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FORMATION OF MINE PROJECT MANAGEMENT OBJECT USING CHARACTERISTICS OF MINERALIZATION FOR THE BENEFIT OF MANAGERIAL DECISION-MAKING AND BUSINESS PROCESS CONTROL*

As part of the holding, two gold deposits are currently under exploration and development. The analysis of the main concerns revealed the need to modify the algorithms and procedure of the approach to an object of management on the basis of outsourcing research of geological and mining patterns of mineralization. The proposed methods were applied at two explored deposits of the holding – poor vein ore and poor skarn gold–copper ores, both non-commercial reserves. The results of the studies of three deposits as objects of management with the potential of productivity and profitability increase require reformation of both the object and subject of business process management based on expert evaluation of mining and geological characteristics of the deposits.

Keywords: *gold deposits, management object analysis, subject, object, development and implementation*
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Introduction

Insufficient attention to geological and economic prospect evaluation at an early stage may result in uncertainty about feasibility or further exploration and development at the final stages of exploration. This is conditioned by geotechnical properties of rock and ore masses, or clusters of mineralization suitable or not for cost-effective industrial development. The complex deposits with poor and scattered metal content and / or the high geomechanical risks during mining in heavily deformed ore bodies and rock masses with negative economic indicators are very problematic to be approached with any business processes.

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At the same time, there are many objects, the industrial value of which can be changed and /or improved by creative research study approach to the object itself. The use of certain innovations, the justification of new non-traditional approaches to research studies and geotechnologies, can significantly improve the results — from negative economic indicators to cost-effective indicators. This requires new tools and approaches to operating a mineral deposit.

A mining project management system is more related to the risks of natural origin (reserves, grades, harmful impurities, distribution and quality of ore, geomechanical risks during mining, etc.). The economics of a mining project depends on and directly correlates with geological and geotechnical features, mineralization parameters and metal distribution patterns. There is a direct connection between the mine management methods and the above-mentioned features: adequacy and reliability of information about the deposit and mineralization characteristics [1].

Statistical variability of mineralization parameters and mineralization contours, as well as the variability and unpredictability of mining conditions determines the uncertain nature of a management system.

For three gold deposits within a holding company, as a result of the long-term non-optimal production indicators and business processes, the approach to the management object has been changed. The approach means a different attitude toward the study of patterns and characteristics of mineralization and selection of mining and pretreatment technologies with the justification of satisfactory production and economic indicators.

Range of problems connected with object of management

The scope of the study embraces three gold deposits of different genesis, commercial value and mining sequence:

— rich gold-bearing quartz veins of at the **Jamgyr** deposit [2];

— poor gold-bearing quartz veins at the **Sharildzhin** deposit [3];

— very poor gold-bearing copper–skarn ores of the Aktash deposit.

1. **Jamgyr deposit**: fourteen ore bodies in exploration and nine ore bodies in mining. The ore bodies are thin gold-bearing quartz veins in a regular structural–kinematic position of shear zones. The average gold content within the explored contours is 9.9–12 g/t. The proven reserves and probable resources are estimated as more than 60 tons of gold. Underground mining technology. The main difficulties are listed below [2]:

— The thickness of the ore bodies is 0.5 to 1.2 m, and the average thickness is 0.6m;

— The method of exploration drilling, with exposure of ore bodies per operation levels every 40 m with continuous observation along the perimeter of exploration blocks 40×40 m along the strike with an interval of up to 3.5 m, and in the flank raises along the dip with an interval of 3.5–4 m. The exploration drilling method is ineffective due to the discontinuity of mineralization — drilling intersections with standard grade ore is less than 30%;

— The exploration method very arduous, costly and disables sufficient stock of mineral reserves to be accumulated to ensure productivity more than 250 Kt/yr;

— The dilution is initial — regular discontinuity in the mineralization contour is from 14 to 25%, and total — more than 54% in mining with the system of open stoping with shrinkage in extraction blocks 40×40 m;

— The mineable ore with the gold content two times lower than the standard grade increases the specific operating costs and reduces total gold recovery;

— The productivity of stoping is 500–1000 tons per month per extraction block, which only allows an extensive increase in the mine productivity to above 200–250 Kt/yr;

— The investment planning horizon is over 50 years;

— The high cost of production — USD 180–192/t (gross profit margin for rich ores, 65.6%).

