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# COST ASSESSMENT OF GOLD ORE DEPOSITS ADJUSTED FOR CAPITAL INVESTMENTS

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The paper focuses on the problems of geologic and economic assessment of mineral deposits. Existing methods have certain advantages and disadvantages, but always rely on unified assessment criteria that fail to take into account specific parameters of each deposit. The author proposes a method of quick and simple cost assessment of gold ore deposits based on ore reserves data. Suggested approach allows to evaluate a true price of gold ore deposits that takes into account field preparation and development costs, as well as to calculate threshold (recommended) amount of investment. Besides that, the method permits to assess the contribution that mineral reserves and resources make to the cumulative market price of the mining company.

The method is based on the analysis of empirical data from actual purchases of gold ore (and associated metals) deposits made by Polymetal International PLC. The results of statistical research are incorporated in a formula of threshold deposit price taking into account field preparation and development costs. Comparison between deposit prices obtained from actual purchase deals and forecast results demonstrates high convergence rate ($R$ = 0.97). The greatest error in the forecast results is attributed to insufficient attention to the geographical position of deposits, existence of infrastructure and relevant facilities. The method has been tested on three purchases of gold ore assets made by Polymetal International PLC and demonstrated high convergence with actual deal prices.

***Key words*:** deposit assessment; investment; deposit costs; reserves assessment

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**Introduction.** Over the past decade, gold mining stayed one of the most promising industries for investment, which is proved by the interest it arouses among a sufficient number of investors. Since 2008 the global production of gold is continually rising, but active development of gold ore deposits results in depletion of easily accessible resources and the need to tap into more complex and hard-to-recover reserves. Exploitation of complex deposits leads to increasing capital costs, and potential investors place higher demands on assessment tools allowing to forecast future profitability of deposits. Development of an effective method to assess the price of the deposit which would allow to forecast profitability of its purchase and exploitation, is a critically important task, both in Russia and abroad [11, 12]. The method can also be used to calculate economic effect from geological exploration [4, 7].

**Discussion.** The key assessment methods of mineral deposits in Russia and abroad are the ones based on income approach (cash flow discounting method), its modification – Edwards-Bell-Ohlson valuation model [2], cost and comparison approaches. The most widely-spread assessment method utilized to define the price of deposit acquisition is the auction selling approach with the elements of reserves valuation [1, 5].

Existing methods of cost estimation have a range of disadvantages. They do not fully encompass geological complexity of deposits, uncertainty of technical and technological parameters, volatility of economic, mining and engineering conditions in the process of field development. These factors hinder accurate estimation of the acquisition price, which complicates the process of decision making (or renders it altogether impossible). Hence, it is evident that up until now there is still no efficient method of geologic and economic valuation of mineral deposits.

The quality of reserves valuation and potential risks of their exploitation are directly related to increasing profitability of the deposits. The most rational way to make a decision on purchasing a mineral deposit is to develop a techno-economic (i.e. mathematical) model. Such model allows to compare characteristics of the deposit with development costs and to prove the possibility of a positive outcome. One of the systems that facilitate decision making in the area of deposit acquisition and

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development is a scoring model of reserves valuation [10]. It is based on reserves data in the categories measured, indicated, inferred, proved of similar deposits developed earlier. As a final result, the assessment allows to divide potential deposits into two groups: profitable under current economic conditions and those whose development is currently unfeasible.

The scoring model significantly enhances the speed of decision making on deposit acquisition and gives the investor more certainty regarding the decisions they have made. In order to classify deposits into several groups, the following information is needed:

- location, climate, transport logistics;
- deposit size, amount of reserves in each category;
- ore extraction and processing technologies;
- proposed method of deposit exploitation;
- mining, geological and hydrogeological conditions;
- presence of processing facilities and transport infrastructure.

Thus, scoring models are statistical models of company's paying capacity, as a deposit (or a group of deposits) represents a core asset of the mining company.

