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Estimation of efficiency of development of copper and gold deposits of Krasnoyarsk North¹



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Abstract. The article presents the probable approach to the assessment of the availability of the mineral deposits. This approach is specially created for initial estimation of resources and reserves of low degree of exploration. As the initial data

the most significant parameters of a deposit are used, which can be proved objectively. These parameters are valuable components in ore, volumes of ore reserves, strip ratio, mining technology. The results of preliminary economic estimation of efficiency of development of predicted gold and copper deposits of the Krasnoyarsk North are presented. Economic efficiency of development of gold deposits Nizhnelitkinskoye, Groznenskoye, and Zhilnoye are estimated. The development of copper deposits is inexpedient.

Keywords: *mineral resources, production efficiency, the probability of development, copper and gold deposits*

With the increase of efficiency of the development of potentially attractive mineral deposits, with the development of the system of licensing of subsoil use and the growth of share of private investors in the domestic mineral and raw materials complex, the need for rapid assessment tools for mineral deposits is increasing, which would promptly let to perform the assessment without time-consuming calculations, without wide range of specialists and using a large amount of initial information. Especially such methods are in demand for assessing the efficiency of field development at the early stages of stock research.

The accuracy of such estimates of the predicted effectiveness of field development is influenced, on the one hand, by a low degree of reliability of geological information on the size

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and quality of the reserves, on the other hand, insufficiently substantiated and subjective economic information on the expected costs for mining and processing of minerals. The estimate is subjective because there is no formalized method for selecting of the analog field. In other words, since there are no two identical deposits and there is no method of bringing them to a "comparable type", the choice of the developed field as the analog for estimated costs of a prospective field will depend on the expert's experience, and will therefore always be subjective. In addition, the expected costs for the development of a new field, obtained by the analogy method, are not always sufficiently justified, since the information on the actual costs of enterprises related to their commercial interests is often inaccessible and unreliable.

In addition, the efficiency of the development of fields is influenced by the factors which are not directly related to the parameters of the development of specific reserves, but characterizing general conditions of subsoil use and the specific investment climate in the region. These factors often cannot be considered even at the stage of the feasibility study of field development.

The method proposed by the authors makes it possible to evaluate the probability of involving deposits in the development, based on the available geological information about the size and quality of the stocks of the aggregate deposits of this genetic type of the regional mineral resource base. With the use of the threshold availability curve (boundary probability), the calculated values of the specific operating costs for the development of deposits located at the margin of profitability can be received. This is a kind of analogue of the maximum permissible, closing costs, allowing to carry out the estimation of costs for deposits of a given genetic type of a given raw material base. In addition, the proposed method allows to consider not only the value of individual deposits, but also the effects of their mutual influence, as well as various, non-formalized social and economic factors, since the estimation of the probability of involvement in the development of a deposit is carried out against the background of other developed and reserve deposits in the region.

It seems that the developed method can make a significant contribution to the methodology for assessing the effectiveness of development in the context of limited initial data and their low accuracy at the early stages of subsoil studies.

The essence of the approach is as follows: based on the data of the State Balance of Mineral Deposits, the "reserves-maintenance" diagrams are constructed for industrial types of deposits for a given region, with the allocation of reserve and in-use facilities.

The developed and reserve deposits are allocated. Using the logit regression procedure, the function of ownership of objects to the classes of developed and undeveloped is determined, that is, the probability of involving deposits in the development (P) is determined depending on the size of the reserves and the content of useful components in the ore (1).

$$P = \frac{\exp(b_0 + b_1 \lg \alpha + b_2 \lg S)}{1 + \exp(b_0 + b_1 \lg \alpha + b_2 \lg S)}, \quad (1)$$

where b_i — the coefficients of the model; α — content of the useful component in the ore (for complex ores — the equivalent content of useful components), d. unit; S — ore reserves, thousand tons.

The coefficients of the b_i model are determined statistically based on the analysis of the distribution of the developed and undeveloped deposits within a specific regional raw material base.

The possibilities of using the approach are considered in [1, Kharitonova, M.J., Matsko, N.A., Mikhaylov, A. G; 2, Kharitonova M.Y., Matsko N.A]. This article presents the results of its application to the assessment of the efficiency of development of copper-bearing and gold-bearing deposits of Krasnoyarsk North.