2. **Shiraldzhin deposit**

The main difficulties:

— very poor ores with an average gold content 3.28 g/t;

— high actual dilution during mining operations (>30%, >40%), which generates mineable ore with the gold contents from 1.68 to 1.92 g/t;

Table 1. Evaluation of reserves and gross margin

Aktash, by maximum stripping ratio	Units of measure	Stripping ratio	
		8	12
Proven reserves	Kt	2312.6	4072
Gold content, equivalent	g/t	1.86	1.50
Gold reserves, equivalent	kg	4310.4	6108
God content in marketable ore	g/t	1.69	1.36
Income	USD×1000000	208.64	295.65
Costs	USD×1000000	198.50	361.56
Gross margin	%	5.11	–18.23

— geotechnical conditions associated with the development of fracture zones and faults in parallel to productive vein bodies;

— complex geotechnical conditions for open stoping, which leads to high technical risks;

— at the cost of mining, by analogy with the Dzhamgyr deposit, USD 134/t (estimate) and total recovery of 88%, the profitability of gold in terms of its content in the ore is about USD 100.9/t. and therefore ores are assumed as non-commercial [3]. The gross margin is 34%.

3. **Aktash field.** Skarn gold–copper deposit. Scattered mineralization blocks–ore bodies. The reserves and gross margin are described in **Table 1**, the geotechnology is open pit mining.

According to the geological and economic evaluation, the expediency of development and further exploration of the deposit is attributed to a high degree of investment risks.

Expert evaluation tool for object management

As an object of management, characterization of mineralization and deposits collides with the established management system in a company [4–6]: the so-called "eye blurring" effect, when a management system presents the results in the form of generating a production plan and income. The accepted practice is reduced to the management a mine itself (functional approach), "distorts from the economic characteristics of the field development and creates practically unrealizable difficulties for proper geological information preparation, use and storage, which makes impossible appropriate managerial decision-making and managerial effect on an object of management object [7].

The tools used are determined by the concentration of expert evaluations and revision of a control object, i.e. the identification of patterns and characteristics of mineralization for subsequent modification and / or optimization of business processes, and enhancement of the project efficiency from feasibility study of an alternative approach to geotechnology. The object of management is overestimated as a natural formation with stochastic characteristics of mineralization (distribution of a useful component, thickness of ore bodies, discontinuity and discreteness of mineralization), geological and geotechnical conditions of its occurrence, and consequences of the afore-listed for the reasonable application and / or replacement: techniques and technologies, exploration procedure, methods of stripping and preparation of a mine field, modification in the system of mining, revision of the requirements for the quality and quantity of run-of-mine and commercial-value ore, and indicators of processing and recovery of a useful component.

Within the framework of the object approach for the purposes of an independent audit, it is chosen to transfer research questions on the control object to an external researcher which is not connected nor involved in existing management system [5, 8–10]. The outsourcing method allows independent researchers to eliminate the effect of inertia in considering different aspects of an object [3, 5, 8, 9, 11, 12].

The issue of authenticity and reliability of new information refers to three aspects. First, sufficient qualifications of external researchers. Second, time-unlimited research and free approach to the definition of research objectives. Third, motivation.

Outsourcing performance and evaluation

For outsourcing research, in view of science intensity, novelty, originality, as well as industrial applicability and approval, it is proposed:

To establish an innovation acceptance committee consisting of chief specialists of project management departments, the chairman of the board, chief geologists, chief engineer, directors of mines, chief miners, chief technologists, (or a representative of the development contractor of regulations and processing facility project), chief economist and other specialized specialists from related areas of expertise.

To accept outsourcing work after:

1) expertise and approval by state and expert bodies, and receipt of work permits (State Committee for Mineral Reserves of the Kyrgyz Republic, subsoil protection, industrial safety, ecology);

2) expertise of third-party specialists and / or design organizations, independent and not related to the company or executors;

3) publications in peer-reviewed specialized periodicals on theory and experience.

Examination, expertise, reviewing, etc. are carried out according to methodology of scientific and technical production reports and projects:

1. Expertise;
2. Review;
3. Collegiate discussion.

Checklist of estimation criteria:

- authenticity and reliability of results;
- methodological compliance;
- practical significance;
- marketability;
- economic and production effect;
- compliance with the norms and guidelines of state regulation in the industry;
- industrial and environmental safety.