To assess the feasibility of deposit exploitation, it is customary to analyze presence and amount of proved reserves. Investor needs to understand the amount of reserves ready to be developed as well as the amount of potential reserves whose exploitation is currently unfeasible.

Factors that have a significant influence on the deposit price and feasibility of its development include:

- operating conditions – net pay, cover thickness, hydrogeological parameters;
- quality of mineral resources, e.g. commercial element content;
- state of infrastructure in the regions of mining operations;
- gold prices;
- mining, technical and environmental conditions of field development;
- technological properties of the ore (primary, oxide, refractory);
- deposit location in regard to transportation routes, processing facilities etc.;
- construction period and capacity of the mining plant;
- exploitation period;
- availability of labour resources;
- current system of taxes, fiscal charges, payments for the use of natural resources etc.

On a provisional basis one can divide all the above mentioned factors into three groups: mining/geological, geographical and economic. In a simplistic form, the scoring model represents a weighed sum of specific mining, geological, geographical and economic characteristics. The resulting value is an indicator of capital investment for the deposit in question.

Each deposit's indicator is compared to the calculated threshold level, i.e. a break-even point. Its physical significance is the amount of financial resources spent on capital investment in order to start development of the deposit and to make up for the initial capital costs as well as subsequent O&M costs. Deposits whose indicators fall below this threshold are potential candidates for exploitation.

**Methodology.** In the current situation it is proposed to utilize the method of cost assessment based on the analysis of already conducted deals published by large Russian gold-mining companies and the analysis of investments into producing deposits. The assessment method is based on the prices of purchase deals, exploration costs, construction and equipment investments.

This approach has already been discussed in literature [3, 6] and assessed deposit costs based on resources value. However, it lacked one important factor – the cost of geological exploration and capital investment. Taking into account growing complexity and hindered accessibility of new deposits, the role of these expenses becomes critical. Specification of rock types, mining and geological conditions and content of commercial elements requires different approaches to mineral processing and strongly influences capital costs of the project.

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Inclusion of these costs into the assessment is necessary not only for an investor as a potential buyer, but also for the state administrating geological exploration and setting budget incomes from natural resources taxes and selling the right to use the subsoil.

Suggested method will allow to assess the following parameters with a greater degree of accuracy:

• costs of deposits with a minor share of reserves or low-quality ore;

• objective costs of low-profitability deposits, enlisted in the State Register of Reserves;

• risks of developing new mineral deposits.

Objective assessment of deposit costs lays the foundation for defining preferential conditions and attracting investors.

Development of the cost assessment method for mineral deposits has been based on the analysis of a major player on the CIS market of gold and complex gold-containing deposits - Polymetal International PLC (Table 1). The company has been chosen for a number of reasons:

• deposits are purchased from former owners based on market deals in a competitive environment, which indicates valuation fairness;

• information on profitability of deposits with different ore types, including complex types (refractory ores etc.), in different CIS regions (diverse climate, transport infrastructure, energy facilities);

• transparency of the company's operations (level of profitability derived from financial reports allows to select deposits for further analysis).

*Table 1*

**Information on Polymetal purchase deals and mineral deposit CAPEX***

| Deposit | Reserves and resources, AuEqv t | | Trade value, million USD | CAPEX, million USD | Acquisition price + CAPEX |
|---|---|---|---|---|---|
| | | Magadan | | | |
| Kubaka | Measured | 4.48 | 21.3 | 55 | 76.3 |
| | Indicated | 3.93 | | | |
| | Inferred | 2.41 | | | |
| Birkachan | Proved | 13.29 | | | |
| | Inferred | 0.00 | | | |
| Oroch | Measured | 5.99 | | | |
| | Indicated | 14.92 | | | |
| | Inferred | 10.13 | | | |
| Sopka Kvartsevaya and Dalneye | Indicated | 31.52 | 94 | 42 | 136 |
| | Inferred | 11.14 | | | |
| Olcha | Inferred | 22.43 | 13.5 | 15 | 28.5 |
| | | Chukotka | | | |
| Mayskoye | Proved | 1.80 | 99.5 | 205 | 304.5 |
| | Indicated | 9.98 | | | |
| | Inferred | 139.42 | | | |
| | | Khabarovsk Krai | | | |
| Svetloye | Inferred | 34.30 | 9.3 | 51 | 60.3 |
| Albazino | Proved | 44.15 | 7 | 58 | 65 |
| | | Kazakhstan | | | |
| Varvarinskoye | Indicated | 99.23 | 277.5 | 81 | 358.5 |
| | Inferred | 13.6 | | | |
| Komarovskoye | Indicated | 43.5 | 100 | 6 | 106 |
| | Inferred | 0 | | | |
| Bakyrchik and Bolshevik | Indicated | 258 | 618.5 | 320 | 938.5 |
| | Inferred | 91 | | | |

