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

ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ

Satbayev University

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ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ
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КАЗАХСТАН
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N E W S

OF THE ACADEMY OF SCIENCES
OF THE REPUBLIC OF
KAZAKHSTAN
Satbayev University

SERIES

OF GEOLOGY AND TECHNICAL SCIENCES

2 (458)

MARCH – APRIL 2023

THE JOURNAL WAS FOUNDED IN 1940

PUBLISHED 6 TIMES A YEAR

ALMATY, NAS RK

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«ҚР ҰҒА 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/

Типографияның мекен-жайы: «Аруна» ЖК, Алматы қ., Мұратбаев көш., 75.

«Известия 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 соедененений.*

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/

Адрес типографии: ИП «Аруна», г. Алматы, ул. Муратбаева, 75.

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/

Address of printing house: ST «Aruna», 75, Muratbayev str, Almaty.

NEWS of the National Academy of Sciences of the Republic of Kazakhstan
SERIES OF GEOLOGY AND TECHNICAL SCIENCES
ISSN 2224-5278
Volume 2, Number 458 (2023), 96–107
https://doi.org/10.32014/2023.2518-170X.284
UDC 553.041/078

© L.Z. Issayeva[1], E. Slaby[2], S.K. Assubayeva[1], M.K. Kembayev[1], K.S. Togizov[1*], 2023
[1]Satbayev University, Almaty, Kazakhstan;
[2]Institute of Geological Sciences P.A.S., Warsaw, Poland.
E-mail: k.togizov@satbayev.university

THE THREE–DIMENSIONAL MODEL OF THE AKBULAK RARE EARTH DEPOSIT (NORTHERN KAZAKHSTAN)

Lyudmila Issayeva — doctor of geological and mineralogical sciences, professor, Satbayev University
E-mail: l.issayeva@satbayev.university, https://orcid.org/0000-0001-7184-6351;
Ewa Slaby — Dr. Hab. professor, director institute of geological sciences P.A.S.
https://orcid.org/0000-0003-1476-5138;
Saltanat Assubayeva — candidate of geological and mineralogical sciences, Satbayev University
E-mail: s.assubayeva@satbayev.university, https://orcid.org/0000-0003-3658-715X;
Maxat Kembaev — PhD, associate professor, Satbayev University
E-mail: m.kembayev@satbayev.university, https://orcid.org/0000-0001-5069-9399;
Kuanysh Togizov — PhD, associate professor, Satbayev University
E-mail: k.togizov@satbayev.university, https://orcid.org/0000-0002-4830-405X.

Abstract. The economy of Kazakhstan was always linked closely to subsoil use, and the well–being of our country is directly associated with robust approach to geological research. The 2021–2025 State Geological Exploration Programme was adopted this year at governmental level to provide sustainable replenishment, development and support to competitiveness of Kazakhstan's mineral resources base. The programme predetermine new principles in geological research methodology for ore objects too. The new approach can be realized through application of modern research technology (MapInfo, ArcGIS, GIS–Micromine), concerned with formation of a scientific digital geodata base to generate 3D models of mineral resource deposits. Analysing the obtained results we can solve actual tasks of prospecting geology in identifying promising areas within known deposits, specifying ore–controlling factors, and estimating its reserves. Input data for the Akbulak 3D–model was supplied in the form of graphics and calculation tables. Based on the Akbulak field geographic information system, we developed the wireframe and block models, as well as the block model slices along exploration profiles. The result enable identifying the promising areas with commercial ores within the deposit.

Key words: rare earth elements, ion adsorption deposits, geoinformation system, framework model, block model
Funding. This research was funded by Geology Committee of the Ministry of Industry and Infrastructure Development of the Republic of Kazakhstan, grant number BR10264324.

© Л.Ж. Иссаева[1], Е. Слаби[2], С.К. Ассубаева[1], М.К. Кембаев[1], К.С. Тогизов[1*], 2023
[1]Сәтпаев Университеті, Алматы, Қазақстан;
[2]Геология ғылымдар институты П.Ғ.А., Варшава, Польша.
E-mail: k.togizov@satbayev.university

АҚБҰЛАҚ СИРЕКЖЕР КЕН ОРНЫНЫҢ ҮШ ӨЛШЕМДІ МОДЕЛІ (СОЛТҮСТІК ҚАЗАҚСТАН)