Gold-bearing deposits

Using the probabilistic approach, a preliminary economic evaluation of the efficiency of development of gold-bearing objects in the North of the Krasnoyarsk Territory was carried out based on the size of reserves, content, market conditions, the current state of the gold's raw materials base in the region. The most promising projected deposits located in the southeast of Bolshevik Island were estimated. Ore deposits and gold mineralization zones on Bolshevik Island are associated with quartz veins, quartz-carbonate breccias, pyrite-laden ferruginous sandstones. Gold is of predominantly low-sulfide gold-quartz and sulphide types [3, Samoylov A.G., Vanyunin N.V., Timkin S.B.].

As can be seen from the "reserves-maintenance" diagram, made for the gold deposits of the Krasnoyarsk Territory with an open-cast mining method (Figure 1), the gold deposits Groznenskoye, Nizhnelitkinskoye, and Zhilnoye are rich and significantly superior to the rest by their main characteristics. To estimate the probability of development of these deposits, the estimated resources were transferred to the conditional category C_1 with the help of coefficients developed by Federal Agency on Subsoil Usage. The estimated probability of involvement of these deposits is 0.9, which significantly exceeds the values for other reserve deposits in the Krasnoyarsk Territory (Table 1). Estimate of costs for the development of the studied fields, performed with

use of the probability indicator of the development, showed that the specific operating costs per gram of gold are 5.6 \$/g (Groznskoye), 7.8 \$/g (Nizhnelitkinskoye), 9.3 \$/g (Zhilnoye). This will allow to achieve efficiency of development (as a ratio of price to cost) 8; 5.8 and 4.8, which is higher than the average figures for gold production in the region.

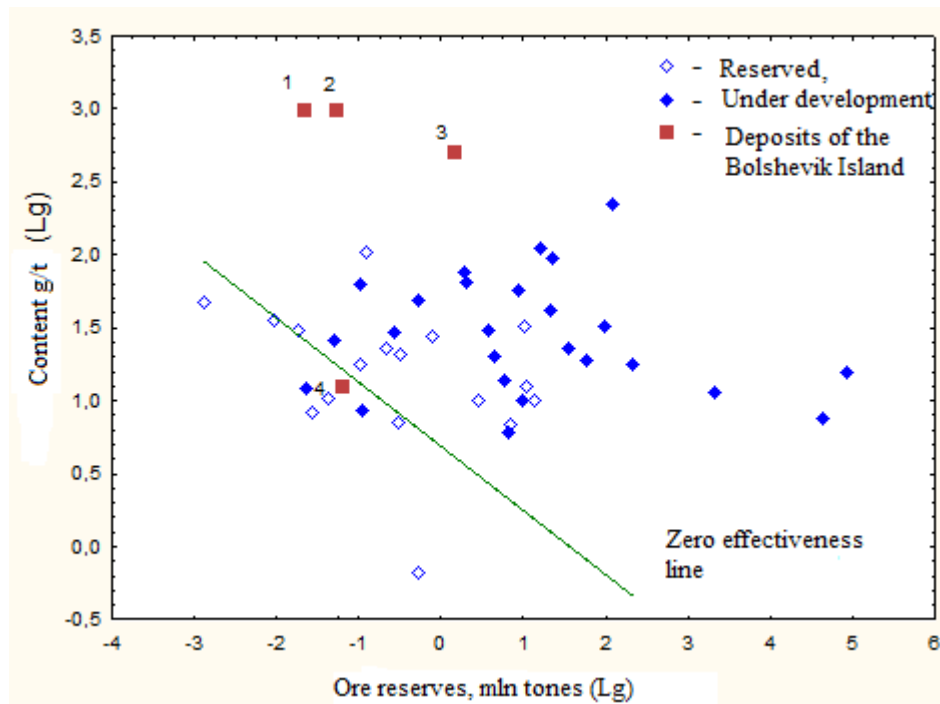


Figure 1. The "reserves-maintenance" diagram for the gold deposits of the Krasnoyarsk Territory. 1 — Zhilnoye, 2 — Nizhnelitkinskoye, 3 — Groznskoye, 4 — Izvilostoye.

