UDC 662.013.3

M. Zh. BITIMBAYEV[1], Professor, Doctor of Engineering Sciences
M. S. KUNAYEV[2], Chairman of the Board of Directors, Doctor of Geological and Mineralogical Sciences
N. A. MILETENKO[3], Senior Researcher, Candidate of Engineering Sciences, nmilet@mail.ru
Zh. N. ALISHEVA[4], Senior Researcher

[1]Satbayev University Almaty, Almaty, Kazakhstan
[2]Caspian Services Inc. JSC, Almaty, Kazakhstan
[3]Institute of Problems of Integrated Development of Mineral Resources, Moscow, Russia
[4]Al-Farabi Kazakh National University, Almaty, Kazakhstan

RESOURCE-REPRODUCING AND RESOURCE-SAVING METAL PRODUCTION WITH A FULL CYCLE OF DEVELOPMENT OF PRIMARY AND SECONDARY GEORESOURCES

Ore deposits, taken in the traditional interpretation of the concept as "natural or man-made accumulations of metallic minerals in the Earth's crust or on the Earth's surface, development of which is economical", are formed during the time length commensurate with the geological time of formation of complexes of minerals and rocks.

In the practice of subsoil use, ore deposits are developed 5–10 thousand times faster than they can be recreated in the subsoil, so the world civilization faces the main task of solving the problems of providing mankind with metal resources for their safe, economically efficient and technologically feasible extraction on the historical time scale.

This problem is complicated by the need to simultaneously address the environmental consequences of human impact on nature. The complications of implementing practical measures depend on two objective factors:

—the impending complete depletion of metal reserves in the continental earth's crust to a depth of anthropogenic-and-technological capability H_{ATC} = 5 km within 30–1500 years depending on the type of metal;

—the demand for metals which continuously increase in geometric progression in relation to the growth of the population.

The authors propose new trends of development of material basis to meet the necessaries by creation of reproduction of reserves using deposits of new type to be mined with application of new geotechnologies and mineralogical sciences, and with a full closed cycle of multiple use of metals.

Keywords: *primary and secondary georesources, geological time, historical time scale, geochemical patterns, new-type deposits, geotechnology, mineralogical science, closed cycle*

DOI: *10.17580/em.2023.02.08*

Introduction

The prosperous existence of civilization since the origin of man has been ensured as a superstructure on a base, the main supporting structure of which is natural mineral wealth and its use. Time is confidently dictating a continuous increase in the demand for metals due to the growing population, improvement of the quality of life at prosperity level of the developed countries, and the creation of new types of equipment quickly becoming in violent demand [1].

Nature, as it turned out, has limited capacities to meet the growing needs because the metal resources are objectively depleting in the subsoil. The proven and undiscovered resources, and their possible volumes determined by the general prerequisites of ore formation [2], are unfit for keeping up with the needs of the Earth's economy in the historical time interval.

Reserves are being depleted because:

—traditional deposits in the continental earth's crust objectively to a depth of 5 km are becoming less and less, and there will come a moment in 30–150 years, depending on the type of metal, when there will be none at all [3];

—mining losses unavoidable due to the design features of the applied technologies, geomechanical conditions artificially created by human intervention in the subsurface, lead to a decrease in reserves against those determined by geological exploration work by 5–40% and more, which are left in various kinds of pillars;

—from 2–3% to 35–40% and more of the mined metals after the beneficiation process go unextracted to the tailings, i.e. in addition to losses the capital costs of exploration and operation increase during both mining and beneficiation;

—a significant negative role is played by metal losses and economic damage from storing waste rock dumps and off-balance reserves on the surface;

—the applied technologies of mineral mining and processing cumulatively influence the economic results in such a way that the concepts of "cutoff grade", "minimum commercial grade", "economic and uneconomic reserves" are forced to be introduced into the characteristic of reserves in the subsoil. They artificially differentiate reserves which are economically profitable to recover with the common or new technology.

This measure adds the planned technological losses with additional volumes of metal accumulations, which are left in the subsoil almost forever, since the declared requirements for subsequent extraction of uneconomic reserves are often impossible to meet due to the lack of safe access to the mining area.

—the dilution of the host ore body by barren rock contributes to the artificial depletion of the excavated metal reserves. It becomes an indispensable part of the mining with drilling and blasting operations, and its volume reaches 5–100% and more.