Исаева Людмила Жандүйсенқызы — геология және минералогия ғылымдарының докторы, профессор, Сәтпаев Университеті
E-mail: l.issayeva@satbayev.university, https://orcid.org/0000-0001-7184-6351;
Ewa Slaby — хаб. докторы, профессор, П.Ғ.А. геологиялық ғылымдар институтының директоры
https://orcid.org/0000-0003-1476-5138;
Асубаева Салтанат Қалықбайқызы — геология және минералогия ғылымдарының кандидаты, Сәтпаев Университеті
E-mail: s.assubayeva@satbayev.university, https://orcid.org/0000-0003-3658-715X;
Кембаев Максат Кенжебекулы — PhD, қауымдастырылған профессор, Сәтпаев Университеті
E-mail: m.kembayev@satbayev.university, https://orcid.org/0000-0001-5069-9399;

Тоғызов Қуаныш Серікханұлы — PhD, қауымдастырылған профессор, Сәтпаев Университеті
E-mail: k.togizov@satbayev.university, https://orcid.org/0000-0002-4830-405X.

Аннотация. Қазақстан экономикасы әрқашан жер қойнауын пайдаланумен тығыз байланысты болды, ал еліміздің әл-ауқаты геологиялық зерттеулерге сенімді көзқараспен тікелей байланысты. Үкімет деңгейінде Қазақстанның минералдық-шикізаттық базасын тұрақты толықтыру, дамыту және бәсекеге қабілеттілігін қолдау мақсатында 2021–2025 жылдарға арналған Мемлекеттік геологиялық барлау бағдарламасы қабылданды. Бағдарлама кен объектілерін геологиялық зерттеу әдістемесінің жаңа принциптерін де алдын ала белгілейді. Жаңа тәсілді қазіргі заманғы зерттеу технологиясын орындарының 3D модельдерін құру үшін ғылыми цифрлық геодеректер базасын қалыптастыруға қатысты. Алынған нәтижелерді талдай отырып, белгілі кен орындарының шегінде перспективалық учаскелерді анықтауда, кенді реттейтін факторларды көрсетуде және оның қорларын бағалауда барлау геологиясының өзекті міндеттерін шешуге болады. Ақбұлақ 3D-моделі үшін кіріс деректер графикалық мәліметтерден және есептеу кестелерінен алынды. Ақбұлақ кен орнының геоақпараттық жүйесіне сүйене отырып, барлау профильдері бойынша каркастық және блоктық модельдері, сондай–ақ блок-моделінің тілімдері әзірленді. Нәтиже кен орнындағы тауарлы кендері бар перспективалы аймақтарды анықтауға мүмкіндік береді.

Түйінді сөздер: сирек жер элементтері, иондық адсорбциялық кен орындары, геоақпараттық жүйе, рамкалық модель, блок-модель
Қаржыландыру. Зерттеу №BR10264324 бағдарламасы бойынша Қазақстан Республикасының Индустрия және инфрақұрылымдық даму министрлігінде Геология комитетінің қаржылық қолдауымен орындалды.

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[1]Сатпаев Университет, Алматы, Казахстан;
[2]Институт Геологических Наук П.А.Н., Варшава, Польша.
E-mail: k.togizov@satbayev.university

ТРЕХМЕРНАЯ МОДЕЛЬ АКБУЛАКСКОГО РЕДКОЗЕМЕЛЬНОГО МЕСТОРОЖДЕНИЯ (СЕВЕРНЫЙ КАЗАХСТАН)

Исаева Людмила Джандуйсеновна – доктор геолого–минералогических наук, профессор, Satbayev University
E-mail: l.issayeva@satbayev.university, https://orcid.org/0000-0001-7184-6351;
Ewa Slaby – хаб. доктор, профессор, директор Института геологических наук П.А.Н.
https://orcid.org/0000-0003-1476-5138;
Асубаева Салтанат Калыкбаевна – кандидат геолого–минералогических наук, Satbayev University
E-mail: s.assubayeva@satbayev.university, https://orcid.org/0000-0003-3658-715X;
Кембаев Максат Кенжебекулы – PhD, ассоциированный профессор, Satbayev University
E-mail: m.kembayev@satbayev.university, https://orcid.org/0000-0001-5069-9399;
Тогизов Куаныш Серикханович – PhD, ассоциированный профессор, Satbayev University
E-mail: k.togizov@satbayev.university, https://orcid.org/0000-0002-4830-405X.