* CAPEX – capital expenditure – capital investments, acquisition or renovation costs of capital assets

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*End of Table 1*

| Deposit | Reserves and resources, AuEqv t | | Trade value, million USD | CAPEX, million USD | Acquisition price + CAPEX |
|---|---|---|---|---|---|
| Promising deposits | | | | | |
| Kutyn | Measured | 11.14 | 67 | | 67 |
| | Inferred | 22.25 | | | |
| Svetloborskoye | Inferred | 28.41 | 9.7 | | 9.7 |
| Maminskoye | Proved | 9.16 | 86.5 | 1 | 87.5 |
| | Measured | 1.37 | | | |
| | Indicated | 1.71 | | | |

Other Russian gold mining companies publish only general information on the deals but do not specify exact trade value of their acquisitions, or purchase directly from the state – those are not market deals and their prices cannot be considered objective and fair.

Deposits, selected for the purposes of a comparative analysis, had to satisfy the following conditions:

• reserves must be in the categories measured, indicated, inferred, proved. Reserves in the category probable are not taken into account as they imply a high degree of uncertainty, which increases the risk of inaccurate estimation [13, 14]. Assessment is based on reserves proved as of the moment of transaction;

• deposits have to be purchased under competition, i.e. at a market price, with an exception of deposits adjacent to operating licensed areas. All the deposits from Table 1 meet this condition.

Cost assessment of gold-ore deposits is based on the detection of a linear correlation between investments and the amount of reserves using least square method (LSM).

$$F(a,b)=\sum_{i=1}^{n}(y_i-(ax_i+b))^2. \quad (1)$$

Results of the proposed method imply identification of linear effect slopes, at which the function form $a$ and $b$ adopts its highest value.

Data from Table 1 have been generalized in Table 2.

Specific value of investment equals 2.4 million USD/ton. Due to the absence of corresponding CAPEX values, results for deposits Kutyn, Svetloborskoye and Maminskoye turned out to be incorrect. In order to ensure accuracy of the assessment by eliminating outliers, data on these deposits have been excluded from the analysis.

A standard system of equations can be constructed as follows:

$$\begin{cases} a\sum x_i^2+b\sum x_1=\sum x_i y_i, \\ a\sum x_i+bn=\sum y_i, \end{cases} \quad (2)$$

where $x$ – amount of reserves, tons; $y$ – acquisition price including CAPEX, million USD.

The system will look as follows:

$$\begin{cases} 167775a+855b=434224, \\ 855a+9b=2074. \end{cases}$$

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*Table 2*

**Specific indicator of investments per ton of Polymetal deposit reserves**

| Deposit | Reserves, t | Acquisition price + CAPEX, million USD | (Acquisition +CAPEX)/reserves, million USD/t | Deviation from specific indicator, % |
|---|---|---|---|---|
| Kubaka | 55.15 | 76.3 | 1.4 | –42.5 |
| Olcha | 22.43 | 28.5 | 1.3 | –45.8 |
| Mayskoye | 151.20 | 304.5 | 2.0 | –16.7 |
| Svetloye | 34.30 | 60.3 | 1.8 | –25.0 |
| Albazino | 44.15 | 65.0 | 1.5 | –37.5 |
| Kutyn | 33.39 | 67.0 | 2.0 | –16.7 |
| Sopka Kvartsevaya | 42.66 | 136.0 | 3.2 | +33.3 |
| Komarovskoye | 43.50 | 106.0 | 2.4 | 0 |
| Varvarinskoye | 112.83 | 358.5 | 3.2 | +33.3 |
| Kyzyl | 349.00 | 938.5 | 2.7 | +12.5 |
| Svetloborskoye | 28.41 | 9.7 | 0.3 | –87.5 |
| Maminskoye | 12.24 | 87.5 | 7.1 | +195.8 |
| Sredneye | 929.26 | 2237.8 | 2.4 | – |

