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Assessing the economic value of copper mineral resources in Ta Phoi area, Lao Cai province

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ABSTRACT

Copper ore is one of the minerals that play an important role in the economic development of Lao Cai province. However, this is a non-renewable resource with high risk and great environmental impact in the mining process. Therefore, it is necessary to study and evaluate the economic value of mineral resources, creating a basis for planning the process of exploration, exploitation, rational use of resources, and environmental protection. This paper evaluates the economic value of mineral resources using resource assessment techniques. The total reserves and identified resources are 21,473 thousand tons of ore, corresponding to 160,278 tons of copper. In the case of using level 122 reserves, the identified resources is 16,412 thousand tons of ore, corresponding to 129,433 tons of copper. The forecasted resources are approximately 41,050 thousand tons of ore, which is equivalent to 198,235 tons of copper. The accompanying minerals, with a resource level 333, include 6.34 tons of gold (Au) and 24.39 tons of silver (Ag). The results show that copper content in the area is varied from 0.01% to 9.18% with an average of 1.50%, and the ore grade is changed from poor to medium. The distribution of copper ores is relatively uniform to very uneven, with the largest concentration found in the Ta Phoi area. The calculated potential recovery value (GTN_{th}) and unit area value (URV) of copper minerals in the study area are substantial, with the highest URV is observed in the Ta Phoi area and the lowest one is obtained in the Coc San area. During the extraction process, the investor should consider recovering accompanying elements such as gold and silver to enhance the mine's economic value.

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1. Introduction

Copper is a widely utilized non-ferrous metal and is an essential raw material in the construction and growth of the national economy, especially for developing countries. Because of the increase in industrialization, the demand for copper also rises. It is estimated that after 2022 the demand of copper ore in Vietnam will increase and reach 35,000 to 40,000 tons per year (Fong-Sam, 2013; Wu, 2007; Hung et al, 2020). Conversely, neighbouring countries such as Japan, China, Korea, and India are deficient in copper, with copper concentrate demands ranging from 500,000 to 700,000 tons per year. China imports approximately 375,000 tons of concentrated Cu ore per year and 1.69 million tons of copper scrap per year. The consumption of copper per capita in China is 1.1 kg per year, while it is around 10 kg per year in the US (Zhang et al., 2014).

Lao Cai, a mountainous province in northwestern Vietnam, has significant potential for copper resources. During the period of 2002-2007, the Intergeo Division assessed that the Ta Phoi area in Lao Cai province held prospects for copper minerals. From 2011 to 2012, Vietbac Geology Joint Stock Company (Vinacomin) conducted explorations and is currently investing and extracting in the Ta Phoi area. However, researches aimed at assessing the economic value of copper mineral resources and accompanying elements in the Ta Phoi copper mine area are limited. Therefore, in order to orient the future mining efforts, it is crucial to study and evaluate the economic value of copper mineral resources, in addition to geological exploration. This research provides a scientific basis and practical document that will contribute to the improvement of efficiency in the management, planning, exploitation, and utilization of copper mineral resources in a rational and effective manner.

2. Geological history

The Ta Phoi area is part of the administrative regions of Ta Phoi Ward, Hop Thanh Ward, Cam Duong Town, Tong Xanh Ward and Quang Kim Ward, Bat Xat District in Lao Cai Province. The study area is located in the northeast region of the PoSen Convex Fold (according to the mineral geological map of 1:50,000), and is composed of sedimentary formations, metamorphic sediments belonging to the Sin Quyen Formation (PP*sq*), Da Dinh Formation (NP*dd*), Cam Duong Formation and loose sediments of the Quaternary system, and large-sized intrusive magma blocks of the Posen Complex.

The study area features a general structure in the form of asymmetrical folds, with the axis extending from Northwest to Southeast, influenced by multiple phases of tectonic activity. The first tectonic phase was characterized by the main force acting in a vertical direction, leading to the creation of faults and gentle folds, partially visible in the southwest of the area. The second one had major tectonic forces in a horizontal direction from Northeast to Southwest, resulting in the creation of large reverse faults and sharp arch folds, reversing the Northeast inclined axis (Anh et al., 2007). This second phase dominates the geological structure of the area.