Аннотация. Экономика Казахстана всегда была тесно связана с недропользованием, и благополучие нашей страны напрямую связано с грамотным подходом к геологическим исследованиям. На уровне Правительства была принята Государственная программа геологоразведки на 2021–2025 годы, направленная на обеспечение устойчивого восполнения, развития и поддержки конкурентоспособности минерально–сырьевой базы Казахстана. Программа предопределяет новые принципы в методологии геологических исследований и рудных объектов. Новый подход может быть реализован за счет применения современных исследовательских технологий (MapInfo, ArcGIS, GIS-Micromine), связанных с формированием научной цифровой базы геоданных для создания 3D-моделей месторождений полезных ископаемых. Анализ полученных результатов позволяет решать актуальные задачи поисковой геологии по выявлению перспективных участков в пределах известных месторождений, уточнению рудоконтролирующих факторов и подсчету его запасов. Исходные данные для 3D-модели Акбулак были предоставлены в виде графиков и расчетных таблиц. На основе геоинформационной системы месторождения Акбулак разработаны каркасная и блочная модели, а также срезы блочной модели по разведочным профилям. Результат позволил выделить перспективные участки с промышленными рудами в пределах месторождения.
Ключевые слова: редкоземельные элементы, ионно-адсорбционные месторождения,

геоинформационная система, каркасная модель, блочная модель

Финансирование. Исследование выполнено при финансовой поддержке Комитета геологии Министерства индустрии и инфраструктурного развития Республики Казахстан, Программа №BR10264324.

Introduction

Kazakhstan has significant prospects for development of its rare earth mineral resource base. Until the late 1980s–1990s in Kazakhstan, the rare earth elements (of, mainly, cerium group) were extracted in the uranium production at the Prikaspian and Tselinny Combines, as well as at the Irtysh Chemical-Metallurgical Plant from imported raw materials (of the Kola Peninsula). This presented the mining industry with new tasks.

Currently, the hypergene deposits of rare earths are of significant interest, especially considering the comparative ease of technological scheme of their mining, as a significant part of rare-earth mineralization is associated with clay minerals. As is known, by composition the REE minerals are divided into the following groups: cerium minerals (bastnaesite, parisite, loparite, monazite, knobotite, eudialyte, fergusonite Ce, etc.); gadolinium (samarskite, etc.); yttrium (euxenite, xenotime, yttrialite, etc.); yttrium-yttterbium (fergusonite, etc.), complex (orthite, pyrochlore, gadolinite, apatite, sphene, etc.).

A number of yttrium and rare earth deposits and ore occurrences are concentrated in Northern Kazakhstan (Kundybai (Omirserikov, 2017a: 6, Omirserikov, 2016b: 12), Shok-Karagai (Issayeva, 2019a: 8, Issayeva, 2022b: 8)), one of which is Akbulak. During last geochemical searches in 1986–90, a Akbulak zone of rare and rare-earth metals was discovered and formalized on the Trough area. As a result, the *Akbulak tin-rare-earth zone* was identified on the south-eastern endocontact of the Akzhar massif (Yermolov, 2019: 11; Stepanets, 2017: 19; D′yachkov, 2022a: 22; Salikhov, 2020: 8). The mineralization is confined to linear weathering crusts. In the south-western part of the Akbulak zone (according to surface metallometry and isolated core holes), the rare-earth mineralization was detected both in weathering crusts and in bedrock (Omirserikov, 2017a: 6; Mizernaya, 2020: 6; D′yachkov, 2021b: 23; Mukhamedzhanov, 2017: 12). Mineralogical analysis defined their mineral forms as xenotime, rhabdophanite, cherchite and bastnaesite. The ore parts have thickness from 1.4 m to 31 m, and the total thickness of weathering crusts is 10 to 50 m. Anomalous yttrium contents are accompanied by elevated contents of tin (0.003–0.12 %), silver (1–100 g/t), zinc (0.2–0.3 %). Prospecting and appraisal work on the deposit established the industrial significance of the site. Average contents of yttrium oxide are 272 g/t, on sides 100 g/t, and sum of rare earths 790 g/t were established at the deposit.

The spectral and semi-quantitative analysis for yttrium and rare earths allowed outlining the yttrium and rare earths ore deposit by the side content of yttrium of 100 g/t and 200 g/t, and three promising areas were identified within the area (Tishhenko, 1994: 246):

1. The central part of the site (the Akbulak ore occurrence itself and its flanks).
2. The southern part.
3. The northern part.

They are all located away from the south-eastern endocontact of the Akzhar massif, confined to linear weathering crusts developed over gneiss granites and characterised by similar mineralisation parameters and a set of elements.