The system can be solved using Cramer rule:

$$\Delta a = \begin{vmatrix} 434224 & 855 \\ 2074 & 9 \end{vmatrix} = 2134642;$$

$$\Delta b = \begin{vmatrix} 167775 & 434224 \\ 855 & 2074 \end{vmatrix} = -23456831.$$

As a result of calculations, coefficients of the approximation function are:

$$y = ax + b, \text{ where } a = 2.74,\ b = -30.13. \quad (3)$$

Graphic interpretation of the dependency is presented in Figure 1.

Amounts of investment (Table 2) and reserves demonstrate relatively high convergence of $R^2 = 0.97$ (Fig. 1). It means that suggested model as a modification of the comparative approach serves as convenient tool that allows to calculate trade value taking into account future investments.

In the explicit form, optimal amount of investment adjusted for CAPEX can be expressed as follows:

$$y_{CAPEX} = (2.74x + 30.13) - M_{100}, \quad (4)$$

where $M_{100}$ – full (100 %) acquisition price of the deposit, million USD.

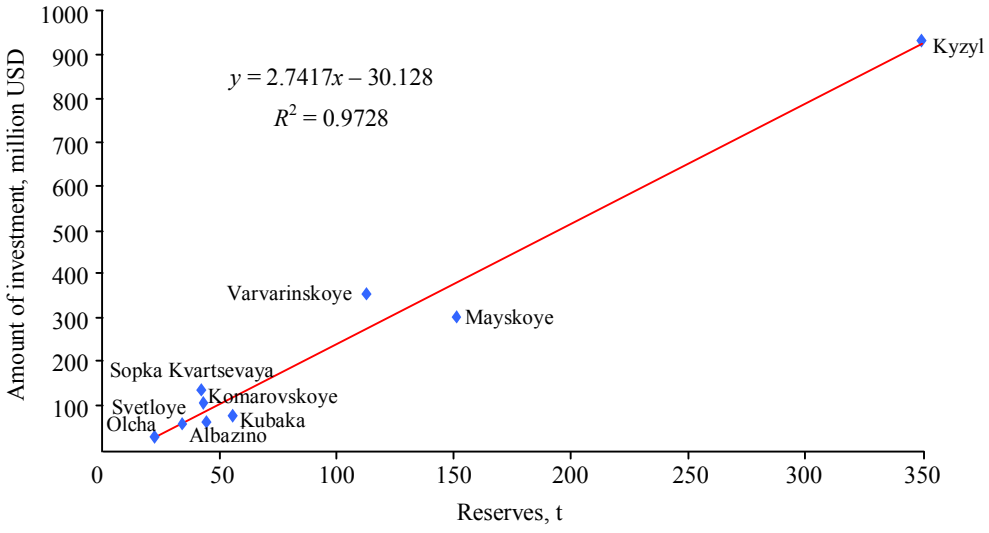



Fig. 1. Dependency of investment adjusted for CAPEX on deposit reserves

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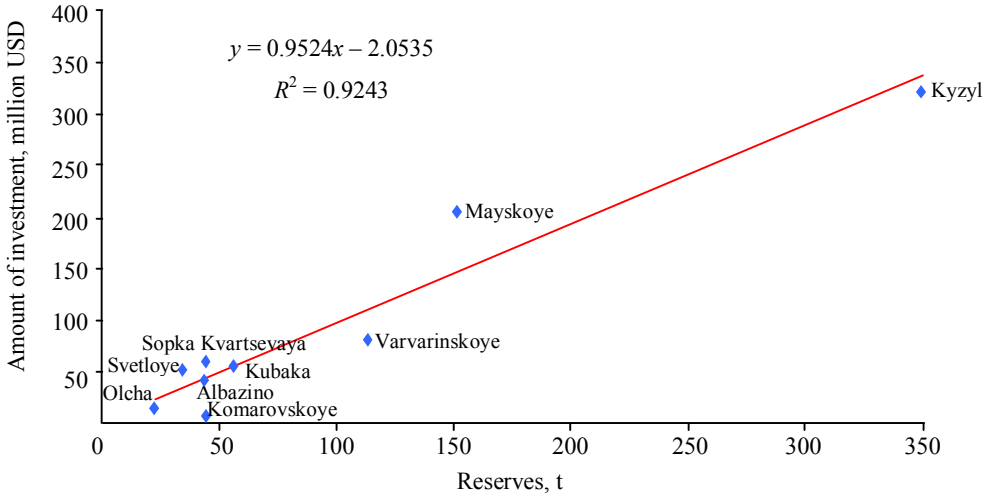



Fig. 2. Dependency of CAPEX on deposit reserves

CAPEX value is a ceiling for the investor, and if a forecasted value exceeds a calculated optimal one, it means that the deal is worse than an average market transaction and the investment will be economically inefficient.

Using derived calculation formula, threshold CAPEX values have been identified for deposits, excluded from the analysis, as well as for those regarded by Polymetal as promising.

Threshold CAPEX values for deposits excluded from analysis are, million USD: Svetloborskoye 38.1, Kutyn – 5.6, Maminskoye – 83.1. From the obtained results it is evident that for Kutyn and Maminskoye deposits CAPEX values are negative, which means that the prices of their acquisition have been unreasonably high.

Deposit Nezhdaninskoye, a 15.3 % share in which Polymetal purchased for 18 million USD, is a very promising project of the company. The price of 100%-share deal is estimated to be around 120 million USD, with gold reserves in categories *measured*, *indicated*, *inferred*, *proved* amounting to 230 tons, threshold CAPEX level reaching 480.5 million USD.