Causal factors due to depletion of metal reserves in the next 30–150 years in the continental earth's crust to a depth of 5 km (we call it the depth of anthropogenic and technical capabilities of H_{ATC}) have determined our goals and objectives. They can be divided into the main generalized directions, the implementation of which is potent and effective, ecologically and economically efficient, safe and technologically feasible:

—Development of a new type of fields formed on the basis of natural geochemical patterns and left beyond the scope of economic mining because of the uncertainty of their properties;

—Creation and practical use of new physicotechnical and physicochemical, including mixed-type, geotechnologies and methods of mineralogy, which can make it possible to economically use the deposits of a new type, to ensure full development of primary georesources at the reduced volume of georesources ranked as secondary in the mining cycle;

—Development of each particular field with a full cycle of the subsoil use;

—Involvement of productive accumulations of metals of anthropogenic migration, formed as a result of the same laws of ore formation on the basis of clarks, accompanied by differentiation, migration, dispersion and concentration, which are effective in natural geological processes;

—The full development of mineral resources based on the principles of resource recovery and resource conservation, first expressed and substantiated by Acad. RAS K. N. Trubetskoy, by creating a circular economy of metal production. The implementation of such production allows the cost-effective recycling of secondary georesources generated by the use of produced metal.

The circular economy technology can ensure stretch-out of mineral wealth with regard to the increasing metal demand and the time of depreciation of metal products at reduced burden of the subsoil.

Research methods

The research methods aimed at creating an evidence base for solving the target problems, which optimize the logical connection and sufficiency of the interacting generalizing directions, should proceed from the scientific and statistical analysis of the topic of our work.

Depletion of metal reserves in traditional deposits is an indisputable fact confirmed by statistics, which is primarily substantiated by scientific research of prominent scientists of our time. Reference of Acad. V. I. Smirnov on the duration of deposit formation from 15–17 thousand years to 1200 million years and statistical material given in the publication [3] says: "In the historical period after 2070–2150 mankind will be left without metal reserves from traditional deposits in the continental earth crust to a depth of 5 km."

We, in our turn, used the clarks according to Acad. A. P. Vinogradov and the minimum industrial concentrations of chemical elements, adopted Acad. L. N. Ovchinnikov in 1988, calculated amount of such reserves in 30% of the area of the continental crust to a depth of 5 km [4]. The data obtained clearly demonstrate the possibility of providing the needs of mankind in at least a millennium period of time for the metals demanded by mankind. Such is the first direction of the applied method of researches based on actual materials [5].

The supporting calculations were performed in the following sequence:

—the volume of the continental earth's crust, possible for the use as an object of geological exploration and mining, was calculated as $0.722 \cdot 10^9$ km^3. It is obtained from the ratio of the depth of anthropogenic-technical possibilities $N_{ATC} = 5$ km to the depth of distribution of the continental part of the earth's crust 33 km, and the ratio of 0.15 (15), the area of the continental crust to the total surface area of the Earth 0.2909;

—the mass of the continental earth crust with volume weight of rocks $2.7 \cdot 10^9$ t/km^3 is equal to $1.95 \cdot 10^9$ billion tons and the volume of the globular layer between the Earth surface and the lower surface of the earth crust $16.3838 \cdot 10^9$ km^3.

The calculations confirm that, using the distribution pattern of metals, which is determined by the degree of prevalence (clark) of each of them in the Earth's crust, it is possible to design new directions for the development of the mining and metallurgical industry.

The calculation of the quantity of a chemical element in accordance with its clark and its comparison with proven reserves in recalculation through the minimum industrial content will show, what quantity of metals is in the bowels in accordance with the clark, its difference from the proven reserves. To what limit should be sought to reduce the minimum commercial grade — this follows from our result on the calculation of reserves depending on clarks (**Fig. 1**). It is possible to solve, functionally it will depend on the availability of the required amount of metals for a specified historical period of time, based on this requirement of the minimum industrial content. In turn, the minimum industrial content, which, in accordance with its purpose in providing the necessary amount of metals to society at any period of human history, must be manageable, will directly depend on the geotechnologies and mineralogy used. Requirements for their content and design must necessarily combine safety, environmental friendliness, completeness of excavation from the subsurface and extraction into a marketable product (concentrate or metal) and, of course, final economic efficiency (**Fig. 2**).

