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MIXED-TYPE GEOTECHNOLOGIES ARE THE BASIS FOR COST-EFFECTIVE, SAFE AND ECOLOGICALLY BALANCED DEVELOPMENT OF ORE DEPOSITS

The steady demand for mineral raw materials requires constant advanced reproduction of the mineral resources.

One of the practical solutions to improve the technical and economic indicators of the use of mineral resources is the mixed-type geotechnologies, which in the current situation are created and applied as a special part of mining sciences with many options in relation to mineral deposits and manmade mineral-bearing waste. The review and analysis of the created and proposed geotechnologies allows distinguishing and classifying them with respect to the methods of mining advance and their correlation, and with respect to technologies of mineral recovery from ore mass.

Considering mixed-type geotechnologies as a part of the "system of knowledge about the laws of manmade transformation of the Earth's interior toward new understanding of management and preservation of mineral wealth as a life-support resource for social development" [1], we must move in our reasoning from the general to the particular.

The article describes the principles of classification and systematization of mixed-type geotechnologies that ensure selection and achievement of the most efficient and safe method for obtaining final products from minerals.

Keywords: *Mineral mining, mixed-type geotechnologies, hybrid mining method, physicotechnical and physicochemical geotechnologies, economic and ecological efficiency, safety*
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Introduction

The development of the mining and metallurgical industry and the continuous growth of volumes and types of minerals to satisfy public needs, which converts a part of treated and processed or to a manmade mineral material in amount much greater than the produced output, is fraught with negative consequences that become global and highly hazardous.

Already in the middle of the 20th century, the human impact on nature led to significant pollution of the atmosphere, shallowing of rivers, reduction of land reserves fund and to a noticeable climate change. For a medium-capacity mining and processing plant, the area of the mining allotment reaches 2–3 thousand hectares, and it is clear that due to the expected 5-fold increase in the volume of mineral extraction, the area of the land withdrawn from agricultural use, a seemingly insoluble contradiction appears between the spheres of life necessary for a human being—between production of food and manufacture of tools from mineral raw materials.

The existing and impending problems in the near future can be summarized as follows:

1. At present, the restoration of land disturbed by mineral mining is an urgent and immediate challenge of a global scale. The current situation needs to be drastically modified with regard to new ways of extraction of minerals from the subsoil and turning them into a final product, without waste formation of waste, environment contamination and land disturbance.

2. Increased comprehensiveness of use of extracted mineral raw materials has been the object of close attention and actualization since the second half of the 20th century, but the issue has always been partially resolved and functionally depended on two factors:

• the economic efficiency, since in many cases extraction of some components from raw materials, although necessary for the economy, was too expensive, as a result of which the total cost of the integrated products became much higher than the cost of sale;

• the processing complexity of mineral extraction since the recovery technologies available for base metals often suppressed by-products and the associate minerals turned into difficult-to-dissociate compounds during processing.

3. A typical and critical shortage of mineral mining is mineral loss in the subsurface. The current technologies, even those primarily designed to reduce losses, fail to avoiding the loss which ranges from 4–6% to 40–50%.

A high economic disbenefit both in mineral mining and processes results from the mineral quality loss, or dilution.

Due to the quality losses, the production capacity in terms of the final output drops both in mining and processing.

The importance of eliminating or minimizing mineral loss and dilution is associated not only with these consequences, but also with the fact that they automatically reduce the mineral resource base in Kazakhstan and in the world market as a whole. Such interconnection calls for the mineral mining and processing technologies to enable complete extraction of mineral from the subsoil without dilution.

As a consequence, the mineral production process will be clean, natural state of the manmade-invaded subsoil will be preserved, and the environmental stress will be abated owing to the decreased specific and total consumption of energy, water and materials.

4. Extraction of a mineral resource from the earth's interior via the systemic and prolonged formation of open, backfilled or caved stoping space of underground openings inside an ore bode is a process accompanied by violation of rock mass integrity, which, in turn, induces the rock mass disequilibrium and initiates hazardous stress redistribution.

The situation is aggravated by the fact that human intervention is carried out with the help of tools that produce destructive effects on rock mass during drilling, blasting or disintegration.

The transformation of 90–99% of mineral raw materials extracted from the subsurface into waste as a result of production processes, which also occupy huge areas on ground surface, and create the sources of dust and harmful runoff, should be accepted as an axiom, and the main challenge of the 21st century is to eliminate the waste and to extract a clean product.

