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IMPROVEMENT AND SYSTEMATIZATION OF PRINCIPLES AND PROCESS FLOWS IN MINERAL MINING IN THE REPUBLIC OF KAZAKHSTAN

The methods and economic parameters of mineral mining are interrelated with the applied technological, structural and organizational solutions. The parameters of individual ore bodies, their occurrence conditions and the totality of natural ore-forming processes govern these engineering solutions.

Considering the relationship between such concepts as the integrity, structures and components of a subsoil use system, the basic principles defining a set of production processes for extracting minerals (or commercial component) from the subsoil are formulated. Due to the improvement of tools and technology, the scopes of the synonymic "mineral mining" and "mineral production" concepts expanded. The technological evolution was accompanied by fundamental clarifications and new understanding of the key concepts in scientific cognition and production management. The scientific relevance of the set of systemic principles rested on their application as a practical guide in mining.

The key definitions included the validated series of the components and their contents. The proposed formulations have a significant weight both in science and technology as they provide more economically efficient and safe level of organization of underground mining with the system-founded and fool-proof selection of mining methods.

Keywords: *deposits, mineral mining, subsoil space, systematization, classification principles, technologies, systems, underground mining*
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Mineral mining and subsoil space use

The development and elaboration of definitions of "mineral mining", "mining methods" and "classification of mining methods" is greatly contributed to by the outstanding scientists in the mining sciences: M. I. Agoshkov, A. I. Arsentyev, O. A. Baikonurov, B. I. Bokiy, G. M. Malakhov, N. V. Melnikov, V. V. Rzhevsky, A. M. Terpigorev, K. N. Trubetskoy, L. D. Shevyakov, E. F. Sheshko, etc.

At the same time, the analysis of the contents of developed and universally used in scientific and educational literature, design documentation and in daily practice concepts of mining sciences sometimes exhibits their contradictions with principles of system-based approach to revealing and establishment of logical sequence and essence of the definitions in development of georesources. These contradictions follow from violation of dependence of each element of the system, being as a whole in a set of elements, on its place and functions within the whole, as well on the hierarchy and plurality of the elements.

It should be noted that the accomplished scientific work is relevant in connection with the introduction of new geotechnologies and technologically important solutions used in the subsoil development in the territory of Kazakhstan, namely:

- the hybrid open-pit/underground geotechnology;
- the mixed-type physicotechnical underground geotechnology;
- the secondary mineral extraction—the physicotechnical geotechnology for extraction of balance reserves earlier estimated as mining losses either deliberately or forcedly left in the safety and rib pillars;
- the physicochemical geotechnology to transfer solid minerals to a fluid state for their extraction through pipelines and (or) wells [1].

"Mineral mining" by the open-pit and underground methods means "a system of organizational and technical measures for mineral stripping, preparation and extraction" [2]. There are several other definitions, which repeat the essence of the statement in the above formulation, with clarifications and amendments [3].

The concepts defining the essence and content of organizational and technical measures (production processes) in underground mining are divided into specific processes of stripping, preparation and stoping. Each of them, in turn, is a set of certain process flows [3] which run strictly sequentially or series-parallel one after another. This provides a free passage toward the ultimate goal of the productive, cost-effective and safe extraction of mineral resources from the subsurface.

The subsoil space within which a mineral deposit and a mine are located, i.e. the empty cavities artificially created by man in the subsoil, is used both during mineral mining and after it, for other needs and purposes. The terms "mineral mining" and "space utilization" have different targets. Implemented using the processes, these component of an integrated system are different in purpose.

"Mineral mining is a material and dynamic system that begins with preparation of the space occupied by a mineral deposit for the mineral extraction from it" [4]. It includes detailed exploration and appraisal, feasibility studies, 3D modeling of all-constituent ore bodies and deposits, evaluation of physical, mechanical and geochemical characteristics, mine project with a financial and economic model (FEM), and construction of the necessary infrastructure.

The term “deposit” is defined as the Earth’s crust space where, through an ore-forming process, the chemical elements that are minerals have become concentrated. Obviously, the process of “mining” is a continuation of the earlier accomplished process flows of “accessing” and “preparation”.

