ISSN 2518-170X (Online)
ISSN 2224-5278 (Print)

«ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ» РҚБ
«ХАЛЫҚ» ЖҚ

Х А Б А Р Л А Р Ы

ИЗВЕСТИЯ

РОО «НАЦИОНАЛЬНОЙ
АКАДЕМИИ НАУК РЕСПУБЛИКИ
КАЗАХСТАН»
ЧФ «Халық»

N E W S

OF THE ACADEMY OF SCIENCES
OF THE REPUBLIC OF
KAZAKHSTAN
«Halyk» Private Foundation

SERIES

OF GEOLOGY AND TECHNICAL SCIENCES

6 (467)

NOVEMBER – DECEMBER 2024

THE JOURNAL WAS FOUNDED IN 1940

PUBLISHED 6 TIMES A YEAR

ALMATY, NAS RK

NAS RK is pleased to announce that News of NAS RK. Series of geology and technical sciences scientific journal has been accepted for indexing in the Emerging Sources Citation Index, a new edition of Web of Science. Content in this index is under consideration by Clarivate Analytics to be accepted in the Science Citation Index Expanded, the Social Sciences Citation Index, and the Arts & Humanities Citation Index. The quality and depth of content Web of Science offers to researchers, authors, publishers, and institutions sets it apart from other research databases. The inclusion of News of NAS RK. Series of geology and technical sciences in the Emerging Sources Citation Index demonstrates our dedication to providing the most relevant and influential content of geology and engineering sciences to our community.

Қазақстан Республикасы Ұлттық ғылым академиясы «ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

НАН РК сообщает, что научный журнал «Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

«ҚР ҰҒА» РҚБ Хабарлары. Геология және техникалық ғылымдар сериясы».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Меншіктеуші: «Қазақстан Республикасының Ұлттық ғылым академиясы» РҚБ (Алматы қ.).

Қазақстан Республикасының Ақпарат және қоғамдық даму министрлігінің Ақпарат комитетінде 29.07.2020 ж. берілген **№ KZ39VPY00025420** мерзімдік басылым тіркеуіне қойылу туралы куәлік.

Тақырыптық бағыты: *геология, мұнай және газды өңдеудің химиялық технологиялары, мұнай химиясы, металдарды алу және олардың қосындыларының технологиясы.*

Мерзімділігі: жылына 6 рет.

Тиражы: 300 дана.

Редакцияның мекен-жайы: 050010, Алматы қ., Шевченко көш., 28, 219 бөл., тел.: 272-13-19

http://www.geolog-technical.kz/index.php/en/

«Известия РОО «НАН РК». Серия геологии и технических наук».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Собственник: Республиканское общественное объединение «Национальная академия наук Республики Казахстан» (г. Алматы).

Свидетельство о постановке на учет периодического печатного издания в Комитете информации Министерства информации и общественного развития Республики Казахстан **№ KZ39VPY00025420,** выданное 29.07.2020 г.

Тематическая направленность: *геология, химические технологии переработки нефти и газа, нефтехимия, технологии извлечения металлов и их соеденений.*

Периодичность: 6 раз в год.

Тираж: 300 экземпляров.

Адрес редакции: 050010, г. Алматы, ул. Шевченко, 28, оф. 219, тел.: 272-13-19

http://www.geolog-technical.kz/index.php/en/

News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences.

ISSN 2518-170X (Online),

ISSN 2224-5278 (Print)

Owner: RPA «National Academy of Sciences of the Republic of Kazakhstan» (Almaty).

The certificate of registration of a periodical printed publication in the Committee of information of the Ministry of Information and Social Development of the Republic of Kazakhstan **No. KZ39VPY00025420,** issued 29.07.2020.

Thematic scope: *geology, chemical technologies for oil and gas processing, petrochemistry, technologies for extracting metals and their connections.*

Periodicity: 6 times a year.

Circulation: 300 copies.

Editorial address: 28, Shevchenko str., of. 219, Almaty, 050010, tel. 272-13-19

http://www.geolog-technical.kz/index.php/en/

NEWS of the National Academy of Sciences of the Republic of Kazakhstan
SERIES OF GEOLOGY AND TECHNICAL SCIENCES
ISSN 2224–5278
Volume 6. Number 467 (2024), 99–113
https://doi.org/10.32014/2024.2518-170X.463

UDC 553.493

©Zh.B. Dossymbekova[1], L.Z. Issayeva[1], K.S. Togizov[1*], D.B. Muratkhanov[2], O.N. Maksutov[1], 2024.
[1]Satbayev University, Almaty, Kazakhstan;
[2]Institute of Geological Sciences named after K.I. Satpaev, Almaty, Kazakhstan;
E–mail: k.togizov@satbayev.university

THE SPECIFICS OF RARE EARTH INCLUSION IN ORE MINERALS OF RARE METAL DEPOSITS OF KAZAKHSTAN

Zh.B. Dossymbekova – 2nd year doctoral student, Satbayev University, z.dossymbekova@satbayev.university, 0009-0000-6683-4604;
L.Z. Issayeva – doctor of geological and mineralogical sciences, assoc. professor of the Department of Geophysics and Seismology, Satbayev University, l.issayeva@satbayev.university, 0000–0001–7184–6351;
K.S. Togizov – PhD, Professor of the Department of Geophysics and Seismology, Satbayev University, k.togizov@satbayev.university, 0000-0002-4830-405X;
D.B. Muratkhanov – researcher, Institute of Geological Sciences named after K.I. Satpaev, daulet.mur@mail.ru, 0000-0001-8322-3311;
O.N. Maksutov – master's student, Satbayev University, o.maksutov@satbayev.university, 0009-0007-8318-4050.

Abstract. Rare earth elements – yttrium and fifteen chemically similar elements from lanthanum to lutetium – can be found in ore minerals of rare metal deposits in Kazakhstan. Therefore, their concentration and form of inclusion in the main ore minerals are of great scientific and practical interest. N.L. Radenko analysed the micro-trace composition of scheelites and wolframites from beds of different formations and genetic types.