Because of the simulation, it has been established that the development of the Izvilostoye deposit, whose ore reserves estimate after recalculation of the expected resources amounted to 0.3 million tons, with gold content in the extracted ore 3 g/t, is unprofitable. Expected effectiveness of the development of reserves (the ratio of the gold price to the specific operational development costs) <1 , net income is negative, the costs will not be covered. In the "reserves-content" diagram (Figure 1), the point corresponding to this deposit is below zero effectiveness line.

Table 1

*Expected effectiveness of gold mining at Bolshevik Island**

Indicator	Groznskoye	Nizhnelitkinskoye	Zhilnoye	Izvilostoye
Content g/t	15	20	20	3
Ore reserves, million tons	1.167	0.281	0.188	0.3
Period of supply with reserves, years	7	5	4	5
Probability of development	0.96	0.93	0.89	0.21
Annual ore output, thousand tons	172	59	43	62
Effectiveness, MU	8.01	5.8	4.8	0.89

Operating costs per gram of gold, \$/g	5,6	7.8	9.3	50.4
Effective reserves, t	15330	4647	2971	-

* The coefficients used in calculations are ones to bring the forecasting resources to the reserves of the conditional category C_1 , recommended by Federal Agency on Subsoil Usage for all ore minerals ($P_1 = 0.25$; $P_2 = 0.125$; $P_3 = 0.0625$)².