Materials and basic research methods

The geological structure of the area involves rocks that were formed during the period between the Proterozoic and the present day. Proterozoic and Paleozoic rocks compose the folded basement, while Meso-Cenozoic sediments form the platform cover. Tectonically, the area is located in the Ulutau anticlinorium, which consists of two structural floors, lower and upper, separated by regional unconformity. The site area consists of the Upper Stage deposits: the rocks of the Aralbai Series, Karasuleimen (PR_2ks) and Duisyun Suite (PR_2ds). These rocks occupy 10–15 % of the area. About 80–90 % of the area are composed of gneiss granites of the Akzhar massif of the Upper Proterozoic complex (γPR_2). The Akzhar massif is poorly exposed, with bedrock gneiss granites coming to the surface in the northern part of the area along the Aschitasty River. The main area is overlain by the cover of Pliocene-Pleistocene sediments of 10–25 m of thickness.

The platform cover is represented by Meso-Cenozoic formations of area or linear weathering crusts of crystalline basement, clays and sands of Kaidaul (P_3^{2-3}kd), Tersek (N_1^{1-2}trs), Pavlodar (N_1^3–N_2^1), Turnei (N_1^{2-3}trm) suites, gravel, sandy loams, loams of Quaternary system.

In the south-eastern endocontact of the Akzhar massif, the Akbulak tin-rare-earth zone is traced for 17 km along the strike, 2–3 km wide. The massif is composed of gneiss granites of light grey, pinkish-grey colour, mica-quartz-feldspar composition with the porphyroblast structure. The hosting rocks (exocontact of the Akzhar massif) are mica-feldspar-quartz schists interbedded with feldspar-biotite-amphibole porphyritoids, attributed to the Duisyun Suite of the Upper Proterozoic (PR_2ds). Tectonically, the anomalous zone is complicated by tectonic faults, clearly revealed by geophysical surveys, of north-eastern and sub-latitudinal directions, along which displacements of rocks and geochemical halos are observed (Tishchenko, 1994: 246; Baibatsha, 2020a: 14; Baibatsha, 2020b: 9; Baibatsha, 2020c: 9; Baibatsha, 2021d: 7; Ratov, 2021: 11; Aidarbekov, 2022: 16).

In the magnetic field, the anomalous zone is characterised by elevated values of 100–400$^{\gamma}$ in the background of $\pm 50^{\gamma}$. In general, the Akbulak zone is characterised by yttrium contents of 0.01 % to 0.1 % and above, elevated contents of tin, silver, molybdenum, niobium, gallium, lead and zinc. Within the zone, a number of anomalous halos were identified with ore concentrations of rare earth elements. The zone is unevenly explored: the north-eastern and south-western parts were identified by surface metallometry, the central part by subsurface lithochemistry data (Nazirova, 2019: 5).

For the north-eastern part of the Akbulak zone, the indices of the transverse and longitudinal series of zonality have been calculated. The longitudinal series of zoning (from south-west to north-east) is as follows: Ti, Sn, Pb, Ga, Be, Nb, Jb, Y, Sn, and indicates the direction of dipping of the ore zone axis from south-west to north-east with changes in the level of erosional cut from the low-ore to the ore and the sub-ore. The type of mineralisation is rare-earth with tin. The cross-sectional zoning series (west to east) is as follows: Yb, Y, V, Mo, Zr, Sn, Yb, Y, Cr, Nb, Sn, Y, Yb, Sn, and indicates that at least three ore bodies can be identified within the zone.

The above data of predecessors and materials of drilling works (Tishhenko, 1994: 246) and data of K.I. Satpayev IGN obtained in 2013–2014 formed the basis of GIS-modelling (MicroMine).

Initial data was used to create a geographical information system for the area in the form of graphic charts (geological map, geological cross-sections and surface sampling plans) and scoring tables.

A total of 13,472 pieces of information on 1,712 wells were utilised for modelling.

The spatial boundaries of the ore body were modelled using the MicroMine software (Kennedy, 2001; Micromine, 2004: 220). The ore body boundaries of yttrium at 100 g/t and 200 g/t lateral contents were used as the basis for the wireframe model (Issayeva, 2019 a: 8; Issayeva, 2022b: 8).