Copper ore is distributed in the formations of the second set of the Sin Quyen Formation, and irregular-grained biotite granites that have been pressed and hydrothermally modified (phase 2), and porphyry granite veins (phase 3) belong to the Po Sen Complex. Copper ore is concentratedly distributed into 3 zones, including: Ta Phoi, Coc San and Nam San (Anh et al., 2007).

The results of the exploration conducted in 2012 revealed and evaluated 18 copper ore bodies of two types, including:

- Large-sized lenticular ore bodies, including TQ.4, TQ.5, TQ.6, a concentrated distribution from TQ.9 to TQ.16, and TQ.9a distributed from TQ.24 to TQ.30.

- Vein or lenticular ore bodies, including TQ.1, TQ.2, TQ.3, TQ.4a, TQ.5a, TQ.7, TQ.8, TQ.9b, TQ.10a, TQ.10, TQ.11, TQ.11a, TQ.12, TQ.13, which are distributed in the walls, pillars of large ore bodies, or scattered in the mine area.

In general, the copper ore bodies in the Ta Phoi area are distributed in deformed rock and are single plugs that incline to the northeast with slope angles ranging from 60^0 to 75^0. The ore mineral composition mainly consists of chalcopyrite, cubanite, pyrite, and pyrrhotite, which are distributed irregularly and form small clusters of particles spreading into veins, that fill

cracks and replace minerals in the rock bed (Anh et al., 2007).

3. Theoretical basis and research methods

3.1. Theoretical basis

The evaluation of mineral deposits should be based on economic-technical parameters and industrial criteria. In the calculation process, it is necessary to adjust the parameters and convert accompanying components to the main components to accurately reflect the true value of mineral resources.

There are many methods to assess the economic value of mineral deposits, in which two commonly used methods are:

- Evaluation criteria system based on market economy model: Organizations such as the South African Mine Evaluation Council and others have proposed methods to evaluate mineral mines using different approaches such as cash flow approach, market approach, and cost approach, linked to each stage of the research and development process (Dinh et al., 2018). The cash flow approach is based on the principle of using present value of future cash flows over the mineral mine's life. This direction includes methods such as present value method, net value/final price method, user cost method, and imported income method. Each method has a unique perspective on parameter calculation but aims to reflect the total land rent of the mineral mine.

- Evaluation criteria system based on centrally planned economic model: Researchers from the former Soviet Union have proposed methods to evaluate mineral deposits from the perspectives of production, investment efficiencies, and the economic value of resources.

To clarify the potential of Cu resource, the author adopts an approach that is both traditional and modern, recognized worldwide by many researchers and applied in Vietnam (Nhi et al., 2003; Phuong et al., 2018).

3.2. Research methods

3.2.1. Resource assessment method

Identified resources: based on geological structure characteristics, layout of exploration network as well as mining conditions, the method of fractionation on vertical cross section along the ore body is selected to calculate reserves and large-sized ore bodies, using the vertical parallel section method (Anh et al., 2007).

Unknown resources: there are many methods used by exploratory geologists in the world and Vietnam to forecast unidentified resources (forecast resources):

+ The method of straight calculation using ore parameters, forecast resources is determined by the formula:

$$Q_{TN} = V' \times d \quad (1)$$

Where: Q_{TN} is forecasted ore resource (ton); d is the average weight of the ore-bearing rock (T/m^3); V' is the volume of the ore zone, calculated by the formula:

$$V' = V \times K_q = K' \times H \times S_{sp} \times K_q \quad (2)$$

Where: K' is the adjustment coefficient due to the degree of terrain separation (choose K' = 1/2); H is the predicted depth of ore existence (m); S_{sp} is the area of the ore zone (thousands of m^2) determined in the 1:25,000 or 1:10,000 geological map established for the study area. K_q is the average ore containment coefficient.