This requirement is also supported by another equally important need to restore the mineral resource base, because eliminated of the above-listed problems will automatically increase resources by 10% to 30–40% at the same cost for the whole system of geological exploration and field operation.

An integrated formulation of this 2st century's challenge was clearly expressed for the first time by Academician K. N. Trubetskoy: "A new property of the substance of lithosphere—mobility—can be provided within the framework of the applied geotechnologies, either by disintegration of the substance within a preset volume (most of solid minerals), or by changing the aggregate state of the substance (for instance, sulfur melting), or by creating conditions for the migration of a useful component, physically (oil, gas, water, heat) or chemically (in-situ leaching of metals) [2].

5. At the same time, the problems of underground mineral mining are coupled with task of eliminating waste generated on ground surface in the form of spoil banks and tailings dumps.

It should be kept in mind that the practical interests of mankind require total avoidance of waste storage on ground surface since even after extraction of useful components from the waste, the remnants will total 40–99% of the initial amount. So, either there should be no waste on ground surface, or the whole mass of rocks extracted from the subsoil should be utilized. The full use of the extracted mass of rocks may be possible with a new approach to the consumption of a mineral raw material to be divided by chemical composition or physical aggregation into products usable in full used for human needs [3–5].

Research methods

Given the identified problems, and based on the theoretical and practical experience and knowledge, researchers and engineers have determined the topical issues and trends of the research.

Considering variety and stochastic nature of mining conditions which influence the problem-related decision-making, the early investigation involved a detailed review of scientific literature and mining practices.

Stochastic approximation of observation results, owing to their nonparametricity and recurrence in mining, is an ideal method for determining the final efficiency of mineral mining and processing.

The research used an integrated approach to producing the final cumulative result, which most accurately determined all intermediate actions in process flows involved in mining and processing.

The method adopted to optimize production data at the geological and geotechnical standards of metal content (a basic metal or reduced to basic metal) in ore and in concentrate with regard to losses, dilution and recovery, pursuant to the recurrence of determination of final indicators, allowed solving the tasks reasonably and with minimal assumptions.

Results and discussion

Commercial-scale implementation of mixed-type, taking into account the achieved results [6–8], should start with the systematization and classification of physicotechnical and physicochemical technologies and their possible combinations. The defining specifications of a workable process flow sheet include geological and geotechnical characteristics of a mineral deposit and its safe and efficient mineability.

There are certain requirements for the final results which should sum up the overall efficiency of mining and primary processing of minerals in the form of produced concentrates, including both open-pit and underground mining methods. These final results, which govern the economic efficiency, safety, environmental cleanliness and completeness of the use of natural resources, in turn, are a functional derivative of the created and selected process flow sheets for the mineral extraction from the subsurface and processing, decomposable into well-known mining and processing operations.

The main target function of mineral extraction is achievable given there is an access from the earth's surface to the ore occurrence, so field development begins with the choice of the method of getting access to a mineral [9, 10].

While proposing and defining the main trends of technological innovation in mineral mining and processing, we are certain that the initial framework is the existing process flows of mineral mining and processing, and the effectiveness of these process flows should improve and meet the requirements of the new era. On this basis, we put forward a classification of process flow sheets with respect to geological and geotechnical conditions.

The proposed classification and the set of the systematization criteria based on the graded factors for the effective selection of a geotechnology consists of separate groups included in the section *Geotechnology* in the general classification of mining sciences, developed and proposed by Academician K. N. Trubetskoy [11].

1. Mining Science: Physical and Technical Geotechnology. Extraction of minerals from the subsurface changes structure of ore mass by disintegration (destruction).

Methods include mechanical, explosive and hydraulic disintegration.

2. Mining science: Physicochemical Geotechnology. Extraction of minerals from the subsurface attaches mobility to mineral components by means of changing their chemical or aggregate state.

Such changes include chemical reactions, influence of physical fields, or physicochemical or biological effect [12].

Presenting mining sciences and their systematization from the point of view of the subsoil development and preservation at constant improvement of technical and economic indicators as opposed to deteriorating objective indicators, we primarily focus on mixed-type geotechnologies [13–15]. Their development toward achieving final results meeting the main requirements can effectively lead to the optimization of mining and processing in general.