Testing and promotion require:

- development of technical documentation according to the standards and procedures of the country localizing the project;
- Obtaining necessary expertise and permits.

It is necessary to apply a scoring system for the acceptance of research materials:

- up to 5 points for each specialist in related areas of expertise in the company, up to 40 points for the company's specialists in aggregate;
- 20–40 points for publications in specialized periodicals:

= indexed in Scopus, WoS — 40 points;
= indexed in RSCI (Russian Science Citation Index) — up to 20 points;
= expertize and approval by state authorized bodies — up to 40 points.

The readiness of materials for implementation, experimentation or detailed elaboration can be assessed according to the criteria on:

<40 points — not accepted;
<40–60 points — needs further development;
60–80 points — suited for evaluation and detailed elaboration;
80–100 points — suited for testing and pilot implementation;
>100 points — ready for commissioning.

Researcher motivation

1. Executers of works accepted for examination and implementation receive orders for creation of technical documentation without competition;

2. Stimulating remuneration — in introduction of new methods, technologies, systems, etc., executers under initial research contract may be payed interest or royalties from economic and / or production effect of R&D and implementation;

3. Material incentives of R&D and commissioning, or payment of profit interest or royalties are adjusted depending on the points received;

4. Further contracts for research expanding and/or supplementing, and detailed elaboration of accomplished R&D projects are concluded on a non-competitive basis.

Specialists from management of mines, companies and holdings come under the above-described procedure of research, project acceptance and implementation, including stimulating remuneration.

Commissioning and creation of technical documentation in cooperation with experts are subjected for separate payoff.

Transition from functional approach to mine management to the approach based on the management object — mineralization, its natural characteristics, quality and behavior, spread, geology, mining and processing technology and equipment — is targeted at economic effect. The change in the approach results not in the number of persons engaged but in the change in the management structure, program motivation, implementation programs, competences, skills, etc.

Results

Jamgyr deposit

Geological aspects. Structural kinematic interpretations of vein and ore bodies of the deposit. Morphological analysis of veins. Characteristics of distribution of gold. The discontinuity and regularity of ore localization are studied by the methods for determining discreteness, fractality of rock mass and ore blocks.

On the basis of fractal geometry, the hierarchies of self-similar blocks composing the deposit, and vein bodies as the boundaries of these blocks are determined with the conclusion on subordination of mineralization fractality and block structure. The fractality of block boundaries led to the description of characteristics of the extent dimension (step) of vein bodies with ore bodies in them.

On the basis of studies into distribution of gold and morphology of ore bodies, the reliability criteria for external and internal contours of mineralization are identified with the characteristic of the fidelity of exploration cross-sections vertically of the mineralization. The dimension and density of the exploration network up to 80 m vertically from the mine cross-section are proposed in collation of the reserves comparable to category C2 as per the classification by the State Reserves Committee of the Kyrgyz Republic. When creating an exploration network composed of two cross-sections spaced at 80 m, the reserves in the contour are comparable to category C1 as per the probable and geological error. Observations down the dip of ore bodies (carried out along the side raises spaced at 40 m) have no significant influence on determination of the main parameters of mineralization and on the appraisal of the reserves. The discrepancy of the reserves estimate and average gold content is not higher than 10–15%.

The discreteness of mineralization makes it possible to conclude that it is possible to eliminate secondary dilution (more than 54%) with avoidance of up to 76% of rock (granites) in invected in ore (quartz).

The company's department investigated potential of pretreatment by sensory sorting of ore by the criterion of atomic density. The investigations showed the possibility of marketable ore concentration of 36% with gold recovery of up to 96–99%, and with elimination of primary dilution due to dirt twitches in extraction blocks.

Based on § 3–5, a new geotechnology is proposed. The geotechnology includes a system of enlarged extraction blocks with dimensions of 80–120 m vertically and 120–160 m along the strike, and with access exploration drifts driven every 80 m down the dip. Preparatory mine workings — sublevel drifts driven every 13–26 m down the dip — have access to sublevels through short cross-cuts from haulage ramps. slopes. Haulage is carried out to reloading chambers of the local ore pass and to the portal of the concentration and support horizon by LHD. Drilling, blasting and haulage use small-sized machinery. Ore pretreatment, as per § 4 and 5, allows decrease in dilution by more than 60–70% with an increase in mining productivity and a decrease in specific operating costs.