+ With the same geological method, forecasting resources are determined as follows:

$$Q_{TN} = K \times q_c \times V_n \times C \quad (3)$$

In which: q_c is the ore resource in a unit (area, volume) determined on the standard area; K is the coefficient determining the similarity between the areas to be forecasted with the "standard" area, this coefficient can be determined according to the problem solved (Nhi et al., 2003).

The reliability of the forecast resource reaches the resource level of 334.

3.2.2. Evaluation of economic value of mineral resources

Economic valuation of mineral resources (macro pricing) is a method used to report the potential value of the mining industry or the value of mineral exploitation's contribution to development. Evaluate the country's socio-economic development through the richness and abundance of certain mineral resources in each region or on the territory of a country.

URVs are usually valued for all minerals or a group of minerals present in the study area. URV is the total value of potential mineral resources for

exploitation, processing and consumption in a certain area at the time of assessment and is calculated in money per 1 km^2 of the area (Torries, 1998, Phuong et al., 2018). It is calculated by the formula:

$$URV = \frac{Q_{th} \times G}{S} \quad (4)$$

or

$$URV = \frac{\sum_{i=1}^{k} D_i, k_t}{S} \quad (5)$$

In which: Q_{th} - recoverable resource, depending on the reliability of the resource, the determined reserve (Q_{th} = Q×K; with: Q reserve/ore resource; K - confidence coefficient by reserve level/resources); G - Value of goods and products; D_i - Revenue from mining copper ore and associated minerals forecast for the study area; k_t - coefficient to adjust VND to USD at the time of assessment; S - rated area.

To determine the potential recoverable value of the mine, the cluster of mines is determined as follows (Nhi et al., 1998):

$$GTN_{th} = Q_{th} \times G \quad (6)$$

3.2.3. Evaluation of the economic value of the mine

- Determining the value of mines according to the land rent method

The value of the mine according to the mine rent without discount (real price method), using the formula:

$$G = \sum_{t=0}^{T} [D_t - (Z_t + I \times i) - T_{dn}] \quad (7)$$

Value the mine according to the discounted mine rent (present value method), using the formula:

$$G = \sum_{t=0}^{n} [D_t - (Z_t + I \times i) - T_{dn}] \times \frac{1}{(1+r)^t} \quad (8)$$

Where: G - Value of mineral deposits (VND, USD); D_t - Product sales in year *t* (VND, USD) and determined by the formula: $D_t = S_t.g_t$ (VND, USD) (with: g_t - Average selling price of products in the year, S_t - Volume of products produced and consumed in the year); Z_t - Total cost of mining and mineral processing (VND, USD); T_{dn} - Corporate income tax in year *t* (VND, USD); I - Total investment capital for production and business, including fixed capital and working capital (VND, USD); i - Rate of return on investment capital in production and business (%); t = 0, usually chosen as the starting year of the project's investment; T - Mine age; r - discount rate (usually chosen by bank loan interest).

- Valuation of mine by profit method and investment method:

+ Evaluation of the mine's economic efficiency according to the total profit standard (LNT) by considering the total profit earned in the future year discounted to the starting year of mining. The developed formula is as follows:

$$LNT = \sum_{i=1}^{T} \frac{D_t - (Z_{tg} + K_n)_t}{(1+r)^t} \quad (9)$$

In which: $(Z_{tg} + K_n)_t$ - production cost in year t; Z_{tg} - cost of mining and training in year t; K_n - investment capital in year t; T - project lifetime. Other symbols indicated in formula (8).

+ Evaluation by investment method:

Assessment according to the standard of true present value: the real present value (NPV) is determined by the formula:

$$NPV = \sum_{t=1}^{T} \frac{CI_t - CO_t}{(1+r)^t} \quad (10)$$

Where: CI_t - cash flow in year t; CO_t - cash outflow in year t, including taxes; r is the discount rate (Osborne, 2010).