The next step is getting access to a mineral deposit by means formation of a set of openings from ground surface to an ore body or layers of minerals [5].

After the access to a deposit is provided, the process of mineral mining is carried out.

The subsystem “use of mined-out space and production waste” is an extension of the system structure on “exploitation of mineral deposit”. The exploitation of a mineral deposit is a static looped system in relationship with other subsystems. The entire mining operation results in a space free from of extracted rocks.

The space that remains free, consisting of underground openings of various configurations that were previously in use, must be used for practical purposes after the end of mining, or isolated with or without backfill. The use of the subsoil void after underground mining is the final subsystem—the last stage of the mineral deposit exploitation, which should bring economic benefit (interests) or contribute to implementation of other tasks, depending on this void quality [6, 7].

With the depletion of conventional mineral deposits coming within 25 to 150 years from 2050 to 2060, the future mining technologies and trends will be governed by new standards requirements that take into account the use of the earlier created mined-out space after completion of mineral mining.

We speak on replacement of drilling and blasting method of rock breakage by dissolution of chemical elements (especially metals) and their simplest compounds using active substances to be injected into rock mass via boreholes. Successful creation of such technologies will lead to artificial increase of mineral resources because the losses and contamination will be minimized. Metals converted to solution will be extracted to concentrates directly in underground mines, thus eliminating the need of haulage, crushing, grinding, flotation, tailings collection and transportation. This will result in a dramatic increase in recovery rates and in the end product quality.

Such technologies are the part of a new technological paradigm and a new trend in the Earth sciences—geoengineering, which is currently announced as one of the most important trends of the Fourth Industrial Revolution at the World Economic Forum in Davos [8, 9]. Thus, the authors have proposed the structure of the “mineral resources exploitation” system for the underground method of mining in the territory of the Republic of Kazakhstan (**Fig. 1**). In essence, it corresponds to the content of a special scientific concept which takes into account in full the correlation with the notions of integrity, structure, connection, element, relationship and subsystems [10].

In the process of preparing a deposit space for exploitation, all decisions related to the mineral mining and the use of mined-out space and production waste concentrate at one engineering solution—the choice of a mining method. The mine engineering system consists of a set of access, development and production excavations, each having its own direct purpose but, at the same time, interconnected via some structural elements defined by the mine project. The interrelationship of the elements is essential for the safe and cost-effective operation of the whole mine to ensure the technological feasibility of reaching the ultimate goal of producing the wanted quantity and quality of mineral resources.

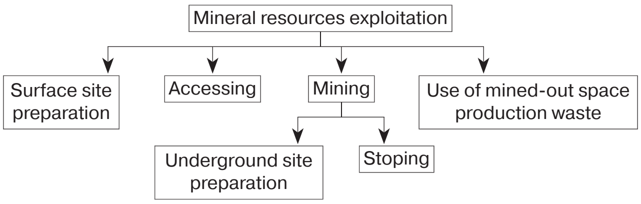

Fig. 1. Structure and Hierarchy of the Mineral Resources Exploitation System

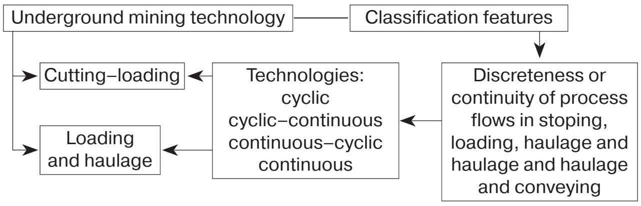

Fig. 2. Underground mining technologies and their classification

Underground mining technologies and their classification

To classify all elements in the “mineral mining” system to embrace all notions and methods of mining at full descriptiveness to ensure selectability of the best method depending on the set of objectives to be achieved, let us discuss the classification concepts first [11].

A classification is a multi-level matrix with horizontally and vertically arranged concepts. This is the way to establish relationships between concepts or classes of objects. Such classifications serve as a means of storing and finding information.

This approach allows keeping the above-listed principles of integrity, dependence of each element, property and relation in the system on its place and functions, structuring and interdependence of the system and environment, hierarchy and multiplicity of description.