In common practice, theoreticians and practitioners and designers still pursue improvement of hybrid technology of surface / underground mining with an open pit—underground mine (OPUM) layer in-between.

Earlier [16], we proposed a classification of hybrid mining methods for both single ore body and mineral resources of surface mining (SM) and underground mining (UM), which are not an extension of each other but located in a single ore zone which is advisable to treat using a single process flow sheet.

The mixed-type physicotechnical method of ore production is developed in underground mining. This method uses a new procedure, non-applicable and not designed anywhere else in the world: ascending (bottom-up) cutting of ore across the entire height of the ore body starting from the bottom layer, with cascade-wise pooling of several conventional horizons [17].

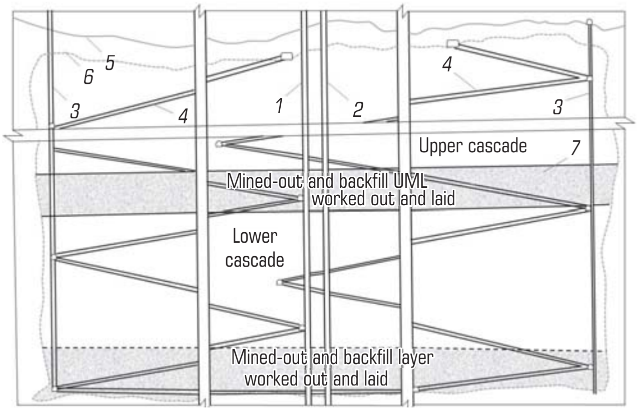

Fig. 1. Physicotechnical flow sheet of mixed-type underground geotechnology:

1–cage shaft; *2*–skip shaft; *3*–side ventilation shafts; *4*–declines; *5*–ground surface; *6*–ore body; *7*–cemented paste backfill

Such process flow sheet of underground mining (**Fig. 1**) makes it possible to increase the stoping front via creation of one or several underground mine levels (UML) united along vertical. Such levels can be mined independently, by the type of cascade, as per the adopted feasibility study and subjected to project time schedule. The bottom cascade in cut bottom-up to the bottom of UML which should already be mined-out and filled with cemented paste backfill. The last cascade cut should enter the bottom of UL.

The total cost-effectiveness of the technology is shown in **Fig. 2**. The efficiency indicator is the total cost of 1 ton of concentrate reduced to copper in our case.

The total reduced cost of 1 ton of concentrate is given by:

$$Cn = (C_1{*}Q_1 + C_2{*}Q_2 + C_3{*}Q_3)/Q_k, \quad \text{USD/t}$$

where Cn is the total reduced cost of the whole ore body; C_1, C_2, C_3 are, respectively, the costs of 1 ton of concentrate obtained from the ore from the upper and lower cascades and UL; Q_1, Q_2, Q_3 are, respectively, the amounts of concentrate produced from the ore from these mining areas; Q_k is the total amount of concentrate produced.

The physicochemical geotechnology for sulfide ores in hard host rock mass includes in-situ electro-chemical leaching (ISEL). The latter was tested on a lab scale and using large-volume samples in field conditions in 2018–2021 [18–20]. The developed flow chart is shown in **Fig. 3**.

This mixed-type geotechnology can almost totally eliminate losses and dilution, while preserving the subsurface in its original form. It is planned to investigate and test two technological solutions of in-situ leaching with getting access to an ore body vi drilling from ground surface or from underground entries. Two options involve dissolving and leaching of rock mass without its disintegration, and the third option involves feeding the leaching solution to a blasted rock block. It is necessary to solve a serious scientific and practical problem of creating artificial permeability for leaching solution in a solid rock mass using solid state physics and fluid dynamics.

Manmade waste on ground surface is also assumed to be processed using continuous controlled leaching [21, 22]. Such process flow sheet for oxidized and sulfide ores has been created and is to be subjected to laboratory and semi-industrial testing (**Figs. 4** and **5**). The implementation of the proposed flow sheets will enable year-round operation, increased gold recovery by 5–8%, reduced land withdrawal by about two times, and will eliminate the harmful effect of calcium carbonate along the route of leaching solution flow.