Evaluation according to the NVA value-added standard of the whole project is determined by the formula:

$$\sum_{t=0}^{T} NVA = \sum_{t=0}^{T} [O_t - (MI_t + I_t)] \quad (11)$$

or

$$\sum_{t=0}^{T} NVA = \sum_{t=0}^{T} [O_t - (MI_t + I_t + R_{Pt})] \quad (12)$$

In which: O_t - expected output value in year t; MI_t - the value of regular physical inputs required to achieve the output (including production costs) in year t; I_t - total investment in year t; RP_t - all foreign payments related to the project (premium, insurance, taxes) in year t.

Internal Rate of Return (IRR) is used for comparison with the Limit Rate, Imin. Finding the primary IRR value is the r value, where the real current value NPV = 0. The IRR can be determined by the following approximate formula:

$$IRR = r_1 . \frac{PV(r_2 - r_1)}{PV + NV} \quad (13)$$

In which: PV - positive value of NPV (corresponding to the discount rate r_1);

NP - negative value of NPV (corresponding to the discount rate r_2).

4. Results and Discussions

The identified resources from the synthesis of survey, assessment, and exploration documents conducted in the Ta Phoi area (Anh et al., 2007) approved by the state management agency, are 21,473 thousand tons of ore, equivaling to 160,278 tons of copper. Among these resources, level 122 reserves has an amount of 16,412 thousand tons of ore, corresponding to 129,433 tons of copper, and those of level 333 reserves are 5,061 thousand tons of ore and 30,845 tons of copper. The accompanying minerals concerning the resource level 333 are 6.34 tons of Au, and 24.39 tons of Ag.

The mineral resources of copper ore in Ta Phoi, Coc San, and Nam San areas were calculated using formulas 1, 2, and 3. The straight calculation method presented in formulas 1 and 2 was used to estimate the ore parameters (excluding the identified resources), and formula 3 was used to predict the financial resources (Table 1).

The predicted copper ore resources in Ta Phoi area are 41,050 thousand tons of ore, equivaling to 198,235 tons of copper, with a total of 334 resources (Table 1).

The economic value of mineral resources in the study area was evaluated Q_{th}, based on the approved exploration results report and the forecasted resources in Table 1. The results are summarized in Table 2.

The calculation results indicate that the potential recoverable value (GTN_{th}) and URV of the study area for copper minerals are substantial and reach to approximately 911 million USD and 1.12 million USD.ha^{-1}, respectively.

+ The mine value was determined using the mine rent method: formulas 7 and 8 were applied using the collected and aggregated data to determine the mine value. The results are as follows:

- The undiscounted mine value (real value method): G = 45,107 million USD.
- The discounted mine value (present value method): G = 22,657 million USD.
- The mine value was determined using the profit method and investment method. Accordingly, the total profit (LNT) with discount (r = 10%) of copper minerals in Ta Phoi area is ~365,118 million VND (Table 3). The mine value determined according to the real present value (NPV) of the project is about 444,695 million VND; NVA value reached 1,174,931 million VND. The achieved commercial efficiency (IRR = 23.1%) and national economic efficiency NVA reached 1,174,931 million VND.

Table 1. Forecasting resources of copper ore in Ta Phoi area by straight method.

Area	Acreage (10^3m^2)	Ore containment coefficient (K_q)	Similarity coefficient (K_{ij})	Content Average Cu (%)	Copper resources in 334 category	
					Ore (10^3 ton)	Cu (Ton)
Ta Phoi	6,384	0.055		0.583	27,685	161,403
Coc San	394		0.70	0.12	2,125	2,550
Nam San	2,393		0.61	0.305	11,240	34,282
Sum	9.171				41,050	198,235

Table 2. Potential of recoverable resources (Q_{th}) of copper ore in Ta Phoi area.

Study area	Defined resource (10^3 ton)		Sum (10^3 ton)	Forecasting resources (10^3 ton)	Sum (10^3 ton)	Resource recovery-Q_{th} (10^3 ton)
	122	333	122 + 333	334		
Ta Phoi	16,412	5,061	21,473	41,050	62,523	15,882

Table 3. Results of economic value of mines by total profit method and investment method.

