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Riskiness of development of subsoil resources

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Abstract
Relevance. The concept of risk covers all spheres of human life. With modern requirements for the organization of subsoil use, the issue of risks in the development of deposits and risk management in order to prevent them or reduce their consequences is becoming increasingly relevant.
The purpose of the research is to clarify the system of risks accompanying the process of subsoil use, and their characteristics.
Research methodology. In the course of the study, methods of system analysis, comparisons of analogies were used, which together ensure the reliability and correctness of the conclusions.
Results. In the course of the study, the manifestation of risks in the development of mineral deposits was clarified. The content of geological risk is disclosed from the standpoint of the reliability of various categories of reserves and forecast resources. The reliability of geological risks is associated with the degree of exploration of the deposit. The regularities of overestimation of reserves due to the growth of reliability coefficients (transfer) are revealed. The negative practice of transferring rights to subsoil users in relation to the ratio of the number of reserves of various categories is noted. Mining risk is characterized as uncontrollable, difficult to predict, not amenable to any patterns, which usually leads to accidents and catastrophic situations. A manifestation of environmental risk is the deterioration of the quality of the environment, the depletion of natural resources during the development of subsoil resources. A significant environmental risk is associated with the placement of technogenic mineral formations on the surface and the storage of washery refuse in tailings. Recipients are endangered by atmospheric and hydrogenous flows formed near the wastes and emergency breaks of tailings dams. Risk management at the pre-project stage is considered from the position of introducing adjustments for risks when justifying the discount rate. At the stage of field operation, risk management is a specialized activity. The main methods of management and sources of financing of activities, the basis of which is the chosen method of risk management, are considered.
Conclusions. The process of subsoil use is accompanied by a system of risks, which include geological, mining and environmental risks. At the pre-project stage, risk accounting is carried out through risk premiums. During the operation of the field - through risk management. The chosen management method makes it possible to develop appropriate activities focused on the goal.

***Keywords*:** subsoil use, risks, risk characteristics, risk management, losses, methods.

Introduction
The process of subsoil development, like any economic activity, is associated with the manifestation of various kinds of risks: natural, technical, economic, etc. As a rule, the risk is characterized by the unexpected occurrence of an adverse event. Most often, the definition of risk is a combination of the probability of an undesirable situation occurring and the consequences (the amount of possible loss if this situation occurs):

$$R = Px,$$

where R – quantitative measure of risk; P – the likelihood of an adverse event occurring; x – the amount of damage caused by this event [1–4].

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Table 1. Standards for reserves of various categories of exploration
Таблица 1. Нормативы запасов различных категорий разведанности

Field groups	Reserves categories			
	A	B	C_1	C_2
I	10	20	70	–
II	–	20	80	–
III	–	–	80	20
IV	–	–	50	50

Risk allows you to quantify the measure of expected failure, danger to human health, possible material and financial losses [5]. There are four approaches that characterize the risk [6]. The first considers the risk from the standpoint of the financial and economic results of the enterprise. According to this approach, risk is the danger of an enterprise losing resources, or not receiving income, or the occurrence of additional costs compared to those predicted.

The second approach defines the risk in terms of deviations from the planned course of events, deviations from the expected values (for example, a decrease in labor productivity, a violation of the rhythm of production, etc.).

The third approach, which is the most common, is the definition of risk from the standpoint of the possibility of an adverse event leading to various kinds of losses.

The fourth approach considers risk as the possibility (danger) of an adverse event, as a result of which the enterprise incurs losses, shortfalls in income, etc. Risk management, aimed at preventing risks or mitigating their negative consequences, requires information about the risks that take place in the process of production activities of the enterprise, including for activities related to the exploitation of mineral deposits.

Results

A specific feature of the enterprises of the mining complex is the subject of their labor, which is located in the bowels, and therefore it is characterized by the impossibility of a visual description. Information about the qualitative and quantitative parameters of the deposit, the shape of the ore body, the depth of its occurrence, the morphological features of ore bodies, associated useful components, etc. becomes available in the process of staging of geological exploration. From stage to stage, the degree of exploration of the deposit and, accordingly, the degree of geological knowledge increases. The share of reserves of higher categories A, B, C_1 is increasing. In general, according to [7], reserves of categories A, B, C_1 and C_2 and forecast resources of categories P_1, P_2, P_3 are subject to allocation. The built-up series of reserves and resources according to the degree of exploration has the form $P_3 \to P_2 \to P_1 \to C_2 \to C_1 \to B \to A$.