In this article, we report the specifics of the inclusion of rare earth elements in ore minerals from the rare metal deposit in Bayan (Northern Kazakhstan) via simulations (computer and mathematical) and thermobarogeochemical studies (by the temperature of the mineral formation). Furthermore, we created a geographic information system of the studied deposit and the 2D and 3D models representing the distributions of the contents of tungsten trioxide between all exploration profiles (2D) and along the whole mineralisation volume. Furthermore, the specifics of the tungsten trioxide distribution in the 3D space, particularly in vein-stockwork ore bodies, were studied. This investigation has an influence on the concentration of rare earth elements and has led to a study of the issue of the condition of the formation of ore minerals from the geochemical and thermobarogeochemical points of view, using the results of actual materials and mathematical simulations of the estimation of the heat conditions of the ore-localising environment. As a result, the cause-and-effect aspects of the change of the composition of wolframites in stockwork ore bodies are disclosed for this deposit, and scientifically-based information was obtained for the determination of the factors of inclusion of rare types of earth elements in scheelites from the Bayan deposit.

Key words: geographic information system, 3D deposit models, 2D sections, ore localising environment, ore-forming solutions, rare metal deposits, tungsten trioxide, formation temperature, thermodynamic state.

©Ж.Б. Досымбекова[1], Л.Ж. Исаева[1], К.С. Тогизов[1*], Д.Б. Муратханов[2], О.Н. Максутов[1], 2024.

[1]Сәтпаев Университеті, Алматы, Қазақстан;

[2]Сәтбаев атындағы геологиялық ғылымдар институты, Алматы, Қазақстан;

E–mail: k.togizov@satbayev.university

ҚАЗАҚСТАННЫҢ СИРЕК МЕТАЛЛ КЕНОРЫНДАРЫНДАҒЫ КЕНДІ МИНЕРАЛДАРНЫҢ ҚҰРАМЫНА СИРЕК ЖЕРЛЕРДІҢ ЕНУ ЕРЕКШЕЛІКТЕРІ

Ж.Б. Досымбекова – Геофизика және сейсмология кафедрасының 2-курс докторанты, Сәтбаев университеті, z.dossymbekova@satbayev.university, 0009-0000-6683-4604;

Л.Ж. Исаева – Геофизика және сейсмология кафедрасының қауымдастырылған профессоры, геология және минералогия ғылымдарының докторы, Сәтбаев университеті, l.issayeva@satbayev.university, 0000-0001-7184-6351;

К.С. Тогизов – PhD, Геофизика және сейсмология кафедрасының профессоры, Сәтбаев университеті, k.togizov@satbayev.university, 0000-0002-4830-405X;

Д.Б. Муратханов – ғылыми қызметкер, Қ.И. Сәтбаев атындағы геологиялық ғылымдар институты, daulet.mur@mail.ru, 0000-0001-8322-3311;

О.Н. Максутов – Геофизика және сейсмология кафедрасының 2-курс магистранты, Сәтбаев университеті, o.maksutov@satbayev.university, 0009-0007-8318-4050

Аннотация. Сирек жер элементтері – иттрий және лантаннан лютецийге дейінгі он бес химиялық ұқсас элементтер Қазақстанның сирек металлды кенорындарының кен минералдарында кездеседі. Осыған байланысты олардың концентрациясы мен негізгі кен минералдарына ену формалары үлкен ғылыми және практикалық қызығушылық тудырады. Н.Л. Раденконың еңбектерінде әртүрлі формациялық-генетикалық құрамдағы кен орындарынан алынған шеелиттер мен вольфрамиттердің микроқосымша құрамы талданды.

Сондықтан, осы мақалада Модельдік құрылыстардың (компьютерлік және математикалық) және термобарогеохимиялық зерттеулердің (минералдардың түзілу температурасы бойынша) нәтижелерін талдау және синтездеу арқылы сирек металды Баян (Солтүстік Қазақстан) кенорнының кенді минералдарының құрамына сирек жерлердің ену ерекшеліктерін ашамыз. Жұмыс зерттелетін кенорнының геоақпараттық жүйесін қалыптастыру және оның

2D, 3D модельдерін құру арқылы жүзеге асырылды, олар үш тотықты вольфрам құрамының барлық барлау профильдеріне (2D) және бүкіл кендену көлеміне таралуын білдіреді. Олардың негізінде үш өлшемді кеңістікте үш тотықты вольфрам құрамының таралу ерекшеліктері, әсіресе сирек жер элементтерінің концентрациясына байланысты тамырлы-штокверкті кенді денелер зерттелді. Ол өз кезегінде нақты материалдардың нәтижелерін, сонымен қатар кеншоғырланушы ортаның жылу жағдайын бағалау бойынша математикалық модельдік құрылыстардың нәтижелерін пайдалана отырып, кенді минералдардың пайда болу жағдайын геохимиялық және термобарогеохимиялық позициялардан қарауға алып келді. Нәтижесінде осы кенорнындағы штокверкті кен денелеріндегі вольфрамиттер құрамының өзгеруінің себеп-салдарлық тараптары ашылып, сирек жерлерді Баян кенорнының шелиттерінің құрамына қосылу факторларын анықтау бойынша ғылыми негізделген ақпарат алынды.

Түйін сөздер: геоақпараттық жүйе, кенорынның 3D моделдері, 2D кесінділер, кеншоғырланушы орта, кен түзуші ерітінділер, сирек металл кенорындары, үш тотықты вольфрам, түзілу температурасы, термодинамикалық жағдай.

©Ж.Б. Досымбекова[1], Л.Ж. Исаева[1], К.С. Тогизов[1*], Д.Б. Муратханов[2], О.Н. Максутов[1], 2024.

[1]Сатпаев Университет, Алматы, Казахстан;
[2]Иститут геологических наук им. К.И. Сатпаева, Алматы, Казахстан.
E–mail: k.togizov@satbayev.university

ОСОБЕННОСТИ ВКЛЮЧЕНИЯ РЕДКИХ ЗЕМЕЛЬ В СОСТАВ РУДНЫХ МИНЕРАЛОВ РЕДКОМЕТАЛЛЬНЫХ МЕСТОРОЖДЕНИЙ КАЗАХСТАНА

Ж.Б. Досымбекова – докторант 2 курса кафедры Геофизики и сейсмологии, Satbayev University, Алматы, Казахстан, z.dossymbekova@satbayev.university, 0009-0000-6683-4604;
Л.Д. Исаева – ассоциированный профессор кафедры Геофизики и сейсмологии, Satbayev University, l.issayeva@satbayev.university, 0000-0001-7184-6351;
К.С. Тогизов – профессор кафедры Геофизики и сейсмологии, Satbayev University, k.togizov@satbayev.university, 0000-0002-4830-405X;
Д. Б. Муратханов – научный сотрудник, Институт геологических наук имени К.И. Сатпаева, daulet.mur@mail.ru, 0000-0001-8322-3311;
О.Н. Максутов – магистрант 2 курса кафедры Геофизики и сейсмологии, Satbayev University, Алматы, Казахстан, o.maksutov@satbayev.university, 0009-0007-8318-4050.