The operations of excavation, loading and haulage are interrelated in terms of their technological sequence and influence on the achievability of the final goal during mining and processing. Therefore, the mining parameters to provide preservation of stoping space and ore extraction completeness should be optimized for the given geological and geotechnical conditions. Consequently, it is necessary to develop a classification of underground mining technology to rely upon [12–14]. **Figure 2** shows the classification of underground mining technologies.

Underground mining systems and their classification

The solution of problems connected with the subsoil management and preservation in underground mining should combine the formation of the interrelated parameters of man-made transformation of the subsoil. The main factor governing the theory and practice of mining is the environment, i.e. geological, physical, mechanical and geochemical characteristics of ore bodies, composing deposits, and enclosing rocks surrounding the mineralization.

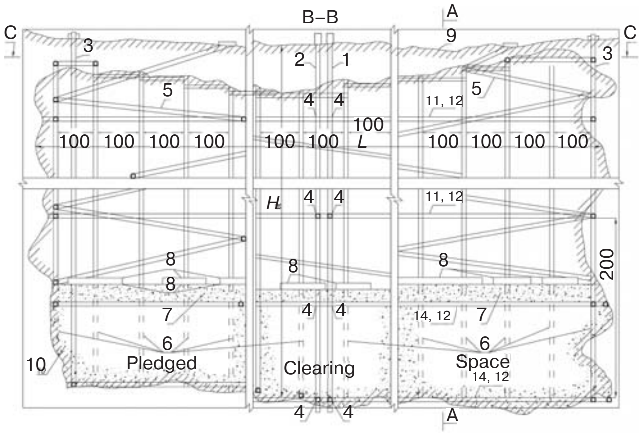

Fig. 3. Bottom-up underground mining

1–Cage shaft; *2*–Skip shaft; *3*–Ventilation shaft; *4*–Crosscut; *5*–Haulage ramp; *6*–Block raiser; *7*–Backfill; *8*–Stopes; *9*–Surface; *10*–Ore body; *11*–Ore drift; *12*–Fringe drift; *13*–Boundary of stoping

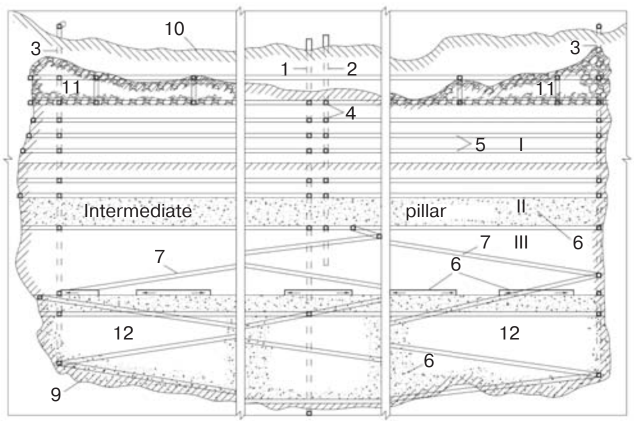

Fig. 4. Schematic of mixed-type descending/ascending mining with temporary intermediate pillar (vertical projection along the strike):

1–Cage shaft; *2*–Skip shaft; *3*–Ventilation shaft; *4*–Crosscut; *5*–Fringe and reef drifts; *6*–Backfill; *7*–Ore haulage ramp; *8*–Upward cascade stopes; *9*–Outline of ore body; *10*–Surface contour; *11*–Mined-out space of descending cascade; *12*–Mined-out space of ascending cascade;

I–Descending cascade; *II*–Intermediate descending-ascending layer; *III*–Ascending cascade

The classification that allow fully encompassing the requirements and constraints imposed by the environment on underground mining technology is hierarchically divided into levels arranged in order of responsibility from the top level to the bottom level as follows:

1. Mineral mining methods:

1) downward (top-down), which is currently traditional;

2) upward (bottom-up), which is not yet considered applicable to vertically extended deposits;

3) hybrid open-pit/underground, with an open-pit/underground layer between purely open-pit and underground methods [15, 16];

4) mixed-type underground method combining elements of descending mining with advanced stoping, or with descending-and-ascending mining layer between the upper and lower parts of the ore body at the late mining stage [17, 18];

5) mixed-type mining with physicochemical geotechnologies.