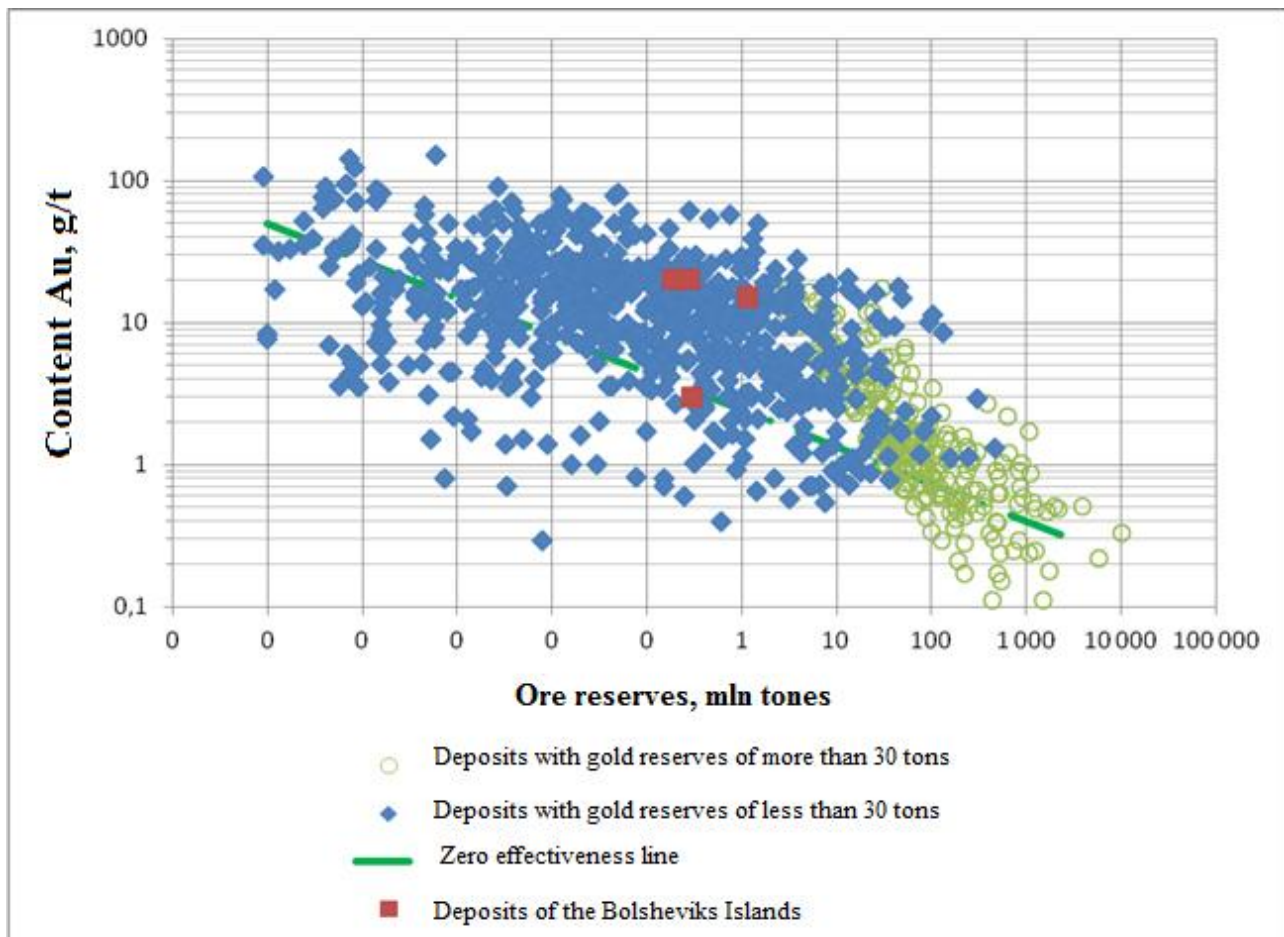


Figure 2. Gold deposits of Bolshevik Island and low-sulfide veins of the world

Considering that the level of profitability, with which the deposits are involved in the development in different regions and countries is different, it is interesting to see how the gold-bearing deposits of Bolshevik Island look like against the background of similar deposits in the world. Comparative characteristics (Figure 2) showed that the gold reserves of Groznenskoye, Nizhnelitkinskoye and Zhilnoye deposits are not large. However, their main characteristics (reserves and quality of ore) are highly competitive with the most world's lode deposits, and it is possible to say about high probability of their involvement in the development. Reserves of Izvilistoye deposit are much lower in content and against the background of the world's ones are

² Ministerstvo prirodnnykh resursov i ekologii Rossiiskoi Federatsii. Prikaz ob utverzhdenii metodiki po opredeleniiu startovogo razmera razovogo platezha za pol'zovanie nedrami ot 30 sentiabria 2008 g. № 232.

marginal effective. Because the business requirements for the profitability of projects in Russia are much higher than in other countries, its development is hardly possible.

Copper-bearing deposits

Estimation of the prognosticated copper-bearing deposits of Taimyr was carried out using the probabilistic approach by modeling the probability of development (formula 1). In Figure 3 there is a diagram for copper ore deposits in Russia. Since about half of the deposits are complex in their composition and contain other non-ferrous and precious metals as the associated components, the ordinate shows the equivalent copper content, which was calculated considering the content and price of associated useful components.