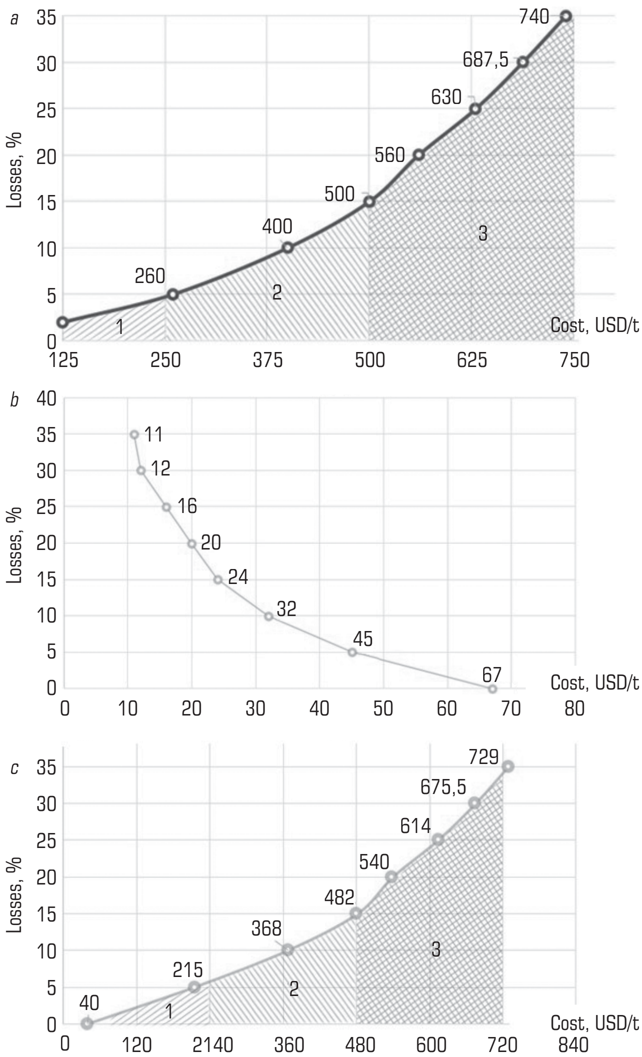

Fig. 2. Cost and loss curves:

a–total mining and processing cost with regard to shortage of copper due mining losses; *b*–mining cost with regard to shortage of copper due mining losses; *c*–processing cost with regard to shortage of copper due mining losses. Copper content of proven reserves is 0.8%, copper content of concentrate is 20%;

1–Application of physicotechnical mixed-type technology of mining with cemented paste backfill, with bottom-up stoping in the lower and upper cascades and with parallel advanced stoping in UML; *2*–Application of physicotechnical mixed-type technology of mining with cemented paste backfill in the lower cascade, without backfill in the upper cascade and with parallel advanced stoping in UML; *3*–Application of conventional mining technology without creation of UML

Conclusions

1. The implemented studies prove that the mixed-type geotechnologies justified using the proposed methods ensure the integrated final efficiency of mineral mining and processing.

2. The final efficiency, which includes economic effect, safety, environmental cleanliness and completeness of use of natural resources, depends on the joint optimization of mineral mining and processing.

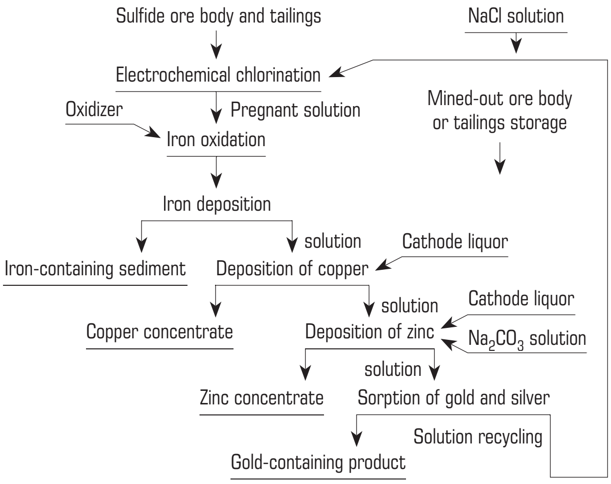

Fig. 3. Electrochemical chlorination flow sheet for ore body and for tailings with iron/copper/zinc precipitation and gold/silver adsorption