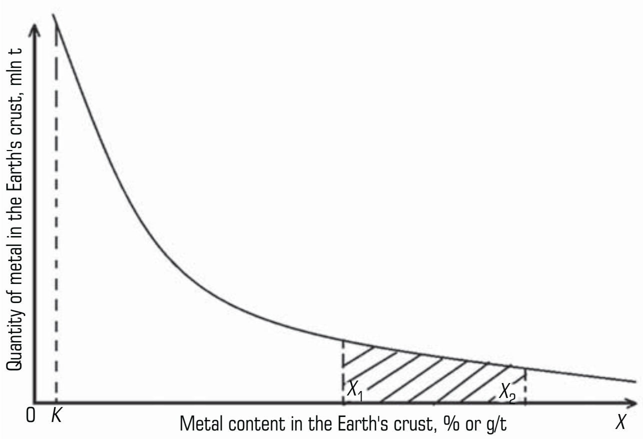

Fig. 1. Reproduction of primary of georesources versus application of new geotechnologies and mineralogy

X_1 – minimal commercial content when applying new geotechnologies and mineralogy, % or g/t; X_2 – minimal commercial content when applying project-specified geotechnologies and mineralogy, % or g/t; K – clark of a chemical element (metal), % or g/t; [hatched box] – reproduced primary georesources using previously unknown geochemical properties

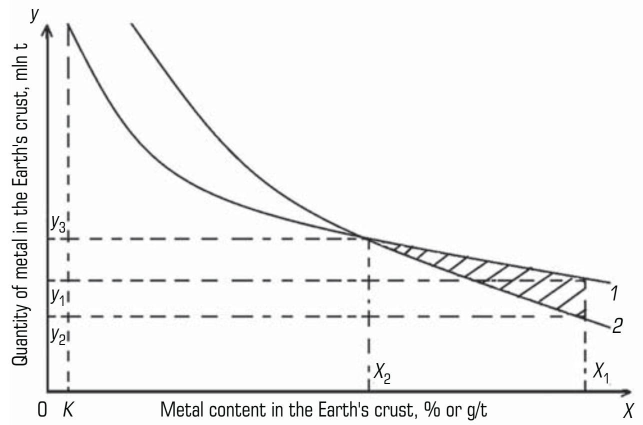

Fig. 2. Efficiency of reproduction of primary georesources from geochemical halos and host rocks of traditional ore deposits

1 – schedule of application of project technology; *2* – graph of new technology application; X_1 – minimal commercial content at application of project technology, % or g/t; X_2 – minimal commercial content at application of new technology, % or g/t; K – clark of a chemical element (metal), %

The application of physicochemical geotechnologies makes it possible to include all metal resources without limitation and from traditional deposits (uneconomic reserves and metals in host rocks) in mineral production.

The development of technological solutions for mineral mining will make it possible to separate primary and secondary georesources in a controlled mode, and to create resource-reproducing and resource-saving production.

An integrated solution of interdependent tasks designed to create resource-reproducing and resource-saving development of natural subsoil and manmade formations of ore deposits of a new type will consist of a combination of the following subjects and trends:

—subsoil objects consisting of areas of primary and secondary halos on the forms of migration and deposition of chemical elements in lateral (subhorizontal) zoning, in the zoning of near-ore change of rocks in hydrothermal systems, in the latitudinal geochemical zone on the earth's surface and in the vertical zoning associated with changes in chemical composition and properties in the subvertical direction;

—separate consideration and use of the concepts of manmade geochemical anomalies, induced dispersion halos, manmade barriers, as well as the model of induced migration associated with manmade landscapes and urban geochemistry;

—a set of technological schemes of open-pit and underground mining, in particular, the hybrid open–underground method with its option of dividing the underground part of the deposit into additional layers [6];

—bottom–up underground mineral mining with the advanced accessing of mineral resources along the whole design depth and stage-wise, with regard to the created underground layers, slice stoping and ore accessing via transport declines driven in ore only;

—creation of new mixed-type physicotechnical and physicochemical geotechnologies and mineralogy to be applied jointly toward development of mineral resources in the form of the integrated mining and processing;

—organization of full-cycle mineral mining [7–11].

The method of research combining the use of geochemical laws and the development of geotechnologies and mineralogy should be particularly effective in conjunction with the circular economy, multi-use technologies and organizational solutions, with respect to the economic and environmental limits of return of metals to the initial state (**Figs. 3 and 4**).