Results and discussion

1) Frame models of the Akbulak site. First of all, the lithological structure of the Akbulak site was modelled**.** It was noted that all prospective zones are located along the south-eastern endocontact of the Akzhar massif, are confined to linear weathering crusts developed on gneiss granites, are characterised by similar mineralisation parameters, and sets of elements. The geological setting is also similar to that of the Akbulak ore occurrence, and therefore can be sufficiently descriptive by the latter.

The modelling of the lithological structure of this area utilised the lithological boundaries shown on the 1991–1994 reserves estimation sections (Tishhenko, 1994: 246). The following lithological layers were identified: the boundary of friable Meso-Cainozoic sediments, the boundary of the weathering crust, the boundary of gneiss granites (Figure 1).

According to geological data, the structure of the Akbulak ore occurrence involves the following vertical constituents (top to down):

- cover deposits (N-Q) represented by loams, clays up to 20.0 m thick (average thickness across the ore occurrence is 13 m);
- weathering crusts (Mz) are clay-silt loam, clay-rubble, rubble with a total thickness up to 50m;
- weakly weathered gneiss-granites (γPR_2) of a light grey, pinkish-grey colour.
- the three-dimensional wireframe model of the lithological structure of the Central zone (the Akbulak ore occurrence) clearly visualises these lithological layers with geometric parameters estimated vertically (Figures 1).

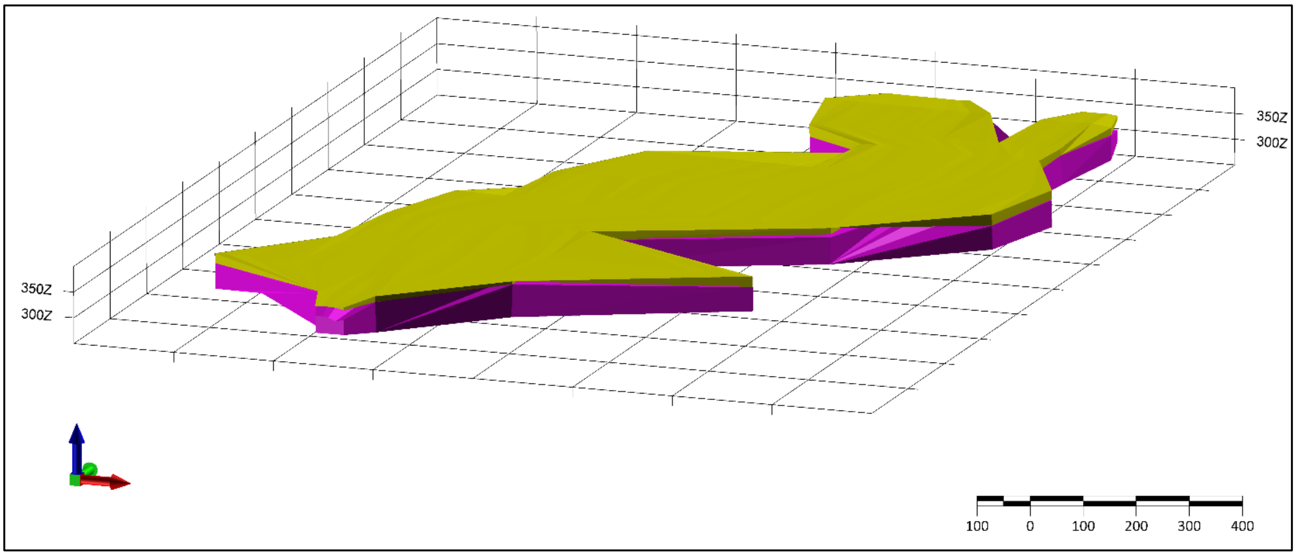

Figure 1. The 3D wireframe model of the lithological structure of the Central zone at the Akbulak site
The SW-NE isometric view: yellow – friable Meso-Cenozoic sediments; grey – weathering crust over gneissogranites; pink - gneissogranites.

The rare earth elements of industrial interest are confined to linear weathering crusts developed over greisenised gneiss granites, hence a 3D wireframe model of the productive horizon weathering crust is considered separately (Figures 2A, 2B).