Аннотация. Редкие земельные элементы – иттрий и пятнадцать химически сходных элементов от лантана до лютеция встречаются в рудных минералах редкометалльных месторождений Казахстана. В этой связи большой научный

и практический интерес представляет их концентрация и формы вхождения в главные рудные минералы. В работах Н. Л. Раденко проанализирован микропримесный состав шеелитов и вольфрамитов из месторождений различной формационно-генетической принадлежности.

Поэтому в данной статье анализом и синтезом результатов модельных построений (компьютерных и математических) и термобарогеохимических исследований (по температуре образования минералов) раскрываем особенности включения редких земель в состав рудных минералов редкометалльного месторождения Баян (Северный Казахстан). Работа была выполнена путем формирования геоинформационной системы изучаемого месторождения и создания его 2D, 3D моделей, представляющие распределения содержаний трехокиси вольфрама по всем разведочным профилям (2D) и по всему объему оруденения. На их основе изучены особенности распределения содержаний трехокиси вольфрама трехмерном пространстве, особенно прожилково-штокверковых рудных телах, с чем связана концентрация редкоземельных элементов. Это привело к рассмотрению вопроса об условии образования рудных минералов с геохимических и термобарогеохимических позиций, где были использованы результаты фактических материалов, но и результаты математических модельных построений по оценке теплового состояния рудолокализующей среды. В результате были раскрыты причинно-следственные стороны изменения состава вольфрамитов в штокверковых рудных телах на данном месторождении, тем самым получена научно – обоснованная информация по определению факторов включения редких земель в состав шеелитов месторождения Баян.

Ключевые слова: геоинформационная система, 3D модели месторождения, 2D срезы, рудолокализующая среда, рудообразующие растворы, редкометалльные месторождения, трехокись вольфрама, температура образования, термодинамическое состояние.

Introduction

Rare earth elements are common elements in geological displays of our Republic; therefore, they are mentioned in all types of ore deposits, such as iron ore, copper, complex, and golden ore. The noticeable concentrations of rare earth elements are typical mainly for rare metal displays.

The study on the inclusion of rare earth elements in the main ore minerals of rare metal deposits in Central Kazakhstan has shown that the highest concentrations of the rare earth elements are typical for quartz-stockwork and greisen deposits (Radenko, 1991: 15; Shcherba, 1988 a).

In the wolframites of the quartz–greisen deposits, such as Akchatau and Karaoba (Central Kazakhstan), maximum concentrations of rare earth elements have been found; on average, 630 g/t with the range of up to 1.9 kg/t with a significant predominance of the yttrium sub-group through the important contribution of yttrium and other heavy lanthanides. The cerium sub-group is represented by two elements—lanthanum and cerium. In this deposit group, hubnerites have been found (Akchatau) with top-cut grades of rare earth elements (2.7%) with $\frac{\sum TR}{\sum Y}$=55. Sixty-five percent of this amount is attributed to the yttrium sub-group (Radenko, 1991: 15).

According to a report, the concentration of rare earth elements in wolframites can be attributed to the variations in ferrous and manganous elements in the composition of wolframites. Wolframites from Kazakhstan form an almost uniform continuous series, from ferberites (5.9% $MnWO_4$) to hubnerites (99.2% $MnWO_4$). This research data has confirmed that the concentration of rare earth elements in wolframites increases with the increase of $MnWO_4$; besides, the share of light lanthanides increases for the Akchatau deposit, while the relation of Ln_{Ce} и Ln_y+Y for Karaoba deposit does not change (V.P. Koval, et al., 1975).

In the late 1980s, high concentrations of rare earth elements were found for the first time in scheelites from the Verkhnie Kayrakty deposit: 3 kg/t (Central Kazakhstan) (Radenko, 1991: 15). This data was confirmed by geochemical works in the process of geological and metallurgical sampling to the depth of 300 m (Romanov and others, 1990). According to the research data, rare earth elements in the Verkhnie Kayrakty deposit increase the industrial significance of stockworks by 20%–40%.

The works of N.L. Radenko (1990) describe the studies on the determination of the form of inclusion of rare earth elements in scheelites of the Verkhnie Kayrakty deposit. Scheelites of three generations from quartz streaks were studied, and it was found that trivalent ions of rare earth elements (TR^{3+}) in scheelite crystal lattice replace isomorphically bivalent ions of calcium (Ca^{2+}) with compensation of the charge by univalent alkaline cations according to the scheme: $2Ca^{2+} = TR^{3+} + R^{+}$; (Getmanskaya and others,1984). Furthermore, a non-isomorphic form of inclusion of rare earth elements in scheelites was found where microscopic insertions of cerium minerals—monazite and rhabdofane—were found in scheelites of II and III generations.

In the deposit Karagaylyaktas (Southern Kazakhstan), rare earth elements are present in the form of natural minerals (monazite, xenotime, and others) as well as disseminate in rock-forming (micas, fluorite, feldspars) and ore minerals (wolframite, scheelite, and others), where their content reaches 0.2% (Shcherba, 1988 a). During the industrial processing of ores of such deposits, rare earth elements may be extracted from scheelite, fluorite, monazite, and wolframite.

From the aforementioned discussion, is studying ore minerals of rare metal deposits as a concentrator of rare earth elements is challenging (Mizernaya, 2021: 6; Amralinova, 2023 a: 24; Amralinova, 2023 b: 6; Zhihua Wang, 2024; D'yachkov a: 23, 2020 a: 8). The exhaustiveness of complex geological information and the application of innovative research technologies allows studying the cause-and-effect aspects of the inclusion of rare earth elements in ore minerals of rare metal mineralisation (Togizov, 2020 a: 8).

In this regard, we have chosen the Bayan deposit (Northern Kazakhstan) where rare earth element content is increased to 600 g/t in the main ore mineral (scheelite) (Shcherba, 1988 a).

The Bayan deposit has a long multi-stage formation history. It is localised in a metamorphous rock column. Only clays and clay soils are determined in the deposit area among sedimentary formations. A weathered rock area of low thickness is marked. On this ore deposit, some potentially productive zones are identified where ore bodies are forming. The body thickness reaches dozens of metres (Northern: 2-98 m, Intermediate: 1-35 m, Central: 1-50 m, Western: 1.5-25 m), their length is 50 to 1,500 m, and they are contoured within the boundaries of the ore field (Figure 1).