When researching geotechnologies, we will also need methods of chemical interactions, in particular, for leaching, selection and deposition of nonferrous and precious metals, which we have already partially used [7].

Results and discussion

1. The basis for the implementation of the idea of the project is the principle of solving the inverse problem of using as a new type of deposits existing, but unidentified properties as the essence of the formation of subsoil development objects of geochemical regularities.

Academician Ovchinnikov L. N. deduced the formula of the law, indicating that the possibility of transition of metals from dispersion to concentration is unlimited. It has allowed the author and after it all world geological community with sufficient reliability to estimate potential stocks of metals in an earth crust.

To such geochemical regularities, having a direct relation to creation of accumulations of chemical elements in the increased concentration, it is necessary to refer geochemical barriers. Their main feature is an abrupt change in the conditions and concentration of elements, when reduction in the space occupied by the geochemical environment leads to transition of quantity to quality, to transformation of a situation into a barrier (and vice versa).

When classifying geochemical barriers there are two main types - natural and man-made. Technogenic barriers formed as a result of large-scale human impact on the environment, nowadays are comparable with the processes of nature itself, because, as A. E. Fersman said, "… Man remakes the world geochemically".

They obey the same laws of nature as the processes made in nature without human intervention [5]. Thus, the possibilities of using the results of technogenesis as a source of metal production are also obvious and confirm D. I. Mendeleev's conclusion that "in chemistry there is no waste, but there is "unused raw material".

2. The tasks of resource-producing and resource-saving development of the subsoil, including the use of deposits of new type and technogenesis objects as a source of metals, can be implemented only with the use of physical-technical and physical-chemical combined geotechnologies:

1) Further development of open-underground physico-technical geotechnology with system division of the underground extended part of the ore body (s) into tiers [7].

2) Creation in practical execution of a method of upward ("bottom-up") development of mining works with predominant extraction of ore by horizontal layers with laying in ascending order. Thus division of an underground part on tiers and cascades between tiers keep the application and strengthen the importance [7].

3) Creation of physicochemical geotechnology with underground leaching of chemical elements and/or chemical compounds of metals with supply of leaching solution from the surface and/or from mining ore and/or rock workings. The technological scheme of the leaching part was created and tested in cooperation with the department of enrichment of the Ural State Mining University "Tiles LLC" (Yekaterinburg, Russia) headed by Y. P. Morozov, Corresponding Member of the RANS.

In Kazakhstan, a team of scientists from Kazakhstan and the Russian Federation is building a research laboratory and pilot plant, which will begin operations in October 2023. From then on, research will be organized on underground leaching of non-ferrous and precious metals from some deposits in Kazakhstan.

Conclusions

The proposed physical-technical and physical-chemical geotechnologies will provide an increase - the "useful" raw material base of metals - by the amount of metals returned from losses.

Notions of "losses" and "dilution" will be excluded from geological and mining lexicon; notions of "cut-off grades" will not be applied in physicochemical geotechnologies and in many variants traditional ore body development will be performed with host rocks in areas of geochemical halos distribution.

1. A unified combined production process of geotechnology and mineralogy creates the following opportunities to radically improve the technical and economic results of the development of traditional and new type deposits:

Extraction of the full volume of metals located within the explored ore body, i.e., extension of the deposit's operation period by the amount of return of losses provided for by the traditional technologies of the project;

Exclusion of the concept of "dilution" since there will be no drilling and blasting (or other mechanical) destruction of the ore body mass;

Reduction of all types of capital and operating costs due to full extraction of useful components, multiple elimination of drilling and blasting operations, mining and rock removal and transportation operations, and all technological enrichment processes.

Virtually complete elimination of hazardous gas emissions, including carbon monoxide, into the atmosphere due to a multiple reduction in the cost of drilling and blasting operations and diesel fuel.

2. Leaching from the ore massif of metals will almost equally cover the entire volume of both balance and off-balance (below the cutoff grade) product, which will increase the raw material base of the developed deposit by the amount of previously unaccounted volumes of metals.