2. Accessing method depending on the adopted mining method:

1) conventional vertical haulage, ventilation, emergency and backfill shafts and/or adits (possibly tunnels);

2) conventional haulage ramps cut from ground surface or from a design horizon in bedrock in combination with the schemes of subparagraph 1.

3) haulage ramps cut from ground surface or from a design horizon in ore body, or in combination with the schemes in subparagraph 1.

4) surface drilling and/or conventional accessing via heading of much smaller drifts and drilling from them.

In the bottom-up mining, assessing must be carried out to the full depth by both vertical openings and by haulage ramps cut in ore (**Fig. 3**).

In mixed-type underground mining, accessing is also carried out to full depth by both vertical shafts and haulage ramps. Furthermore, a crown pillar is left between the top and bottom of the ore body (a), with the vertical height of each to be determined by technical and economic calculations. It can be mined out in the future from top to bottom or from bottom to top (**Fig. 4**).

The use of upward, hybrid and physicochemical methods depends on the advantages of stoping, which, against the background of increasing mining depth and deterioration of geomechanical situation (especially in open stoping), give a positive effect on economic indicators, manufacturability and safety.

Ore extraction using the first four underground mining methods involves drilling and blasting to form the mine workings and to separate ore from rock mass.

In the fifth method, to be developed on an industrial scale, almost complete abandonment of drilling and blasting is expected, which is a tremendous achievement [19].

3. Underground Mining Systems.

The classification of underground mining systems, which largely dependent on the attributes chosen by various authors as the initial selection, had a single goal to create a workable, safe and cost-effective set of technological subsystems [11, 20].

The systems can be divided into material and abstract, static and dynamic; the relationships—into closed (closed) and open (open).

Strictly adhering to this special scientific concept, the authors have defined the concept of “underground mining system” (UGS) as a set of development and production roadways, structurally interconnected depending on geological conditions, located in the space occupied by the ore body, and advanced in it in time in a predetermined order with a view to extracting ore and associated gangue rock from the subsoil.

In accordance with this definition, mining systems must be arranged into classes, subclasses and groups. The choice of a mining method, justification of optimal mining technologies and process flow charts, and parameters of ore accessing, preparation and extraction is the main content of a geotechnology task [21].

As a part of a geotechnology task of ore extraction and subsequent use of mined-out space, the classification is crucial for the choice of a mining system. Of the currently existing classifications of underground mineral mining systems, three classifications stand out:

1. M.I. Agoshkov's classification based on the attribute "Stoping space quality during mining" [22];

2. The unified classification of the USSR Ministry of Nonferrous Metals Industry based on the attribute "Ground control method" [23];

3. The classification by "mined-out space condition" presented in the treatise *Mining Sciences. Subsoil Development and Preservation* of the Russian Academy of Sciences and edited by Academician K.N. Trubetskoy.

In the Mining Engineering Glossary [5], there is a list of 10 basic characteristics of mining system division into classes and further division into subclasses, groups, etc., which begins with "the ground control method". The review and analysis of the criteria attributes shows that the main attribute is the characteristic of the structure and technology of a mining system and its application conditions, i.e. the state of the stoping space at the end of mining [5, 24].

Such classification characterizes a material and dynamic system with regard to the principle of hierarchy which tolerates interfering in order to improve characteristics of its constituents.

4. Classification of mining using physicochemical geotechnologies [19]:

1) with feeding a chemically active agent into permeable rock mas by means of boreholes drilled from ground surface;

2) with feeding a chemically active agent through holes drilled from access underground roadways and with transportation of solution in pipes on the same roadways;

3) with feeding chemically active agent via boreholes drilled from ground surface or from access underground roadways for irrigation of preliminary blasted rocks.

The proposed classifications are inter-related in terms of the main challenges facing physicochemical geotechnologies including:

1. The maximum economic efficiency;

2. The most complete and economically feasible extraction of reserves from the subsoil;

3. The optimal quality;

4. The maximum safety;

5. The maximum preservation of the ecological balance and natural equilibrium un the subsoil;

6. The preservation of non-mined minerals and other potentially valuable georesources in the subsoil;

7. The use of mined-out space for industrial and other economic purposes.

One of the main tasks of harmonious interaction of the system and environment should also be perceived as making the system manageable, similarly to any methods and means used by man to provide himself and society with comfortable living conditions.