Geological risk is associated with the possibility of non-confirmation of mineral reserves due to insufficient reliability of the studied deposit, i.e. unreliability of geological information. The analysis shows that initially the calculation of reserves was based only on reserves of categories A, B and C_1. Over time, C_2 reserves and probable resources were introduced into the calculation. Naturally, with an increase in the share of predicted resources, the reliability of determining the value of reserves decreases, and non-confirmation of reserves leads to significant losses for investors (reduction of the annual productivity of mining, non-confirmation of quality characteristics, increase in cost, decrease in the period of development of reserves, etc. are possible) [8]. Low exploration of reserves and resources introduces an error in the calculation of reserves, which requires the introduction of reliability coefficients (conversion factors) for various categories.

It should be noted that there is a huge amount of these coefficients used both in legal documents and in the works of researchers and research teams. At the same time, the size of the reliability coefficients increases with time. Thus, the reliability of reserves (A + B) and C_1 in some cases began to be assessed as equal. The reliability of C_2 is estimated on average as 0.5, although in the reports of the MINGEO of the USSR its value was determined as 0,2. Particularly large claims relate to predictive resources. In particular, for hypothetical P_3 resources, the reliability coefficient is set at 0,07–0,125, in some cases even 0,2 [9]. Even more serious is the situation when, while calculating reserves, there is a rejection of reliability coefficients, which overestimates the size of reserves and leads to negative consequences [10]. The most dangerous is the risk of overestimating the content of useful components and the risk of incorrect geometrization of ore bodies [11].

The situation is aggravated by the fact that the increase in forecast resources has become a measure of the efficiency of the federal budget expenditures on exploration, and exploration of reserves has become the exclusive right of business [12]. Under these conditions, the practice of developing deposits, the calculation of reserves of which is based on categories with low reliability, has expanded, and this despite the fact that earlier the level of reliability of information was based on the ratio of reserves of categories A_1, B_1, C_1 и C_2 (Table 1) [13].

This condition was already canceled in the first Russian classification of reserves (in 1997) [14]. In the methodological recommendations on the application of the classification of reserves of a deposit (2006), as in previous versions, it is indicated that the subsoil user has the right to the ratio of the number of reserves of various categories [15].

In addition to the geological risk, there is also a mountain risk. Mountain risks are associated with such phenomena as karst, suffosion, karst-suffosion processes, landslides, ravine and river erosion, abrasion, flooding of territories, negative and positive deformations of the earth's surface, rock bursts, liquefaction, softening, swelling, frost heaving and shrinkage of soils, etc.

Karst hazard and the karst risk caused by this hazard are typical for deposits in the geological structure of which there are massifs of carbonate rocks, usually occurring at a depth of tens to hundreds of meters. The greatest karstification of massifs of carbonate rocks is observed in weakened tectonic zones in rocks with increased fracturing. In areas with a disturbed natural regime of groundwater, as a result of their pumping (pumping of groundwater is carried out at most mining enterprises), karst and karst-suffosion processes are activated, which leads to deformations of the earth's surface and the collapse of buildings and structures of the mining complex. Suffusion hazard and suffusion risk manifest themselves in the form of sinkholes and subsidence of the earth's surface, similar to karst, but having a smaller area and depth (up to 3 m), which in most cases does not exceed 2–3 m. Usually these risks arise when driving mine workings in the strata sandy rocks of Quaternary, Cretaceous and Jurassic age. Rock bursts, shocks, micro-shocks occur during the development of coal deposits. The probability of rock bursts and outbursts starts from a certain critical depth, usually below 150 m, provided there are potentially shock-prone rocks or a stressed state of the massif (rock or coal seam).

By the nature of predictability, the listed risks are almost all random – they may or may not be, the time and place of the occurrence of the risk is difficult to determine, the damage cannot be predicted. Unlike geological risks, for which many researchers have proposed various boundary quantitative estimates of errors in calculating reserves, mining risks do not lend themselves to any regularities, they cannot be measured quantitatively. Available risk assessment methodologies link these assessments to industrial safety, design work, and economic performance. The "risk maps", "risk matrices", etc. offered in the literature clearly show only the qualitative side of risk. A well-known scientist in the field of economics of mineral raw materials G. Yu. Boyarko notes [16] that the mining and technical risk is associated with the probability of the appearance of various operating conditions that have not been identified previously, but numerically does not go beyond the stability tolerance of engineering systems of 1%, with which it is impossible to agree, since numerically the risks can reach more than 5%, judging by the accidents at mining enterprises. Accidents and catastrophes occur mainly in underground mining and most often in the coal industry.