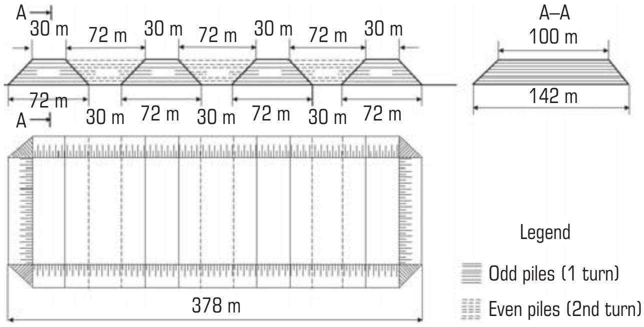

Fig. 4. Continuous piling of tailings

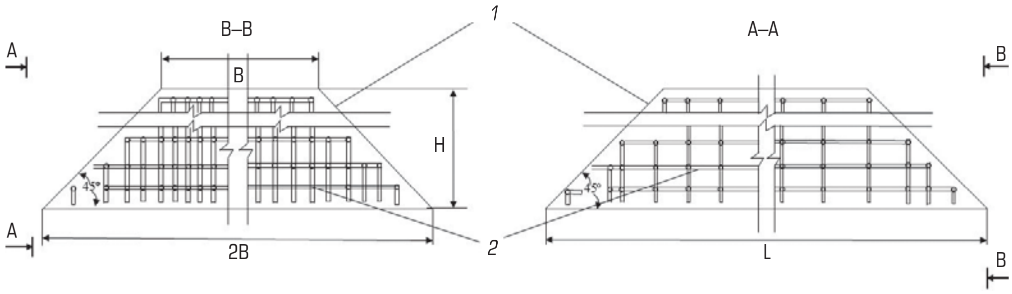

Fig. 5. Continuous controlled heap leaching flow sheet

1—ore piles; *2*—perforated pipes for pressure feed of leaching solution

3. The mining and processing output statistics should be based on the minimum final cost of unit concentrate of a certain quality and metal content in proven reserves with regard to quantity and quality losses during production.

4. The implementation of the minimized production costs model in compliance with the proper requirements requires a classification of mixed-type geotechnologies using physicotechnical and physicochemical methods.

5. The authorial geotechnologies described in this article can serve as a standard model for stochastic approximation.

6. Further development of the idea and topic of this research will include process flow design and testing of physicochemical metal extraction from hard rock mass.

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PHYSICAL AND CHEMICAL ASPECTS OF URANIUM EXTRACTION FROM ZONES OF RESERVOIR OXIDATION USING ULTRASONIC TECHNOLOGY

This article gives physical and chemical aspects of uranium extraction from zones of reservoir oxidation using ultrasonic technology, and offers theoretical substantiation of the technology of in-situ uranium leaching in Kazakhstan. The presence of significant and well-explored uranium resources, developed uranium mining and processing facilities, as well as the current situation on the world uranium market predetermine the prospects for the development of the uranium mining industry in Kazakhstan. Host rocks of uranium localized at the fronts of reservoir oxidation zones are largely similar in terms of the chemical composition. Fe, Al, Mg, Ca, K, Na are among the most widespread petrogenic elements of rock-forming minerals. Uranium is observed in association with iron, vanadium, selenium, molybdenum, rhenium and other elements. Uranium mineralization is represented by exogenous (secondary) minerals—pitchblende and coffinite. In the general balance of uranium minerals, pitchblende is about 30% and coffinite is about 70%. Nasturan ($xUO_2 \times yUO_3 \times z$) represents an association of tetravalent uranium dioxide and hexavalent uranium trioxide with a variable composition: ($UO_2 + UO_3$)—65—85%, coffinite—tetravalent uranium silicate $USiO_4$.

Keywords: *physical and chemical aspects, recovery, uranium, reservoir oxidation, ultrasonic technology, theoretical substantiation, in-situ leaching, wells*
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Introduction

Being in the group of actinides of the periodic system of elements by D. I. Mendeleev, the electronic structure of uranium, which determines the valency, is completed in the fifth shell from the top. Deep electrons located on the fifth electronic level, due to the large atomic radius, are less firmly bound to the nucleus and, because of this, take part in the formation of valence bonds. Differences in the energy bonds of the electrons of the uranium nucleus shells are relatively small, but still exist, and this explains the multivalency of uranium. The main valency of uranium is 4, 5 and 6. Variable valence leads to the formation of various complex compounds of uranium. Uranium mining by in-situ