3. The implementation in accordance with the proposed unified technological classification of the circular economy of the mining and metallurgical industry in the traditional and new mining boundaries will increase the reserves of metals already ready for use (without mining and processing) with multiple returns of metal raw materials to the initial state in the cycle of machine building several times. The circular economy will make it possible to eliminate from accounting all the costs of mining and enrichment processing, on the volume of metals returned into circulation.

4. Production of metals in a controlled mode with the involvement of all primary and secondary georesources with a full cycle of their development is a realized creation of civilization resource-producing and resource-saving subsoil use [12–15].

5. This scientific work, based on the application of geochemical regularities operating in nature and objective laws of physical and chemical and physical-technical phenomena and properties of inanimate matter, creates real opportunities and solves the most important task of continuous expanded reproduction of non-renewable in the historical time scale resources of metals and providing the world civilization with their inexhaustible reserves.

6. The performed work on its novelty and relevance, the use of existing in nature, but unidentified laws, safety in implementation, global significance, economic efficiency and solving the most important material problem of human existence is a scientific discovery.

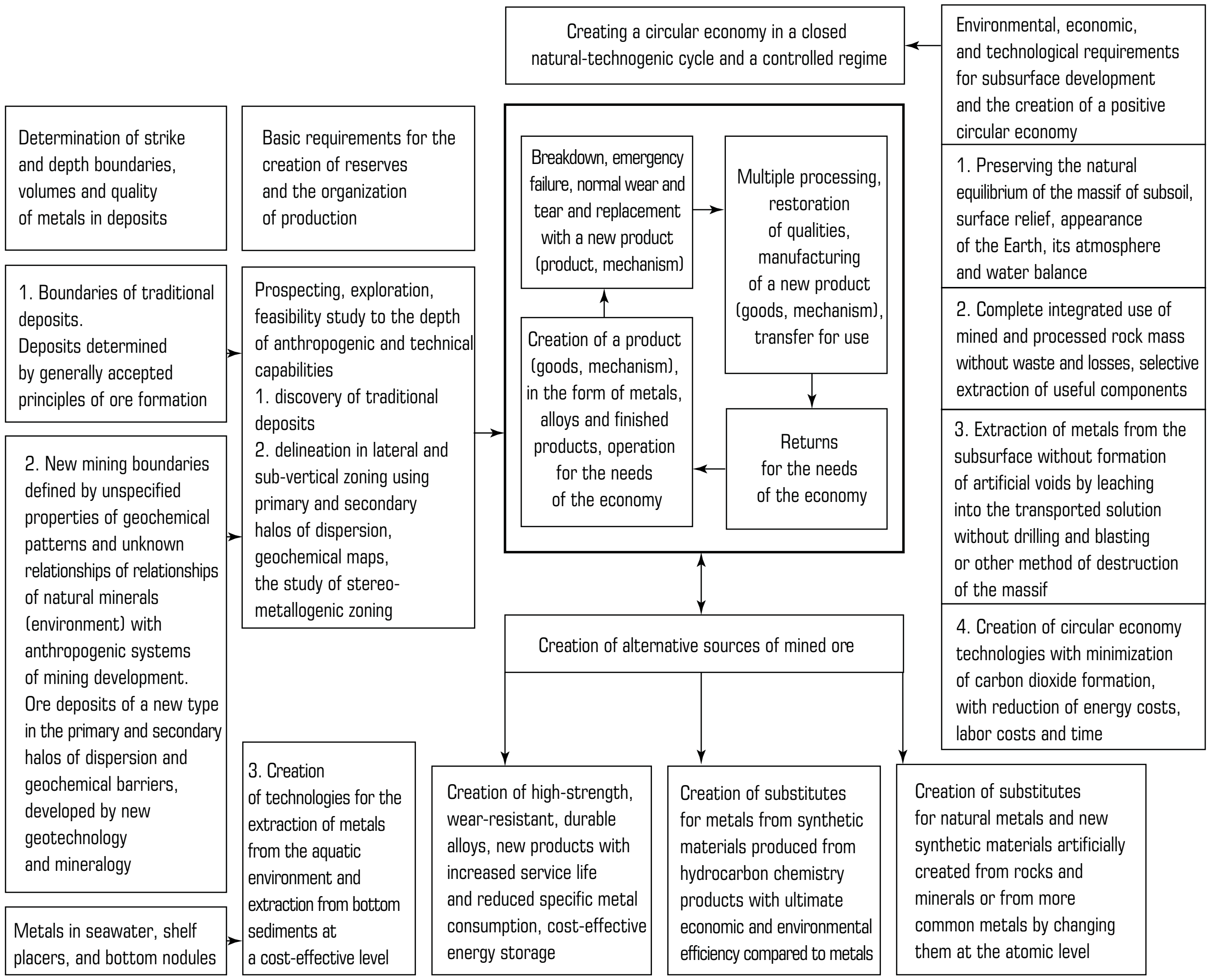

Fig. 3. Unified technological classification of complete development of primary and secondary georesources in the new framework of mining and circular economy of metal use