The main ore mineral is scheelite, bismuthinite, and native bismuth. Scheelite is identified in four generations, the main ones being first and second; the first one is found in actinolite-epidote ores and contains up to 23 g/t of rare earth elements, while the second one is found in ore veins and quartz epidote-phlogopite metasomatites where the rare earth content reaches up to 600 g/t.

The main research interest relates to the isomorphic inclusion of rare earth elements in scheelite. We have studied this issue by considering the thermodynamic conditions of ore mineral deposits and geochemical conditions to determine the energetic stability of scheelite crystal lattices.

Research Methods and Materials

The following materials have been used in this study:

- the digital base of geodata: geographic information system (with complex geological, geophysical, geochemical, space, petrological, mineralogical, and petrophysical data and ERS data) in the Bayan deposit area based on the GIS technology with the use of ArcGIS – 10 software;

- 3D models (wireframe and block types) of this deposit represent digital visualisation of the distribution of rare metals and rare earth elements in its boundaries with the use of Micromine software. It allows one to relate the pattern of distribution of ore elements of mineralisation to its ore-controlling factors and to improve the methods and criteria of forecasting and the search for rare metals (Omirserikov, 2017 a: 9)

- the results of mineral-thermometric studies with the determination of temperature intervals of ore formation;

- the results of geochemical studies for the determination of wolframite formation conditions.

As seen above, the methods of Bayan deposit study, besides field geological works, include transformations of geological information (complex geodata) to digital data based on GIS technology. This technology is provided by the software: Mapinfo, Arcgis, and Micromine (Zakrevsky, 2009; Goovaerts, 1997). The geographic information system of the Bayan deposit and its 2D models and 3D wireframe and block models were created with the use of these. The temperature conditions of ore mineral deposits were analysed by the results of thermobarogeochemical methods of the study of gas and liquid inclusions in minerals, and theoretic developments in the simulation of temperature fields of ore-bearing arrays in the system of an intrusive super-intrusive zone (Oceane Rocher, 2024; Togizov 2023 b: 17).

Results

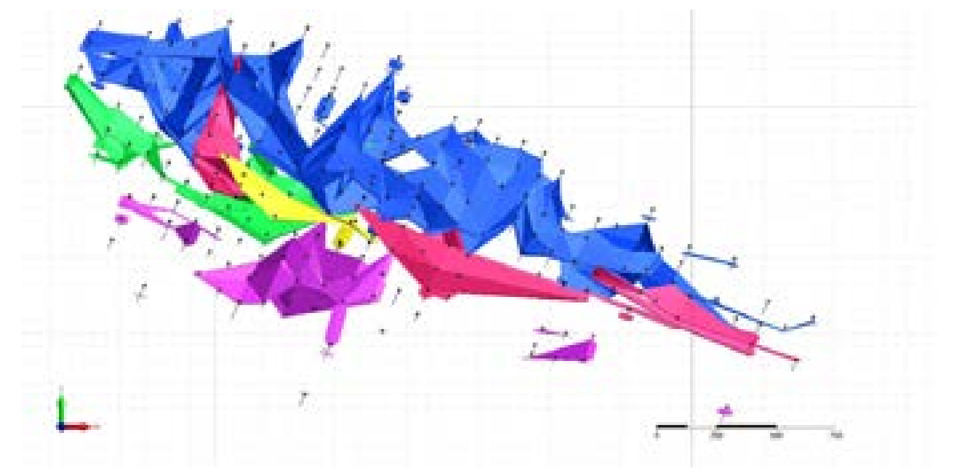
To create the three-dimensional models of this deposit, 39,428 items of geological data were entered into a computer database. The boundaries of the ore-carrying area were considered as the basis of the wireframe model according to the cut-off of tungsten trioxide of 0.06% (Guliaev, 1980; Shcherba, 1984 b: 8; Adamyan, 1989).

In the three-dimensional space, the complex structure of the ore-carrying area is clearly visualised, where the ore-carrying area is narrowed to the south-east, and thus the ore-carrying area has an asymmetrical image. In the deep levels of the ore-carrying area, separate ore bodies are found in the form of atomised skarnoids and skarnified rocks which are found in all the ore-controlling areas, and empty rock levels are clearly visualised in the ore-carrying areas and the ore sections (Figure 1A).

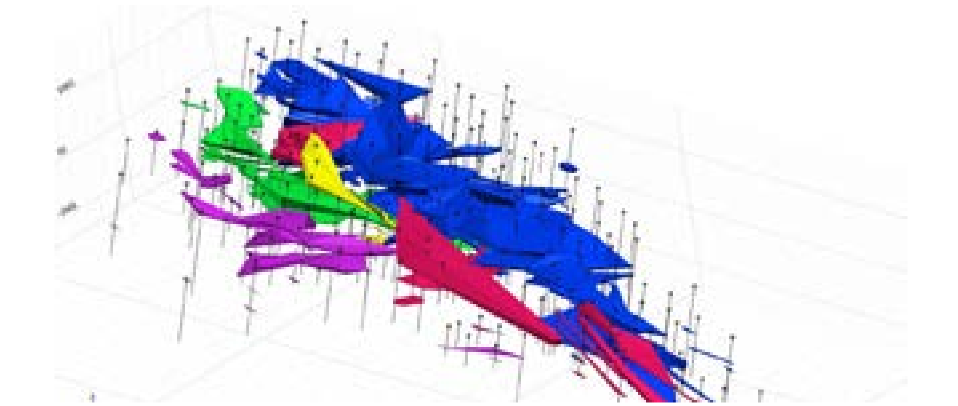
In Figure 1B, irregularity of the thickness of the section of the ore-carrying areas can be seen. According to the geological data, it relates to the occurring transformations of ores that have undergone scarnification to other types, unfavourable to the ore deposit, on the one hand, and with intense processes of granitisation leading to full skarnoid destruction, on the other hand.

Thus, the created wireframe model of the ore-carrying area allows one to show the specifics of the Bayan deposit structure and the changeable thickness of the ore intervals within its limits in digital form.

According to the researchers' data, more than 60 hypogene minerals are determined in the primary ores of the Bayan deposit where scheelite determines the production value of the deposit, and it is found in four generations (Shcherba, 1988 a; Adamyan, 1989).



