	**3,872,469**	
	Total Mineral Resource	**52,833**	0.34			**181,244**		
SULPHIDE	Proven	189,135	0.41	0.07	0.03	775,454	13,239	58,146
	Probable	610,669	0.40	0.06	0.02	2,442,674	36,640	129,796
	Total Mineral Reserve	**799,804**	0.40	0.06	0.02	**3,218,128**	**49,879**	**178,875**
OXIDE	Proven	12,884	0.38			49,300	3,218,128	
	Probable	**37,378**	0.33			124,307	173,607	
	Total Mineral Reserve	50,263	0.35			**173,607**	**3,391,735**	

South Africa's Harmony Gold acquires Eva Copper for US$170 m

By Bizclik Admin

October 07, 2022

Harmony Gold, the South African gold mining company, has announced that it has entered into an agreement to acquire Copper Mountain Mining, the entity that owns 100% of the Eva Copper Project in Queensland, Australia, along with a package of regional exploration tenements, for an upfront cash consideration of **MUS$170**, plus a contingent payment of up to a maximum of US$60 m.

In a statement, Harmony Gold said that Eva Copper and the acquired tenements comprise a total of 2295 square kilometres within the North West Minerals Province in Queensland. It added that the acquisition of Eva Copper will add **1.718 BlbCu** and 260,000 ounces of gold to Harmony's Mineral Reserves and will extend the company's diversification into copper, a future-facing metal critical to the global energy transition.

$$170{,}000{,}000/1{,}718{,}000{,}000 = 0.099 \approx \underline{10\ \text{cUS\$/lbCu}}$$

South32 Investor Presentation: SOUTH32 TO ACQUIRE A 45% INTEREST IN THE SIERRA GORDA COPPER MINE

"*South*32 *will acquire a* 45% *interest in Sierra Gorda from Sumitomo Metal Mining* • *Pro-forma ownership structure* (31.5%) *and Sumitomo Corporation* (13.5%) (*collectively Sumitomo*)—45% *interest in the Sierra Gorda S.C.M.*

(*SGSCM*) (*a*) *incorporated Joint Venture alongside* 55% *joint venture partner KGHM Polska Miedz, a global miner listed in Poland-Joint Venture Agreement provides South*32 *with joint control* (*refer slides* 23 *and* 34) • *Sierra Gorda is an operating mine in the prolific Antofagasta copper mining region of Chile, expecting to produce* 180 *kt of copper,* 5 *kt of molybdenum,* 54 *koz of gold and* 1573 *koz of silver in CY*21*e*(*b*) • *Upfront consideration of US*\$1.55*B*(*c*) *payable in cash on completion—A further amount of up to US*\$500*M structured as contingent price-linked consideration, payable annually over four years as a percentage of incremental revenue realised above agreed copper price thresholds, when both agreed copper price and production thresholds are met*(*d*) • *Acquisition to be funded through a combination of cash on hand and an underwritten acquisition debt facility*"

MINERAL RESOURCES AND MINERAL RESERVES AS AT 31 DECEMBER 2014 (55% BASIS)

3,872,469 × 2204 × 5 cUS\$/lbCu 42,674,608,380 > mineral resources (average)

3,391,735 × 2204 × 15 cUS\$/lbCu 112,130,759,100 > mineral reserves (average)

7,264,204 × 2204 × 9.68 154,805,367,480 >> 1.55 B\$

7,264,204 × 2204 = 16,010,305,616 lbCu

155,000,000,000 ctsUS\$/16,010,305,616 lbCu = 9.7 ctsUS\$/lbCu × (45/55)

= 7.9 ctsUS\$/lbCu

6. Conclusions

The purpose of this paper has been to show the mechanics of a binomial nodes' mine appraisal procedure and corroborate this mechanism through validation using actual negotiation data; It has not been to show the theoretical details involved in the binomial nodes methodology.

Even though the options methodology is not frequently used (Ampofo, K. 2017 [3]; Ayodele, T.O. and A. Olaleye, 2021 [4]), the binomial nodes approach is very useful for various industrial applications (Botin, J., del Castillo, F. and Guzman, R., 2012 [5]; Brach, M.A, 2003 [6]; Smit Han, T.J. andTrigeorgis, L., 2003 [7]; Tulcanaza, E. and Zenteno, L., 1995 [8])]. The implementation of the procedure in this paper can be applied to any commodity that is subject to an exploration, innovation, o research project developed along a sequential series of phases in which the success in one of these phases allows the transit to the next one. The methodology is especially applicable to innovation and investigation projects.

Acknowledgements

Author is thankful of reviewers and various colleagues in Chile and Spain where the contents of this paper have been presented and the essentials of its conclusions have been taken as guidelines for mine exploration and development.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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