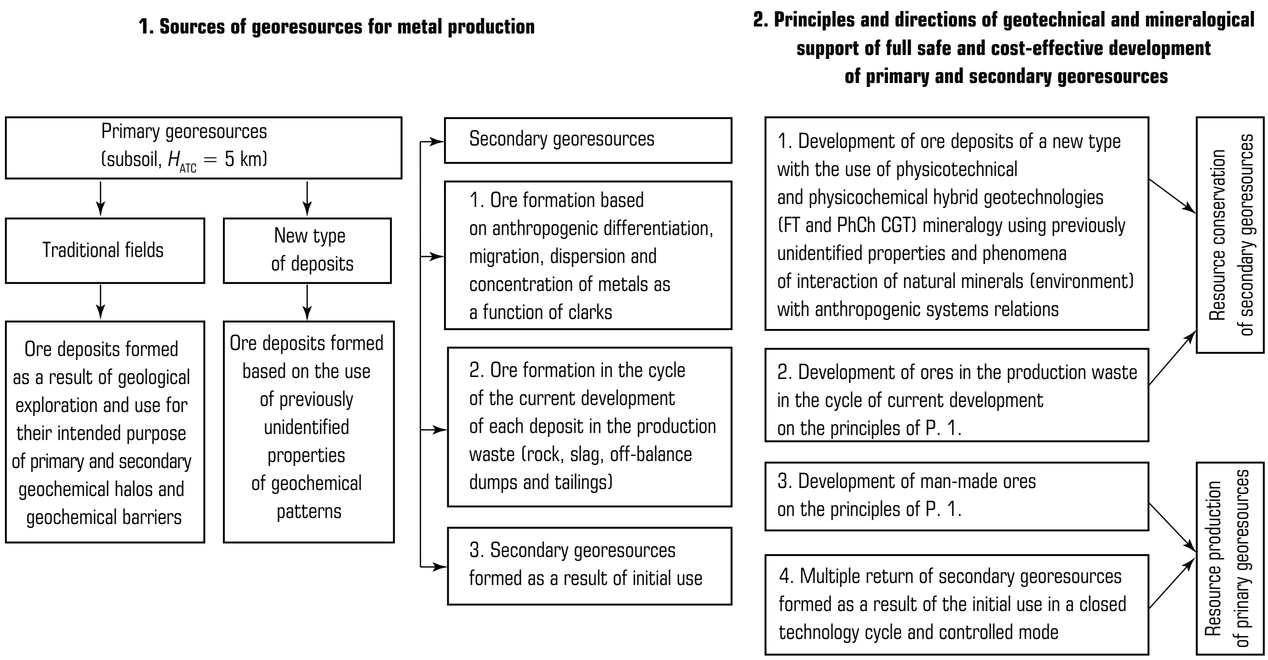

Fig. 4. Classification of technological principles for full development of primary and secondary georesources in closed natural-technological cycle and in controlled mode

The study and analysis of the content of modern publications show that, despite the various topics of the geochemical regularities considered and the expressed alarm about the depletion of reserves of traditional deposits, about the ways of reproduction of the raw material base of metals is not specifically mentioned [16–20].

Acknowledgements

This research was supported by the Committee on Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan, Grant No. N AP14871011.