(a)



(**b**)

Figure 1. 3D wireframe model of the ore zone of the Bayan deposit (Blue: Northern zone, Red: Intermediate zone, Yellow: Western zone, Green: Central zone, Lilac: Southern zone). (**a**) combined with the geological map and the map of actual materials; (**b**) in the three-dimensional space.

Two generations are leading. Scheelite I, whose amount reaches 2%, is spread in actinolite-epidote ores in the form of small (0.2–0.8 mm) disseminated inclusions of irregular isometric granules and rare bunches (1–10 mm) in quartz-epidote-actinolite metasomatites in close association with epidote II, actinolite II, granite II, quartz, pyrite I, pyrrhotite I, and other minerals. Its specific feature is the increased content of M_oO_3(0.17-1,3%), which allows one to attribute it to molybdenum scheelite. Its section is yellow in ultra-violet rays. The rare earth element content is not high (23 g/t).

Scheelite II associates with minerals of quartz-epidote-phlogopite metasomatites and ore veins. It is represented by small (0.2-2 mm) irregular, often isometric granules, bipyramidal crystals, and aggregate bunch segregations (reaching 2-3 cm in quartz-sulfide veins 2-3 cm), and more seldom – by micro-veins and even veins (Figure 2). Its colour in UV-rays is blue. It features a low (0.006-0.09%) content of M_oO_3 and a slightly increased amount (up to 600 g/t) of rare earth elements (Shcherba, 1988 a; Adamyan, 1989).

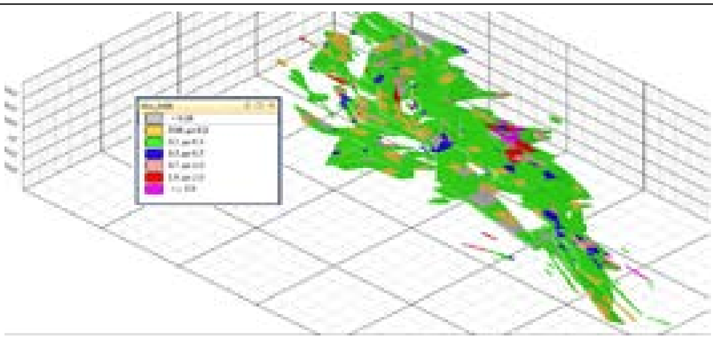
(**a**)

(**b**)

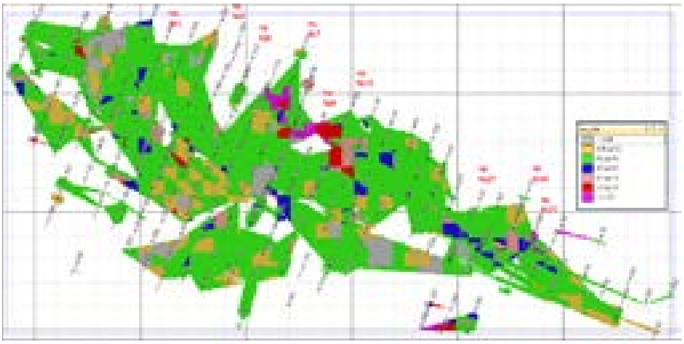
(**c**)	(**d**)

Figure 2. Scheelite extraction morphology: (**a**) Granular scheelite aggregate of pointed form (grey well-shaped) in quartz (light) replacing the skarnoids (dark-grey relicts), without analyser, magnification 70; (**b**) 'Branched' scheelite aggregate (dark) in quartz (light) – fluorite (grey) vein cutting the skarnoids (their relicts are at the bottom right section), without analyser, magnification 70;. (**c**) A scheelite micro vein (grey) in biotite-feldspar gneiss, without analyser, magnification 100; (**d**) A granular scheelite inclusion (light-grey well-shaped) associated with phlogopite (grey), apatite (light granules), and sulfides (black), without analyser, magnification 100.

The 3D digital model of the Bayan deposit created by us allows us to visualise the distribution of the contents of tungsten trioxide (scheelite) along the studied ore field (Figure 3). Within its limits, even distribution of tungsten trioxide in the interval 0.1%–0.5% is found. Such specifics of tungsten trioxide distribution remain along the vertical section. The areas containing tungsten trioxide in the amount of 0.5%–1.0% are spread in all ore zones but are unevenly distributed. Most areas containing tungsten trioxide (0.5%–1.0%) are located in the Intermediate and Southern zones. Areas with the highest contents of tungsten trioxide from 1.0 to 2.0% and more are spread in the central part of the Northern zone where their distribution is equal on all levels, from top to bottom. According to geological data, a sharp increase in mineralisation concentration is seen in the areas with a combination of replacement and vein ores. It is also worth mentioning that actinolite-epidote ores (replacement) in skarnoids are richer in tungsten than in quartz-feldspar rocks (G.N. Shcherba, 1988).



(**a**)



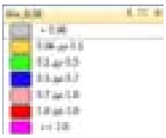
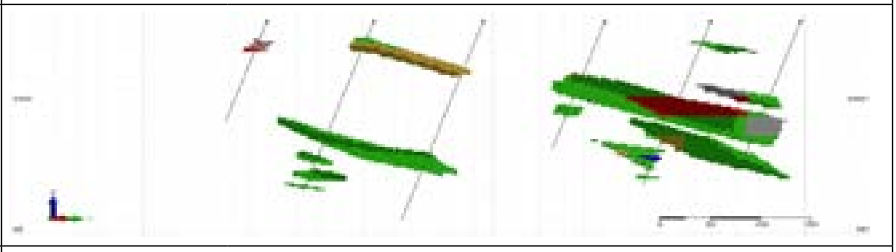
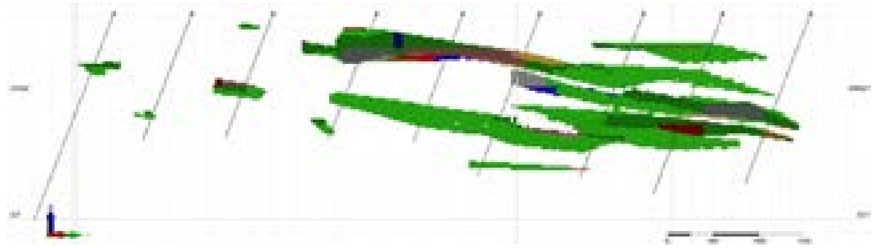
(**b**)