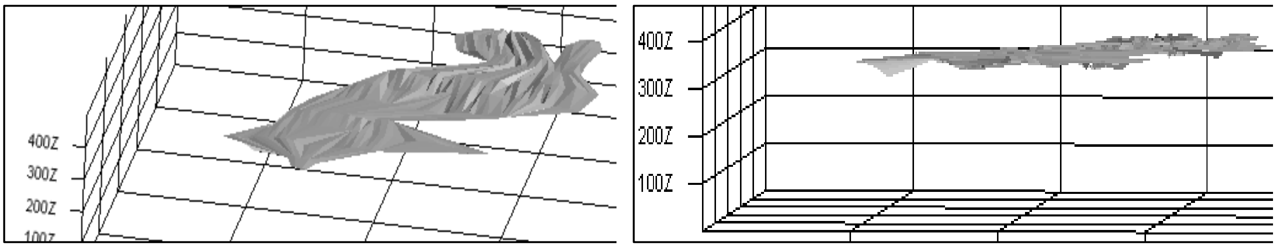

Figure 2. The 3D wireframe model of weathering crusts at the Akbulak site Central Zone. A) Isometric SW-NE view. B) Side view.

According to geological data, they are divided according to their degree of weathering:

1. The muddy-clayey weathering crusts. This is the most weathered crusts, caolinised and ferruginised in varying degrees. The horizon can be traced almost throughout the entire ore occurrence. Its thickness varies from the first metres to 30.0 metres. It consists of 30–60 % of kaolin, 5–10 % of hydromica and 30–50 % of quartz grits.
2. Clay-rubbly weathering crusts, consisting of 20–40 % clayey material, 10–30 % quartz gravel, 30–60 % rubble of gneiss-granites heavily weathered but retaining the structural features. The horizon is 20–28.0 m thick. The crusts are weakly kaolinised and ferruginised.
3. Rubbly weathering crusts. These are represented by rubble of weathered parent rock. The weathering degree decreases towards the face. The horizon thickness is not great and amounts to the first metres.

A wireframe model of ore bodies in the Akbulak site. Three prospective zones were identified in this ore district based on geological data and they are delineated within the ore district. Therefore, we considered the wireframe models of each prospective zone individually.

The northern zone of the site is analogous to the Akbulak ore occurrence in terms of its geological and tectonic setting. The ore prospective halo has an isometric shape in plan with dimensions of 1.6×2.0 km, with the halo not delineated in the north (Fig. 3).