No less loss comes with an environmental risk, which, according to the law "On Environmental Protection", is defined as "the probability of an event that has adverse consequences for the natural environment and is caused by the negative impact of economic and other activities, natural and man-made emergencies." Many scientists in the field of ecology include in the concept of "environmental risk" along with the probability of a negative event "the amount of damage [17], i. e., as a quantitative measure of risk, they also use an indicator of the amount of damage caused by it. A. G. Shmal defines environmental risk as "the probability of receiving certain damage as a result of the manifestation of an environmental hazard factor or their combination in relation to a specific object of assessment" [18], i. e., on any natural or anthropogenic object. Currently available industry methods and regulatory documents make it possible to assess the harm and damage caused to any natural objects (environments). The total economic damage is defined as the sum of damages from various types of harmful effects on the environment. The existing environmental risk is associated with the presence of waste. Its disposal is the most effective solution to the problem of protecting nature from pollution. The toxicity of mining waste, such as tailings, classified as low-toxic and non-toxic, during long-term storage can significantly increase due to the transition of insoluble compounds and minerals into soluble forms during the oxidation process, when atmospheric precipitation containing free oxygen and acid solutions is filtered through it.

A change in the toxicity of waste over time leads to a complication of processing technologies, an increase in economic damage, impacts, consequences, corresponding payments and, possibly, refusal to process them. So, for large particles typical for overburden dumps, substandard ores, the delay in the increase in toxicity is 10–15 years. During this period, dust formation and oxidation processes are practically absent. After 20–30 years, as a result of seasonal temperature fluctuations and periodic moisture, the specific active surface of waste in the body of dumps and tailings begins to increase rapidly. No less harm is caused by enrichment waste. Millions of tons of waste are dumped during ore beneficiation. Their storage requires storage facilities that have appropriate capacities and meet the conditions of environmental protection. The storage capacity of any type – plain, slope, upland, floodplain, etc. – is designed based on the topography of the area. All storages are protected by dams or embankments, which are usually dumped from overburden. V. V. Malakhanov [19] provides an overview of the causes of accidents in earth dams according to various authors. The main ones are:

– insufficient capacity of spillways, which leads to water overflow over the dam crest (30–38% of accidents);

– seepage deformations of the body of dams and foundation soils (33–56);

– sliding and deformation of slopes (15%);

– wave effects (5%).

In order to ensure accident-free and safe operation of tailings facilities, the development of projects must comply with the special requirements set forth in the safety certificate 03–438–02 (updated on 01.01.2019), which clearly regulates all parameters and indicators of mining waste storage facilities. Accidents occur only when safety requirements are not met. At the pre-project stage of mining projects, the identification of environmental risks is included in the environmental impact assessment (EIA) procedure, based on the results of which environmental measures are developed to reduce or minimize environmental risks. The reasons for the implementation (manifestation) of the identified environmental risks in most cases are associated with a violation of environmental legislation, i. e. non-compliance with norms, regulations and rules in the field of environmental protection. Preventive measures allow a mining enterprise to increase the investment attractiveness of its business by reducing environmental risks in its current activities.

It should be noted the complexity of drawing up an EIA, its coordination with supervisory authorities, as well as, in general, permits for subsoil use. The study by G. Yu. Boyarko [20] describes a schematic diagram of "passing through" approvals of design decisions with state bodies, he also gave recommendations on reducing the bureaucratic burden on subsoil users and liberalizing these procedures. When performing various assessments (increase in waste toxicity and changes in the quality parameters of useful components, taking into account the activation of various negative processes) and

Table 2. The scale of premiums for the risk of reliability of determining mineral reserves depending on the group of complexity of the deposit and the category of reserves according to the degree of exploration

Таблица 2. Шкала премий за риск достоверности определения запасов ТПИ в зависимости от группы сложности месторождения и категории запасов по степени изученности

Groups of reserves according to the complexity of the geological structure	Reserve categories			
	A	B	C_1	C_2
I	0	0,25	1,0	3,25
II	–	0,50	1,5	4,00
III	–	–	2,0	4,75
IV	–	–	2,5	5,50

the mandatory environmental review procedure at the pre-project stage, environmental risks are minimized (3–5%), although the possibility of adopting new environmental acts in the direction of tightening (and in connection with this, the inevitable increase in investment costs for additional environmental measures) is not excluded. If the environmental risk is excessive and exceeds the income from the activities of the enterprise, it is necessary to look for other measures to manage environmental risks or refuse to implement the project (according to the principle of the Concept for the Transition of the Russian Federation to Sustainable Development – "... no economic activity can be justified if the benefit from it does not exceed the damage caused") [21].