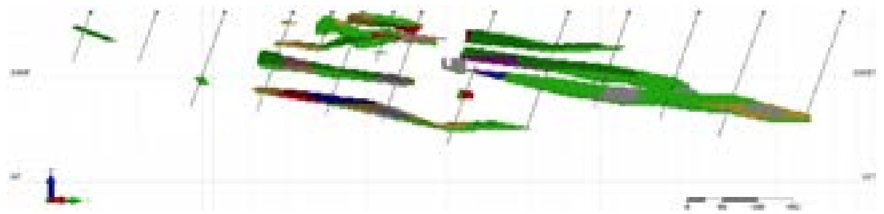
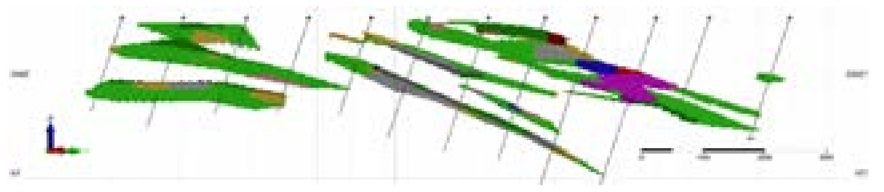
Figure 3. 3D block model of the Bayan deposit:
(**a**) in the three-dimensional space; (**b**) on the exploration profile plan.

Thus, a 3D model of the rare metal Bayan deposit shows that it features not only a complex structure but also an uneven distribution of the main ore element—tungsten trioxide—in space.

Micromine allows one to study a ready model from a perspective of any direction where 2D sections of the exploration profiles have an applicable value. Its matches to the respective geological sections allow one to determine the nature of confinedness of ore element contents to specific types of rocks of the contained environment as well as to the structure specifics of an ore field (Table No.1).

Table 1. Image of 2D sections of the block model of the Bayan deposit.

Pr. No.	 Images of 2D sections of the block model and geological sections of exploration profiles of the Bayan deposit
-3	
1	

3	
5	
7	

The results of the studies showed that the lower levels of the western and north-western parts of this deposit have the applicable interest for it which is confirmed by the following factors:

1. The visualisation of tungsten trioxide distribution along the sections of the exploration line shows that its highest concentrations are located in skarnoids among granite gneiss. Also, the tungsten mineralisation is associated with gneiss-amphibolite sequences in the deposit's central part and with granite gneiss rocks in its peripheral parts (Table No.1, pr. No. 3, 7);

2. Areas with high content, from 1.0% to 2.0% and above (exploration lines 3 and 1) are also found in the bottom levels of the deposit's western part. Here the stockwork veins are crossed by skarnoid bodies at the depth of 200 to 300 m, which is the main reason for the occurrence of areas with a high concentration of tungsten trioxide (Table No.1).

3. Tectonic faults limiting the deposit on its western flank play an important role in the formation of ore stockwork where the prevailing system of ore fractures in the deposit has a northern–western direction.

Considering that an ore body has been found in the Northern zone, and the tungsten trioxide content is higher than the cut-off (0.06%) at the depth of 410 m (pr. No.7), then ore bodies with high content of tungsten trioxide may be localised below the level of 200 m (Table No.1).

In general, the visualisation of tungsten trioxide distribution at the Bayan deposit shows that the bottom deposit levels may give an additional reserve increment. Besides, areas with high contents of tungsten trioxide of 1.0%–2.0% and above are found in the western and north-western deposit parts.

The above-mentioned means that the depth of exploration can be increased at the western flank of the Bayan deposit. However, the potentially productive areas are determined by the bottom levels (250–400 m) of its western flank, between exploration lines No.1 and 5. Deep levels are also potentially productive in industrial ores mainly in the Northern and partially in the Central zone (Figure 3).

The ore bodies at this deposit are formed by actinolite-epidote-scheelite metasomatites in skarns and stockwork quartz-feldspar-scheelite zones. Vein mineralisation is associated with granites and metasomatic as well asgranites and granodiorites (Radenko, 1991: 15).

Based on the data of A.B. Darbadaev (1988), four temperature intervals of ore formation can be determined. The earliest quartz and feldspar-quartz associations have been crystallised from solutions enriched with gases with a temperature interval of 420°C–400°C. Further main scheelite-sulfide-quartz associations have been formed from gas-liquid solutions with the temperature interval of 320°C–200°C, scheelites = 300°C–255°C, while the main volume of sulfides has been extracted with the temperature interval of 250°C–200°C. The ore process has been completed by the formation of quartz-fluorite associations with the temperature interval of 200°C–150°C.

Discussion

Vein-stockwork ore bodies are composed of a network of parallel, (and more seldom – crossing, quartz, quartz-sulfide, quartz-albite) veins of several generations with scheelite. Scheelite features slightly increased content of rare earths. Consequently, their concentrators are scheelites. Let us consider this issue from the point of view of geochemical conditions of mineral formation and thermodynamic conditions of ore stockwork formation.

Many authors pointed out the following geochemical factors leading to a concentration of rare earth elements in scheelites of Kazakhstan deposits:

- The first one is the conditions of wolframite formation. According to the researchers' data, the increase of alkalinity of acid greisenising solutions creates a favourable environment for the formation of tungstates of Fe, Mn, and Ca in the order of increase of solubility of their compounds expressed by the row $FeWO_4$: $MnWO_4$ –$CaWO_4$ with the presence of Fe^{2+}, Mn^{2+}, Ca^{2+} cations in the ore-forming solutions (Bryzgalin, 1976). The increase of pH and Eh of acidic greisenising solutions leads to the decrease of the content of the ferberite molecule in the tungstate. Scheelites crystallise in almost neutral weakly alkaline conditions (pH = 7.3) (Radenko, 1991: 15);

- The second one is the energy characteristics of the strength of crystal lattices determined as a share of energy contributed by each ion to a heteropolar compound when it is formed from ions. The values of energy coefficients of ions of the above-mentioned chemical elements also influence the change of wolframite composition.

For bivalent cations Fe^{2+}, Mn^{2+}, Ca^{2+}, the energy coefficients are determined, and they, respectively, have the values of 2.15, 1.95, and 1.75 eq. (eq. is a conditional unit, it can be expressed in electron volts) (Gavruseevich, 1988). Crystal lattices created by the composition of ions of different types will be stable and strong if their energy coefficients are high. That is why we can state that wolframite crystal lattices with a ferberite molecule are much stronger than crystal lattices of hubnerite and scheelite.