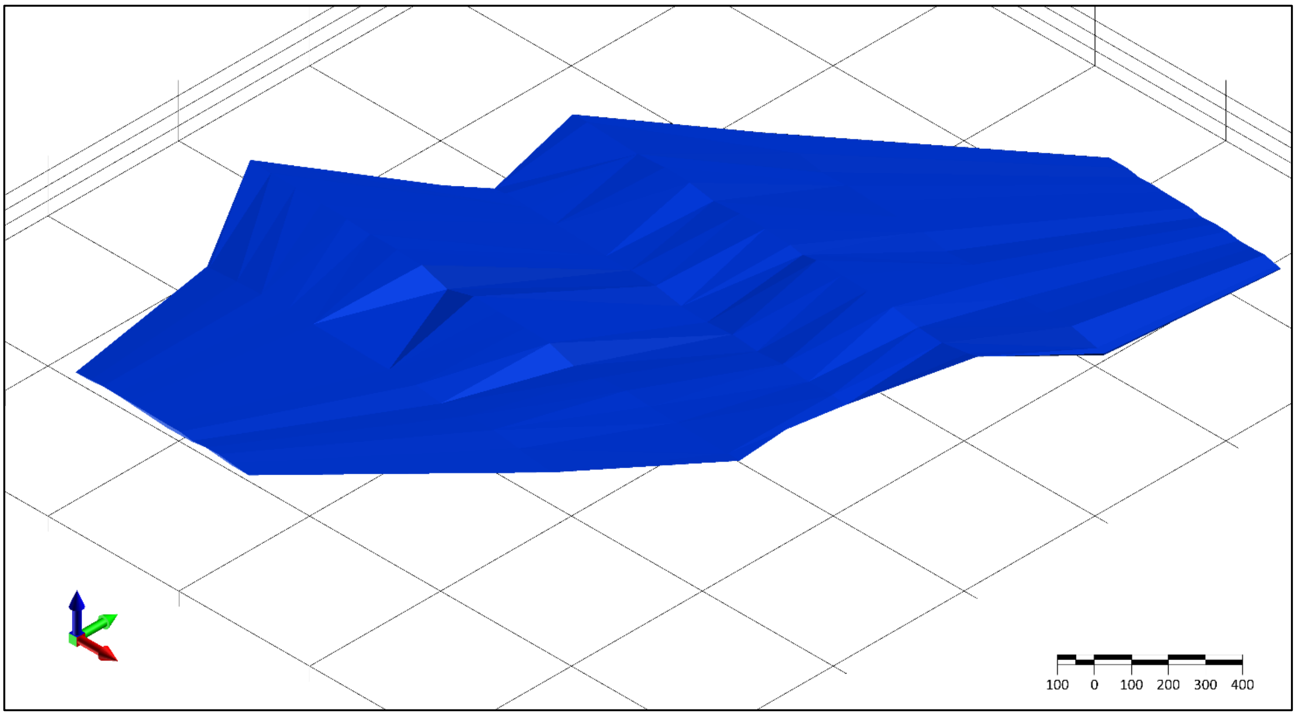

Figure 3. The 3D wireframe model of the Northern part of the Akbulak site ore bodies. SW–NW

The central zone (the Akbulak ore occurrence) is confined to linear gneiss granite weathering crusts developed along the south-eastern endocontact of the Akzhar massif. The mineralization is in the form of a horizontal deposit extending from south-west to north-east, sizing on average 2.2×0.55 km, with the area of 1.1 sq. km (Fig. 4).

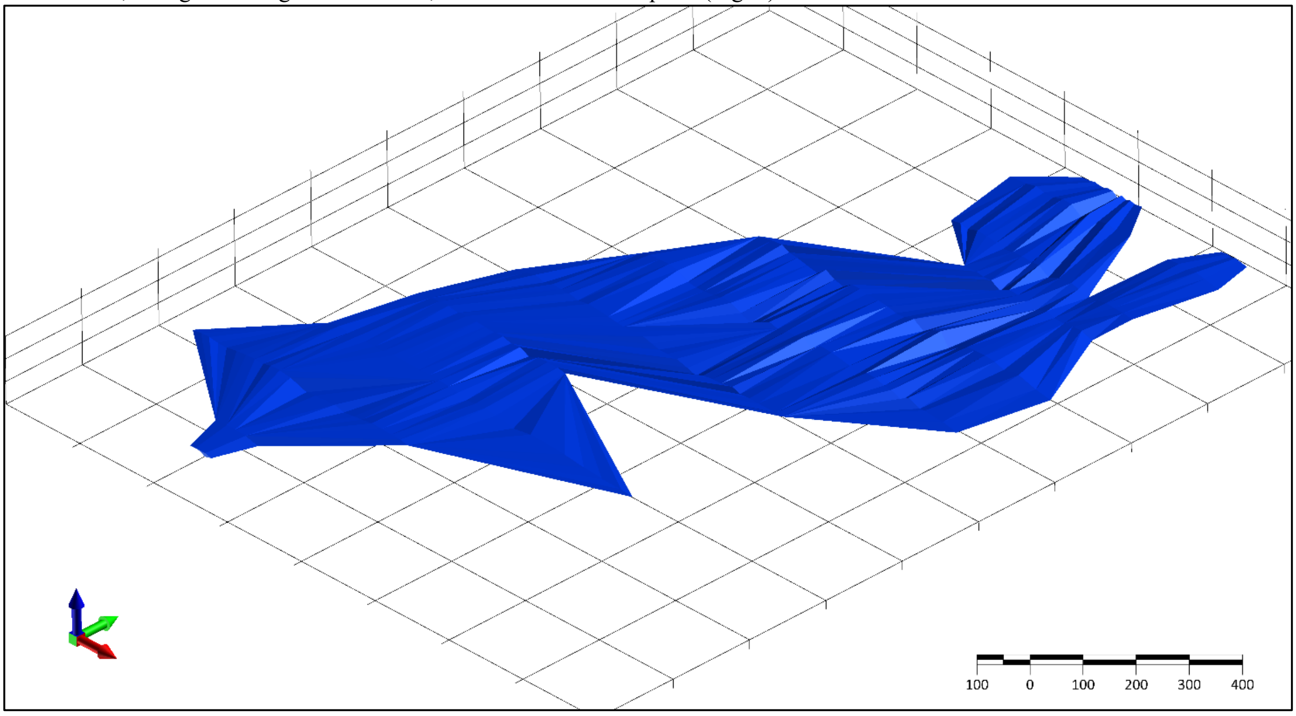

Figure 4. The 3D wireframe model of the Central part of the Akbulak site ore bodies. SW–NW

In *the southern zone* of the site, the yttrium-rare earth ore prospective halo is isometric in plan with dimensions of 1.2×2.0 km. The geological setting, as mentioned above, is similar to that of the Akbulak ore occurrence (Fig. 5).