Product Recovery	LNT (million VND)	NPV (million VND)	NVA (million VND)	IRR (%)
Copper	365,118	444,695	1,174,931	23.1

5. Conclusions

The research results allow to draw some conclusions and recommendations as follows:

- Copper mineral resources in the study area are abundant and primarily concentrated in the Ta Phoi area, followed by the Nam San area. The conditions for exploitation are quite favourable. In addition to copper, the ore also has the potential to recover Au and Ag. The total reserves and identified resources are 21,473 thousand tons of ore, equivaling to 160,278 tons of copper; those of level 122 reserves are 16,412 thousand tons of ore and 129,433 tons of copper. The forecasted resources at level 334 are approximately 41,050 thousand tons of ore, corresponding to 198,235 tons of copper. The accompanying minerals, with a resource level 333, include 6.34 tons of Au and 24.39 tons of Ag.

- The research results emphasize that the Ta Phoi copper ore mining project, as well as the study area have substantial commercial and high national economic efficiency.

Contributions of authors

Phuong Nguyen - conceptualization, supervision, writing-review and editing; Dong Phuong Nguyen - methodology, writing, review and editing; Anh Lan Thi Vu - methodology, formal analysis, writing original draft.

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References

Anh, B. X., Dung, T. M., Khuong, V. T., Hung, N. D. (2007). The report assesses the prospect of copper ore and other minerals in Ta Phoi area, Cam Duong town, Lao Cai province. Intergeo Division (in Vietnamese).

Dinh, N. Q., Phuong, N., Trong, P. D., Thai, P. T., Thuc, N. C., Cha, P. V., Loi, N. T., Anh, V.T.L., Hang, N. T. T., Thu, L. A., Nga, N. T. H., Diep, Q. D. (2018). Research on economic assessment of resources and economic value of several polymetallic mines in Northeast Vietnam for sustainable development. Ministry of Natural Resources and Environment (in Vietnamese).

Fong-Sam, Y. (2013). The mineral industry of Vietnam. US Geological Survey Minerals, 2011 Yearbook, p. 28.1-28.14.

Hung, K. T., Sang, P. N., Phuong, N., Dung, N. T., Bac, B. H., Phi, N. Q., Sang, B. V. (2020). Polymetallic Nodules Resource Estimation in the Suoi Thau-Sang Than Area, Northeastern Vietnam. Inżynieria Mineralna 1.2: 7-14.

Nhi, D. V., Luan. T. X., Dung, N. T. (2003). Methods of geoeconomic assessment of solid mineral deposits. Hanoi University of Mining and Geology (in Vietnamese).

Osborne, M. J. (2010). A resolution to the NPV-IRR debate?. The Quarterly Review of Economics and Finance 50(2): 234-239.

Phuong, N., Binh, L. D. (2009). It is necessary to price mineral resources in the policy "Economy of the Geology - Minerals sector". Proceedings of the conference on mineral resources and mining industry in our country: current situation and solutions. Office of the Party Central Committee. Ministry of Natural Resources and Environment (in Vietnamese).

Phuong, N., Huan, T. D. (2018). Establishing criteria for calculating ore reserves and assessing the economic value of Na Tum Pb - Zn mine in Bac Kan with the recovery of useful. The Fifteenth Regional Congress on Geology, Minerals and Energy of Southeast Asia (GEOSEA XV). HaNoi.

Torries, T. F. (2014). Evaluating mineral projects: applications and misconceptions. SME, 1998.

Wu, J. C. (2007). The mineral industry of Vietnam. 2006 Minerals Yearbook: Vietnam. US Geological Survey, Reston, USA.

Zhang, L., Yang, J., Cai, Z., Yuan Z. (2014). Analysis of copper flows in China from 1975 to 2010. Science of the Total Environment 478, p 80-89.