References

1. Atrushkevich A. V. Mining: Terminological Dictionary, 5-th edition, revised. Moscow : Gornaya kniga, 2016. 633 p.
2. Ovchinnikov L. N. Formation of ore deposits. Moscow : Nedra, 1988. 255 p.
3. Bitimbayev M. Zh., Kunaev M. S., Alisheva Zh. N. Creation of inexhaustible metal supplies using the recently dormant geochemical laws of inorganic nature. *Vestnik Rossiyskoi Akademii Nauk*. 2023. No. 1. pp. 55–64.
4. Bitimbayev M. Zh., Kunaev M. S., Parilov Yu. S. The role and value of clarks of chemical elements in the expanded reproduction of mineral resources. *Problems and prospects of complex development and conservation of the Earth's bowels.* Moscow : IPKON RAN, 2022. pp. 21–24.
5. Geochemistry: textbook for geological specialties of universities, 2-th ed. revised. Perelman A. I. Moscow : Vysshaya shkola, 1989. 527 p.
6. Trubetskoy K. N., Kaplunov D. R., Rylnikova M. V. Problems and prospects in the resource-saving and resource-reproducing geotechnology development for comprehensive mineral wealth development. *Journal of Mining Science.* 2012. Vol. 48, No. 4. pp. 688–693.
7. Bitimbayev M. Zh., Yusipov Kh. A., Aben E. Kh., Alisheva Zh. N. et al. Innovative technological schemes of combined geotechnologies. *Problems and Prospects of Complex Development and Conservation of the Earth's Bowels.* Moscow : IPKON RAN, 2022. p. 12–16.
8. Kaplunov D. R., Rylnikova M. V. Design and realization principles of full-cycle comprehensive mining of ore deposits. *GIAB*. 2013. No. S27. pp. 3–11.
9. Bitimbayev M. Zh., Oryngozhin Y. S., Miletenko N. A., Alisheva Zh. N. An Innovative way of underground mining. *Eurasian Mining.* 2022. No. 1. pp. 38–40.
10. Micro- and nano-mineral components of ores as a resource for replenishment of mineral reserves in Kazakhstan for the development of technologies for their development. Report on research work. Almaty : K. I. Satpayev Institute of Geological Sciences, 2021. 156 p.
11. Vorobyov A. E., Peregudov V. V. Technologies for Extracting Nanogold from natural and technogenic ores. *Mining Journal of Kazakhstan*. 2022. No. 5. pp. 42–46.
12. Trubetskoy K. N. State and Main Directions of Complex Development and Preservation of the Earth Subsoil. *Problems and Prospects of Complex Development and Conservation of the Earth's Bowels.* Moscow : IPKON RAN, 2020. pp. 3–12.
13. Shumilova L. V., Khatkova A. N. Factors of intensification of resource use when implementing the principles of the best available technologies. *Problems and Prospects of Complex Development and Conservation of the Earth's Bowels.* Moscow : IPKON RAN, 2020. pp. 45–48.
14. Zakorshmenniy I. M., Blokhin D. I. Involvement in industrial production of abandoned reserves through the use of thermochemical processing technology. *Problems and Prospects of Complex Development and Conservation of the Earth's Bowels.* Moscow : IPKON RAN, 2022. pp. 193–196.
15. Rylnikova M. V., Radchenko D. N., Zalevskaya K. N. New approaches to the development of man-made deposits. *Problems and Prospects of Complex Development and Conservation of the Earth's Bowels.* Moscow : IPKON RAN, 2020. pp. 19–22.
16. Abramson G. Structure of Anomalous Geochemical or fields of various Hierarchies (ore body to ore deposit). *Geologiya i ohrana nedr*. 2016. No. 4. pp. 17–19.
17. Goldberg I. S. Formation of Mo-W deposits in unified geochemical systems from regional to local scales (using the example of the southeastern Province of China). *Geologiya i ohrana nedr*. 2021. No. 4(81). pp. 4–11.
18. Wu. W. -W., Yang, J. -S., Dibek, Y., Milushi I., Lian D. Multiple episodes of melting, depletion and enrichment of the Tethyan mantle: Petrogenesis of the peridotites and chromitites in the Jurassic Skenderbeu massif, Mirdita ophiolite. *Lithosphere.* 2018. Vol. 10, Iss. 1. pp. 54–78.
19. Dittrich T., Seifert T., Schulz B., Hagemann S., Gerdes A. et al. Archean raremetal pegmatites in Zimbabwe and Western Australia: Geology and metallogeny of pollacite mineralisations. Switzerland : Springer International Publishing, 2019. pp. 134–138.
20. Congalves A. O., Melgarejo J. -C., Alfonso P. et al. The distribution of rare metals in the LCT pegmatites from the Ciraul Field, Angola. *Minerals*. 2019. Vol. 9, Iss. 10. ID. 580. EM