Conclusions

As follows from the analysis, the process of subsoil use is quite risky and is accompanied by a series of risks: geological, environmental, etc. The authors of [22] combine all these risks into a group of geological ones. Reducing riskiness requires setting up risk management activities. At the pre-project stage, risks are taken into account when determining the discount rate through risk premiums.

$$d = r + \sum\nolimits_{r=1}^{n} P_i,$$

where d – discount rate; r – alternative risk-free rate; P_i – premium for i-th type of risk; n – number of risks considered.

In [23], recommendations are given on the value of the premium for geological risks (table 2).

At the stage of field operation, risk management becomes important [24, 25]. A methodical approach to risk analysis involves: risk identification, assessment of the probability of an adverse event, determination of economic damage. Generalized research on risk management allows us to identify the following methods of enterprise risk management:

– risk avoidance – the development of measures that exclude the occurrence of risky situations;

– risk reduction – reduction of the probability or magnitude of expected losses;

– transfer of risk – transfer of risk to third parties;

– risk distribution – division of risk between several different entities;

– compensation of risk – the creation of conditions that exclude the appearance of causes and risk factors;

– preservation (acceptance) of the risk – the absence of any actions in relation to the risk.

The selected risk management methods serve as the basis for the development of specific actions and activities. The source of financing can be: the cost of production, the company's own funds, credit and investment resources, insurance funds, special state budgetary and extrabudgetary funds. The economic justification of measures in the field of risk management is recommended to be carried out according to [6, 17].

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Рискованность освоения ресурсов недр

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Аннотация

Актуальность. Понятие риска охватывает все сферы человеческой жизни. При современных требованиях организации недропользования все более актуальным становится вопрос о рисках при освоении месторождений и управлении рисками в целях их предотвращения или снижения последствий.
Цель исследования – уточнение системы рисков, сопровождающих процесс недропользования, и их характеристики.
Методы исследования. В процессе исследования использовались методы системного анализа, сравнений аналогий, которые в совокупности обеспечивают достоверность и корректность выводов.
Результаты. В процессе исследования было уточнено проявление рисков при разработке месторождений полезных ископаемых. Раскрыто содержание геологического риска с позиции достоверности различных категорий запасов и прогнозных ресурсов. Достоверность геологических рисков увязана со степенью разведанности месторождения. Выявлены закономерности завышения величины запасов за счет роста коэффициентов достоверности (перевода). Отмечена негативность практики передачи недропользователям права в отношении соотношения количества запасов различных категорий. Горный риск характеризуется как неуправляемый, труднопрогнозируемый, не поддающийся никаким закономерностям, который обычно приводит к авариям и катастрофическим ситуациям. Проявлением экологического риска является ухудшение качества окружающей среды, истощение природных ресурсов при освоении ресурсов недр. Существенный экологический риск связан с размещением на поверхности техногенных минеральных образований и хранением отходов обогащения в хвостохранилищах. Опасность для реципиентов представляют атмогенные и гидрогенные потоки, формирующиеся у отходов, и аварийные прорывы плотин хвостохранилищ. Управление рисками на предпроектной стадии рассматривается с позиции введения поправок на риски при обосновании ставки дисконтирования. На этапе эксплуатации месторождения управление рисками представляет собой специализированный вид деятельности. Рассмотрены основные методы управления и источники финансирования мероприятий, основанием которых выступает выбранный метод управления рисками.
Выводы. Процесс недропользования сопровождается системой рисков, в число которых входят геологический, горный и экологический. На предпроектной стадии учет рисков выполняется через премии за риск. При эксплуатации месторождения – через управление рисками. Выбранный метод управления дает возможность разработать соответствующие мероприятия, ориентированные на поставленную цель.

***Ключевые слова*:** недропользование, риски, характеристика рисков, управление рисками, потери, методы.

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