The estimated cost of works is up to USD 98/t of ore, the gross margin is 224% [1].

Table 2. Operating costs of open pit mining at limit stripping ratio

Description	Unit of measure	Unit costs, USD$/t of ore	
Stripping ratios	t/t	17	35
Total operating costs	$	73.32	100.16

Shiraldzhin deposit

1. Ore pretreatment by sensor sorting:

• Ore 30/3 — 1.97 to 2.90 ppm, extraction up to 92.26%, cumulative yield 62.67%

• Ore 40/2 — 1.59 to 2.27 ppm, extraction up to 89.71%, cumulative yield 52.67%

• Ore 50/1 — 1.37 to 3.27 ppm, extraction up to 87.20%, cumulative yield 36.43%.

The substantiated geotechnology is open pit mining with maximum estimated stripping ratios up to 17 and 35 t/t (**Table 2**). The operating costs of underground mining is USD 116/t.

Ore pretreatment by sensory sorting reduces the properties of the diluted ore up to the marketable ore with the gold content up to 90%. Obviously, the proposed technology is decisive for the Shiraldzhin field.

Open pit/underground mining of the ore body Sterzhnevoy at a ratio of 60 : 40% to a large extent determines the economic parameters of the mining project.

The cost of hybrid open pit/underground mining is estimated as USD 108.5/t. With a revenue of USD 157.8/t of marketable ore, the gross margin is as up to 60%, with IRR from 10% to 31%, taking into account reduction of ROM ore up to marketable ore using Steinert technology. The level of preliminary assumptions is up to 15% [3].

Aktash deposit

1. The first analyses assumed that skarn gold–copper ore was processible by sensory sorting (Steinert, report No. 3 and 5, Miner's Week Symposium). The assumption was based on the experience of introducing sorting at 104 processing plants for various minerals (gold, copper, non-ferrous, rare metals). The concentration of mineralization ranges from 30 to 60% with the yield of the useful component from 86 to 99%.

2. The other hypothesis was based on the analysis of ore discreteness by the laws of fractality. The studied blocks of the deposit are distributed according to the following hierarchy: deposit, ore body sites, ore bodies, large blocks and 14 hierarchical levels of subsystems of blocky mineralization.

3. Based on the discreteness and basic hierarchical levels of mineralization, it was concluded on possibility of ore concentration up to 20% after pretreatment by sensory sorting of 60% and more of ore.

4. Geological appraisal of the deposit showed its profitability at maximum stripping ratios (> 8–12 t/t) up to IRR from 10 to 11.5% (gross margin 33.05%).

Table 4. Comparative economics of mining projects

Deposits and parameters	Unit of measure	Previous evaluation	Re-evaluation
Jamgyr			
cost	USD/t of ore	192	98
gross margin	%	65.6	224
Shiraldzhin			
cost	USD/t of ore	134	108.5
gross margin	%	–34	60
Aktash			
cost	USD/t of ore	85.83	67.8
gross margin	%	5.11	33.01

5. Discreteness and contours of mineralization, concentration of useful components and appraisal are described in **Table 3**.

Summary and discussion

The found discreteness and discontinuity of mineralization in three deposits of different nature but with similar parameters of influence on geotechnologies (costly and low-productive), the validated approach to elimination of primary and secondary dilution in ROM ore during mining, and the resultant indicators of concentration of the useful component in commercial ore as a result of low-cost pretreatment by sensory sorting made it possible to justify changes in the methods of accessing, preparing and mining ore bodies using more productive and less expensive processes at a certain estimated economic effect (**Table 4**).

The proposed management tools consist in research-based re-evaluation of actual resources of mineral deposits and in additional critical revision of existing data, decisions, calculations and justifications of geological, geotechnical and economic parameters of mining projects unlimited by geological and technical specifications. For the expert evaluation of the research and feasibility studies of mining and pretreatment technologies, materials and solutions are accepted by three stages:

1. By home specialists in related areas of expertise and by home management of companies and holdings;

2. By state authorized expert and licensing authorities (State Committee for Mineral Reserves of the Kyrgyz Republic, industrial safety, environmental impact, subsoil protection and geological departments);

3. By scientists and technical journals with independent review ranked by indexing and citation factor.

A motivation concept should be created, and ranking of relevance and applicability of materials and solutions at the previous three stages should be performed using a scoring system per the following levels:

— acknowledge;

— extend, present details and refine for the subsequent commissioning;

— introduce into production.