Conclusions

Functionally, mineral mining is exploitation of a mineral deposit both for the initial purpose of mineral extraction and for the economic use of the mined-out space both during and after extraction.

It is substantiated that the set of preparatory and production stopes represents a mining system within which a mining technology operates.

The distinctive features of underground mining technologies are described. The underground mining technologies, subject to the type and specifications of mining and haulage machines and their systems, are subdivided into cyclic, cyclic-and-continuous, continuous-and-cyclic and continuous technologies.

The directions of classification of technological system, acting in dependence on each other under the conditions of requirements and restrictions of the environment in the order of responsibility of the upper level before the lower one, are determined.

Based on reviewed and analyzed criterion attributes and on the scientific interpretation of the "classification" and "system" concepts, a new content is offered for the notion of an underground mineral mining system.

The classification principles are developed to finally solve the target problem connected with the creation of workable, controllable, safe and economically effective set of technological subsystems in interrelation with natural geosystems. This objective is accomplished by applying a multi-level classification that begins with the ground control method of controlling rock pressure which, in its turn, ensures safety of mined-out stoping space.

Based on the set out principles, the classifications of underground mining depending on the vertical advance direction are proposed.

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EFFECT OF HIGH-POWER ELECTROMAGNETIC PULSES AND DIELECTRIC BARRIER DISCHARGES ON PHYSICOCHEMICAL AND FLOTATION PROPERTIES OF PEROVSKITE

The methods of FTIR, SEM–EDX, microhardness test, electrokinetic potential and contact angle measurements, as well as the sorption and flotation experiments are used to study the influence of high-power electromagnetic pulses (HPEMP) and dielectric barrier discharge (DBD) on the structural, physicochemical and flotation properties of perovskite (Afrikanda deposit).

The analysis of FTIR data shows that short treatment times (t_{treat} = 10÷30 s) lead to opposite changes in the surface condition of perovskite: oxidation (hydration) of the surface in case of HPEMP and deoxidizing (dehydration) under DBD.

According to SEM results, the surface of perovskite undergoes destruction as a result of HPEMP and DBD treatment. The surface of some areas of the samples is modified with the formation and opening of deep parallel cracks, most likely due to the polysynthetic twinning typical of perovskite crystals; the subparallel pyramidal protrusions are also observed in some surface areas. The determined morphological changes cause softening and a monotonic decrease in the microhardness of the mineral surface with an increase of the HPEMP and DBD (plasma) treatment times (t_{treat} = 0÷150 s) by ΔHV_{max} = 27÷33%.

The effect of HPEMP and DBD on the physicochemical properties of the mineral surface represents a shift in the electrokinetic potential towards positive values, an increase in the contact angle (t_{treat} = 10÷30 s), as well as the improved adsorption of the collector and the higher flotation activity of perovskite by ~ 10–15%.

Keywords: *perovskite, electromagnetic pulsed discharges, Fourier-transform infrared spectroscopy, scanning electron microscopy, surface modification, microhardness, zeta potential, contact angle, sorption, flotation*

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Introduction

By 2018 the global titanium reserves amounted to 872 Mt, including 799.15 Mt of proven titanium dioxide reserves. Russia holds 17.3% of the world's proven reserves occurred in 10 primary deposits (93.4%) and in 10 placers (6.6%) [1]. At the same time, Russia takes only 0.4% in the global production of TiO_2 concentrate. In the meanwhile, the Murmansk Region, alone, holds three titanium–magnetite ore deposits—Kolvitsa, Pudozh and Afrikanda. The largest primary deposits of perovskite–titanomagnetite ore on the Kola Peninsula and in North Karelia contain great reserves of titanium, rare metals (Nb, Ta) and rare earths [2].

Russia's Afrikanda deposit features the largest titanium reserves (the total reserves amount to 52.2 Mt, and the average content of TiO_2 is 9.2%) and represents a promising source of titanium,