At the Bayan deposit, the concentration of rare earth elements in scheelites shows that it is advantageous energetically if we add an ion (TR^{3+}) with a high energy coefficient (3.6-4.1 eq.) to the scheelite crystal lattice instead of the bivalent calcium cation (Ca^{2+}). In this case, the energetic stability of the scheelite crystal lattice increases.

The host medium and the mineral formation temperature make additional changes to mineral composition. Temperature and pressure are considered crucial factors determining the wolframite composition by many authors (Ermilova, 1964, and others): with temperature decreases, the hubnerite molecule in wolframite increases. The vast practical materials in thermobarometry show that the temperature limits of wolframite formation of different formation and genetic types on average fall within a narrow interval of 380°C–280°C. Hubnerites fall within the same interval. Skarn deposit scheelites feature lower temperature intervals (340°C–200°C). As we can see, the mineral formation temperature also influences the wolframite composition.

That is why thermodynamic conditions of crystallisation of ore minerals, in particular, scheelites, are of great interest. Such issues are solved by the application of data of thermobarogeochemical studies of the temperature of ore mineral formation as well as of the results of quantitative simulation considering the estimation of the thermodynamic conditions of the ore localising environment (Togizov, 2019: 8).

That is why we have analysed the thermodynamic conditions of concentrator mineral crystallisation. At this deposit, the sources of the tungsten ores were represented by the intrusions of early granodiorites and late granites, with the latter being associated with vein mineralisation that was formed in its thermal field. Therefore, we have thoroughly reviewed the types of heat flows in endogenous ore formation (conductive and convective).

As it is known, a combination of some conditions is necessary for the formation of endogenous rare metal deposits. The first of them is the presence of granitoid intrusions with dome morphology, the second one is the position of the potentially productive area in the interval of temperature zonal sequence meeting the requirements of high-temperature rare metal formation, and the third one is the extensive development of faults contributing to the increased permeability of the mineral formation medium.

The above conditions allow us to determine the state parameters in the ore-forming system consisting of ore-forming fluids and their operation medium for the deposit of ore substances. They are temperature, pressure, and the substance composition of ore-forming systems, which are determined by methods of analytical studies, in particular, the methods of thermobarogeochemistry. These methods can describe the thermodynamic state of the ore-forming system in the period of ore formation, but the thermodynamic state of the ore localising system can be determined only by mathematic simulation of the heat field of granitoid intrusions.

Late leucocratic granites, related to the vein mineralisation at the Bayan deposit, form the energetic state of the ore localising medium. Besides, the analysis of temperature conditions of deposit of ore minerals shows that ore formation at the Bayan deposit is of a hydrothermal nature. Consequently, the ore-forming fluids with temperatures of 350°C–200°C adjust the patterns of heat distribution in zones of ore component deposit, i.e., create heat-abnormal areas interacting with the main heat field of the granite intrusion.

In such an analysis, it is obvious that the study of the ore formation process is based not only on geologic patterns but also on the principles of heat and mass transfer and exchange. In this case, such important issues are covered as relations between ore-forming and ore localising heat systems in mineral formation.

In general, unstable heat conditions are typical for all zones of the intrusive granitoid level of ore formation (except the intra-intrusive one) at mineral crystallisation. But their aspects are different, and they are clearly expressed in the super intrusive zone. The low migration speed in relation to the low-temperature front determines the immobility of the heat field of ore carrying massive in the super intrusive zone. When the ore forming solutions with high temperatures reach a low-pressure zone, they create 'heat-abnormal' areas and disturb the immobility of the heat field of the ore-hosting medium. The contrast in ore-forming and ore localising systems contributes to sharp fluctuations of temperature driving the system to balance and leading to a high speed of crystal growth.

In this regard, it is worth mentioning that the speed of crystal growth depending on thermodynamic conditions is a factor leading to the isomorphic inclusion of other ions in crystal lattices.

Scheelites associated with granite gneiss rocks at this deposit have been crystallised in unbalanced thermodynamic conditions due to their spatial position.

Conclusion

Thus, the specifics of rare earth inclusion in scheelites at the Bayan deposit are based on:

1. geochemical conditions of wolframite formation where scheelites crystallise in almost neutral weakly alkaline conditions;
2. the energetic specifics of the strength of wolframite crystal lattices; it is more advantageous energetically for scheelite crystal lattice to receive an ion (TR^{3+}) with high energy coefficient instead of the bivalent calcium cation (Ca^{2+});
3. thermodynamic conditions of ore mineral crystallisation, including scheelites. The remoteness of ore localising structures from the source of thermal energy (granite intrusion) is the main factor of expression of thermodynamic imbalance at their crystallisation leading to the high speed of crystal growth and isomorphic inclusion of other ions in crystal lattices.

References

N.L. Radenko, L.V. Ivanov, O.M. Tiugay, Z.S. Tilepova. New rare earth region in Central Kazakhstan // Izvestia of the Academy of Science of Kazakh SSR, the series of geology -1991. – No.5, p.3-17

G.N. Shcherba, A.V. Kudryashov, N.P. Senchilo. Rare metal mineralization in Kazakhstan. - Almaty: Science, 1988. – p. 221

Omirserikov M.S., Duczmal-Czernikiewicz A., Isaeva L.D., Asubaeva S.K., Togizov K.S. (2017). Forecasting resources of rare metal deposits based on the analysis of ore-controlling factors. *News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences, 3*(423), 35-43

K.E. Zakrevsky. Geologic 3D simulation. Moscow: Mask Publishing House, LLC, 2009. P. 376

Goovaerts P. Geostatistics for Natural Resources Evaluation. Oxford University Press, 1997.

Oceane Rocher. Unravelling the magmatic and hydrothermal evolution of rare-metal granites through apatite geochemistry and geochronology: The Variscan Beauvoir granite (French Massif Central). *Chemical Geology, 670*, 20. https://doi.org/10.1016/j.chemgeo.2024.122400

Togizov K., Issayeva L., Muratkhanov D., Kurmangazhina M., Swęd M., & Duczmal-Czernikiewicz A. (2023). Rare earth elements in the Shok-Karagay ore fields (Syrymbet ore district, Northern Kazakhstan) and visualisation of the deposits using the Geography Information System. *Minerals*, *13*(11), 1458. https://doi.org/10.3390/min13111458

A.P. Guliaev. Ore-hosting skarnoids of the Bayan deposit (Kazakhstan) // Petrology of ore-carrying metasomatites. Frunze: Ilim, 1980.