Table 3. Indicators for development options of the Aktash field

Indicator	Unit of measure	Stripping ratio, t/t							
		8	12	8	12	8	12	8	12
		Open pit	Open pit	Open pit	Open pit	Open pit	Open pit	Open pit	Open pit
C2 geological reserves	t×1000	2312.6	4072	2312.6	4072	2312.6	4072	2312.6	4072
Average content	g/t	1.86	1.50	1.86	1.50	1.86	1.50	1.86	1.50
Gold reserves	kg	4310.44	6108	4310.44	6108	4310.44	6108	4310.44	6108
Estimated minimum commercial content	g/t	1.34	1.39	0.97	0.99	0.60	0.62	0.28	0.29
Cut-off grade	g/t	0.84	1.08	0.60	0.77	0.37	0.48	0.17	0.23
Income	$×1000000	208.64	295.65	208.6	295.65	208.6	295.65	208.6	295.65
Costs	$×1000000	188	343.22	180.1	324.93	167.2	306.54	156.8	288.25
Profit	$×1000000	20.6	–47.57	28.53	–29.27	41.39	–10.89	51.78	7.41
Gross profitability	%	10.9	–13.86	15.84	–9.01	24.74	–3.55	33.01	2.57
IRR, 10 %		3.80		5.50		8.60		11.50	

Conclusions

The proposed procedures for re-evaluation of an object of management with concentration of studies into control objects represented by natural characteristics of mineral deposits allow effect in short terms, at minimal cost and minor modifications of a system of management.

The expert research of an object of management enable subsequent adjustment of subjects and objects of management depending on the obtained results of research and commissioning, which allows transition to the program control of business processes [7]. The authenticity and reliability of geological assessment of mineralization, which permits reducing variability of the object characteristics, enhances efficiency and improves predictability of business processes.

The real economic effect achieved at an insignificant cost of material encouragement of the outsourcing research allows predicting further increase in production and economic factors of mining projects.

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SPATIAL ORGANIZATION OF ARCTIC MINERAL RESOURCE CENTERS

In modern conditions of geopolitical instability, the problem of developing regional space to strengthen territorial integrity and ensure energy security is becoming increasingly important. The organization of mineral resource centers (MRC) is one of the effective forms of spatial development, especially for the regions of the Arctic zone. MRC contribute to solving the problems of integrated development of energy resources and the formation of a transport and logistics framework for poorly studied territories, which governs the effective advancement of the regional economy. The article systematizes the theoretical foundations for the development of MRC and updates the prerequisites for their formation in the Arctic. A conceptual scheme of territorial development is proposed with the allocation of the Arctic MRC in the north of the Krasnoyarsk Krai, a financial and economic model is built, an assessment of the main production and technical indicators is made, and the criteria for investment attractiveness are calculated. It is shown that the expediency of organizing the Arctic MRC is defined primarily by the strategic goals and objectives of the development of the Arctic zone at the federal level, and economic efficiency – by the development of a multi-level transport and logistics infrastructure. At the same time, despite large-scale capital investments and their long payback, the authors substantiate feasibility of developing the Arctic MRC through a high multiplier effect and propose a system for its assessment on the national, regional and corporate scales.

Keywords: *Arctic region, mineral resource center, transport system, spatial organization, oil export, Northern Sea Route, social and economic development*

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Introduction

Spatial development becomes increasingly more topical in the Russian Arctic and in adjacent countries to stimulate their social and economic advance. Russia has authorized some legal documents to support the regional development in the Arctic zone, including such strategic enactments as the: 2025 Spatial Development Strategy of Russia; 2035 Energy Strategy of Russia; Regional Social and Economic Development with Regard to Infrastructure; 2035 Strategy of Development of Mineral Resources and Mineral Reserves of Russia; 2030 Transport Strategy of Russia, etc.

The term of *spatial development* was introduced in the early 21st century, in the framework of spatial economy theory, and the term assumed a national economy as a multiregional integration of social, economic and social factors on a regional and international scale.

The issues of the spatial development and selection of effective stimulation tools for the regional development are the most debatable points in the community of