This approach can be applied when the purchase price of the deposit is stated. But what does one do if the purchase price is unknown, or on the contrary, the buyer has limited financial resources and wishes to obtain a certain trade value? It is possible to use the same approach, but to select deal price and CAPEX as variables. In the latter case the convergence will also be relatively high with $R^2 = 0.9243$ (Fig. 2).

In the explicit form, optimal amount of CAPEX can be expressed as follows:

$$y_{\text{CAPEX}} = 0.9524x + 2.0535. \quad (5)$$

Thus, calculating threshold amount of investment using formula (5) and subtracting CAPEX from formula (4), one can estimate threshold cost of the deposit.

Taking into account assessment principles and the possibility to add new data, one can state that suggested method provides an accurate and efficient valuation of the deposit cost, and due to its flexibility and the opportunity to include information on new transactions allows to increase precision of estimations and recommendations regarding deposit acquisition.

**Conclusion.** Suggested method is an initial step towards efficient assessment of gold-ore deposits taking into account growing complexity and limited accessibility of mineral resources. However, there is a need to create a unified database on investments, performed transactions and capital costs, which will allow investors to make more accurate estimations of the trade value, future capital costs and to mitigate financial risks. The government, in its own turn, will be able to implement resource base development projects with greater efficiency and to set a fair price for subsoil users. All these improvements together will enable quicker preparation and exploitation of mineral deposits.

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Suggested method allows to assess threshold price of the project and implies a possibility to impact the negotiation process of the deal, so that potential investor could accurately evaluate the prospects of deposit acquisition and his future income.

Valuation method can be further improved and developed, as currently there is a need for a simple, transparent and accessible approach to cost assessment of mineral deposits, based on both amount of its reserves and the expected value of required investments.

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