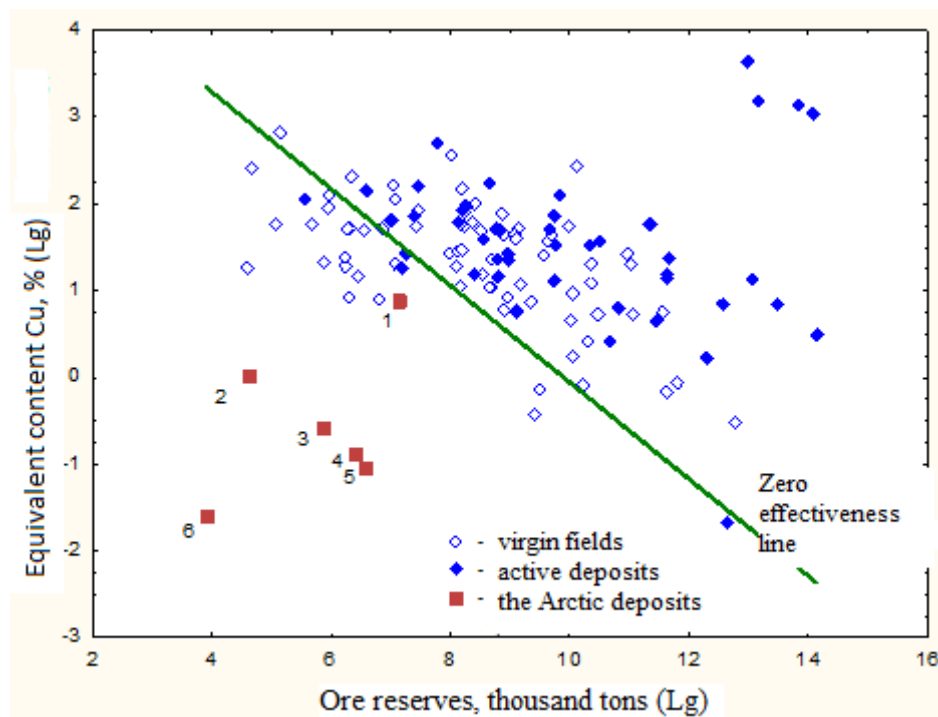


Figure 3. Copper-bearing deposits of Russia. 1 — Graviyskoye, 2 — Sukharinskoye, 3 — Imangdinskoye, 4 — Arylakhskoye, 5 — Ikechenskoye, 6 — Porfirovoye.

The following prognosticated copper-bearing deposits of the Krasnoyarsk North were studied: Graviyskoye (north-east of Igarka), Sukharinskoye (lower reaches of the Yenisei River, Sukharikha River), Ikechenskoye (Kulyumbe River), Arylakhskoye (upper Pyasina River), Porfirovovoe (In the northeast of the Mountainous Taimyr), Imangdinskoye (south-east of Lake Melkoye, the river Imangda). These deposits are below the zero-efficiency line in the "reserves-maintenance" diagram, they have a probability of developing below the boundary for this type of raw material (the boundary probability of development is 0.182). Evaluation of development of the effectiveness is given in Table 2. The efficiency of development, calculated as the ratio of the price of finished products to operating costs, for all evaluated fields is less than one. Thus, at present, with the

existing supply of reserves, the construction of mining enterprises since the Graviyskoye, Sukharinskoye, Ikechenskoye, Arylakhskoye, Porfirovovoe, and Imangdinskoye fields is inadvisable. Gravel deposit, with ore reserves of 1259.9 thousand tons and a copper content of 2.42%, located on the diagram (Figure 3) near the boundary efficiency line, during the change of the economic conditions (price change, the emergence of new technologies) can become cost-effective.

Table 2

Prognosticated efficiency of copper production at Taimyr fields

Indicators	Graviyskoye	Sukharinskoye	Ikechenskoye	Arylakhskoye	Porfirovovoe	Imangdinskoye
Content, %	2.42	1.02	0.35	0.41	0.2	0.55
Ore reserves, thousand tons	1259.9	102	725	600	50	358
Period of supply with reserves, years	6.70	3.60	5.83	5.60	3.00	4.9
Annual ore output, thousand tons	180.51	27.40	119.26	103.48	16.05	70.29
Operating costs per ton of metal, \$ / t	13 439	129 538	126 461	119 970	983 180	118 397
Total capital development costs, mln. \$	736	281	596	554	214	37
Efficiency, MU	0.52	0.05	0.06	0.06	0.01	0.06
Probability of development, MU	0.099	0.009	0.010	0.011	0.001	0.011

Conclusion

Thus, the assessment of the potential efficiency of the development of prognosticated copper and gold deposits in the Arctic part of the Krasnoyarsk Territory has showed that with the current state of the regional copper and gold resource base, only the gold deposits Zhilnoe, Nizhnelitkinskoye and Groznenskoye are promising. It can be expected that the involvement of these reserves in the development will be economically viable even against the background of other reserve deposits. Reserves of the Izvilistoye field are currently ineffective, but with the growth of gold prices or cost reductions (because of the introduction of new gold mining and processing technologies), they can become profitable in the future.

The volume of the reserves of copper deposits in Taimyr and the content of useful components in ores are much lower than the minimum acceptable values for effective development. In areas of the North where industrial, social and transport infrastructures are poorly developed, and climatic conditions are close to extreme, the capital and operational costs of developing of the deposits are significantly higher than in other regions. Therefore, the

development of small deposits of poor ores in the short term is unlikely from the economic point of view.

The conducted analysis has showed that at present there are no significant reserves of economically attractive copper and gold resources, except, of course, the Norilsk industrial area, in the Krasnoyarsk North. In this regard, the development of the territories requires the setting of large-scale prospecting and exploration works by modern methods to assess their resource potential. The relevance and role of scientific research aimed at developing of new technologies is rising. These new technologies will increase the availability of Arctic deposits and, thereby, contribute to solving of the economic, social, demographic and environmental problems of the North.

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