G.N. Shcherba, F.G. Gubaydullin. On the origin of the Bayan scheelite deposit. – Ore deposit geology, 1984. No.5. P. 20-27.

Report No.41342. N.Kh. Adamyan. The Bayan tungsten deposit in the Kokshetau region of Kazakh SSR,1989.

B.A. Gavruseevich. Basic general geochemistry. M.: Subsoil, - 1988. – p. 327.

Mizernaya M.A., Dyachkov B.A., PyatkovaA.P., Miroshnikova A.P., Chernenko Z.I. Leading genetic types of base metal deposits of Rudny Altai // Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, № 2, 2021. C. 11-16. DOI 10.33271/nvngu/2021-2/011

Amralinova B., Agaliyeva B., Lozynskyi V., Frolova O., Rysbekov K., Mataibaeva I., Mizernaya M. (2023). Rare-metal mineralization in salt lakes and the linkage with composition of granites: Evidence from Burabay Rock Mass (eastern Kazakhstan). *Water*, *15*(7), 1386. https://doi.org/10.3390/w15071386

Amralinova, B. B., Frolova, O. V., Mataibaeva, I. E., Agaliyeva, B. B., & Khromykh, S. V. (2020). Mineralization of rare metals in the lakes of East Kazakhstan. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (5), 16–21. https://doi.org/10.33271/nvngu/2021-5/016

Zhihua Wang, Jun Hong, Xin Lin, Huishan Zhang, Yasir Shaheen Khalil, Naghma Haider, Mehboob Ur Rashid, Muhammad Jawad Zeb, Asad Ali Narejo. Concentration and distribution patterns of rare earth elements (REEs) in stream sediments of Pakistan, *Journal of Geochemical Exploration*, *258*, https://doi.org/10.1016/j.gexplo.2024.107386.

D'yachkov B., Bissatova A., Mizernaya M. et al. Mineralogical Tracers of Gold and Rare-Metal Mineralization in Eastern Kazakhstan // Minerals, 2021, 11 (3). Pp. 1-23. DOI:10.3390/min11030253

Togizov K.S., Zholtayev G., & Isaeva L.D. (2019). The role of three-dimensional models of deposit and thermodynamic conditions of its formation at selecting and evaluating resources of perspective sites. *NEWS of National Academy of Sciences of the Republic of Kazakhstan*, *5*(437), 169–176. https://doi.org/10.32014/2019.2518-170x.139

Togizov K., & Antonenko A. (2020). The structural tectonic position and predictive search criteria for the lead-zinc karst mineralisation (South Kazakhstan). *SGEM International Multidisciplinary Scientific GeoConference EXPO Proceedings*. P.335-340. https://doi.org/10.5593/sgem2020/1.1/s01.042

Khromykh S.V., Oitseva T.A., Dyachkov B.A., Kuzmina O.N., Mizernaya M.A., Agaliyeva B.B. Rare-metal pegmatite deposits of the Kalba region, Eastern Kazakhstan: Age, composition and petrogenetic implications // Minerals, 2020, 10 (1017). Pp. 1-15. DOI: 10.3390/min10111017

D′yachkov B.A., Bissatova A.Y., Mizernaya M.A., Khromykh S.V., Oitseva T.A., Kuzmina O.N., Zimanovskaya N.A., Aitbayeva S.S. (2021) — *D′yachkov B.A., Bissatova A.Y., Mizernaya M.A., Khromykh S.V., Oitseva T.A., Kuzmina O.N., Zimanovskaya N.A., Aitbayeva S.S.* Mineralogical tracers of gold and rare-metal mineralization in Eastern Kazakhstan, Minerals, 11(3):1-23, DOI:10.3390/min11030253 (in Eng.).

Publication Ethics and Publication Malpractice in the journals of the National Academy of Sciences of the Republic of Kazakhstan

For information on Ethics in publishing and Ethical guidelines for journal publication see http://www.elsevier.com/publishingethics and http://www.elsevier.com/journal-authors/ethics.

Submission of an article to the National Academy of Sciences of the Republic of Kazakhstan implies that the described work has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis or as an electronic preprint, see http://www.elsevier.com/postingpolicy), that it is not under consideration for publication elsewhere, that its publication is approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out, and that, if accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder. In particular, translations into English of papers already published in another language are not accepted.

No other forms of scientific misconduct are allowed, such as plagiarism, falsification, fraudulent data, incorrect interpretation of other works, incorrect citations, etc. The National Academy of Sciences of the Republic of Kazakhstan follows the Code of Conduct of the Committee on Publication Ethics (COPE), and follows the COPE Flowcharts for Resolving Cases of Suspected Misconduct (http://publicationethics.org/files/u2/New_Code.pdf). To verify originality, your article may be checked by the Cross Check originality detection service http://www.elsevier.com/editors/plagdetect.

The authors are obliged to participate in peer review process and be ready to provide corrections, clarifications, retractions and apologies when needed. All authors of a paper should have significantly contributed to the research.

The reviewers should provide objective judgments and should point out relevant published works which are not yet cited. Reviewed articles should be treated confidentially. The reviewers will be chosen in such a way that there is no conflict of interests with respect to the research, the authors and/or the research funders.

The editors have complete responsibility and authority to reject or accept a paper, and they will only accept a paper when reasonably certain. They will preserve anonymity of reviewers and promote publication of corrections, clarifications, retractions and apologies when needed. The acceptance of a paper automatically implies the copyright transfer to the National Academy of Sciences of the Republic of Kazakhstan.

The Editorial Board of the National Academy of Sciences of the Republic of Kazakhstan will monitor and safeguard publishing ethics.

Правила оформления статьи для публикации в журнале смотреть на сайтах:
www:nauka-nanrk.kz
http://www.geolog-technical.kz/index.php/en/

ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Директор отдела издания научных журналов НАН РК *А. Ботанқызы*
Редакторы: *Д.С. Аленов, Ж.Ш.Әден*
Верстка на компьютере *Г.Д.Жадыранова*

Подписано в печать 15.12.2024.
Формат 70x90 $^{1}/_{16}$. Бумага офсетная. Печать – ризограф.
14,5 п.л. Тираж 300. Заказ 6.

РОО «Национальная академия наук РК»
050010, Алматы, ул. Шевченко, 28, т. 272-13-19