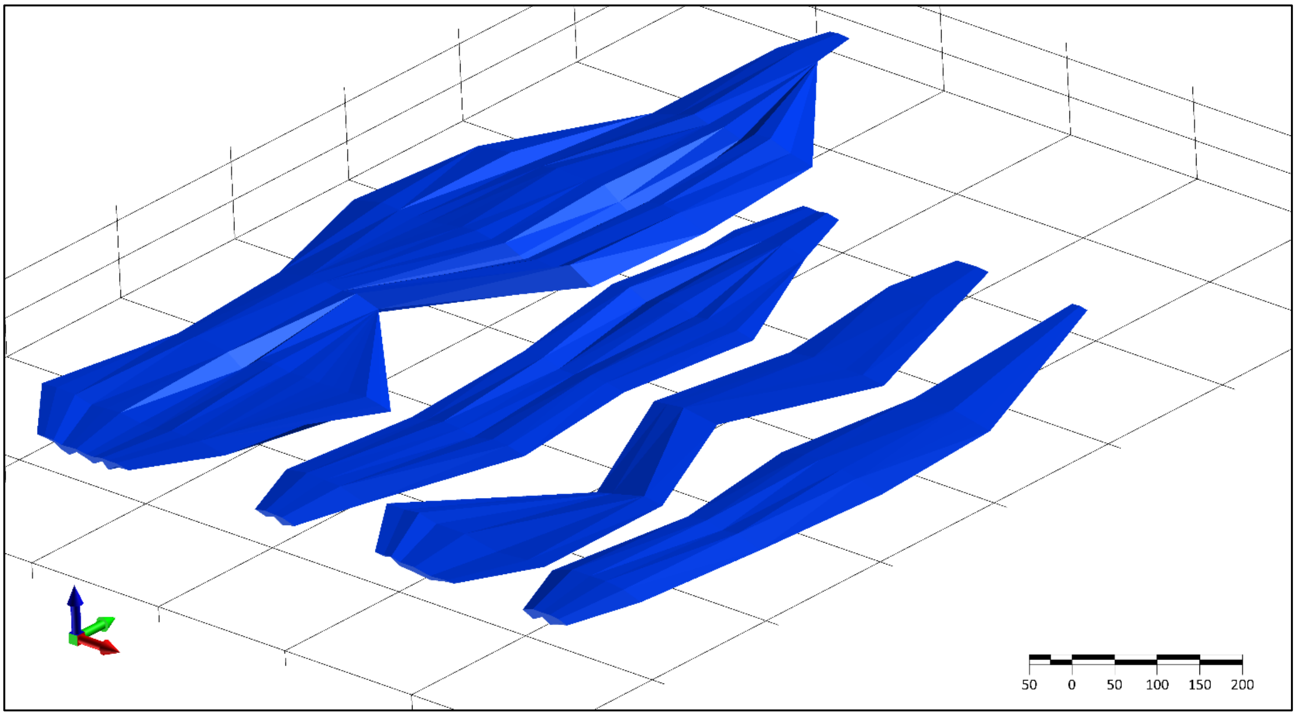

Figure 5. The 3D wireframe model of the Southern part of the Akbulak site ore bodies. SW-NW

The constructed framework models of the lithological structure of the Akbulak ore occurrence area and the framework models of the weathering crusts at all its sites visualise the morphology of the ore deposits in the area, as the localisation of rare earths in the area is associated with linear weathering crusts.

2) The block model of the Akbulak site. The next stage of the study is to build block models of the above zones of the Akbulak site. These models visualise rare earth distributions within the ore bodies. Upon the volumetric wireframe modelling of ore bodies, a block model of ore bodies is created, i.e. the internal space of the wireframe model is filled by cells (blocks). Dimensions of blocks correspond to parameters of the exploration network of the area and proportions of the ore body. It will deliver the visualisation of different yttrium oxide contents in the Akbulak site, a block model of the Akbulak area. The block model of this area was built separately for each zone, thus allowing to conduct a comparative analysis on distribution of their rare earth contents.

The northern zone. This block model shows that ore zones with yttrium oxide content within the lateral content of 0.01 to 0.02 % are most prevalent in this zone of the Akbulak site, and they cover both the upper and lower horizons of the gneiss granite weathering crust. Ore zones with high yttrium oxide concentrations (>0.07 %) are common only in the upper horizons of the North Zone of the Akbulak site (Fig. 6).

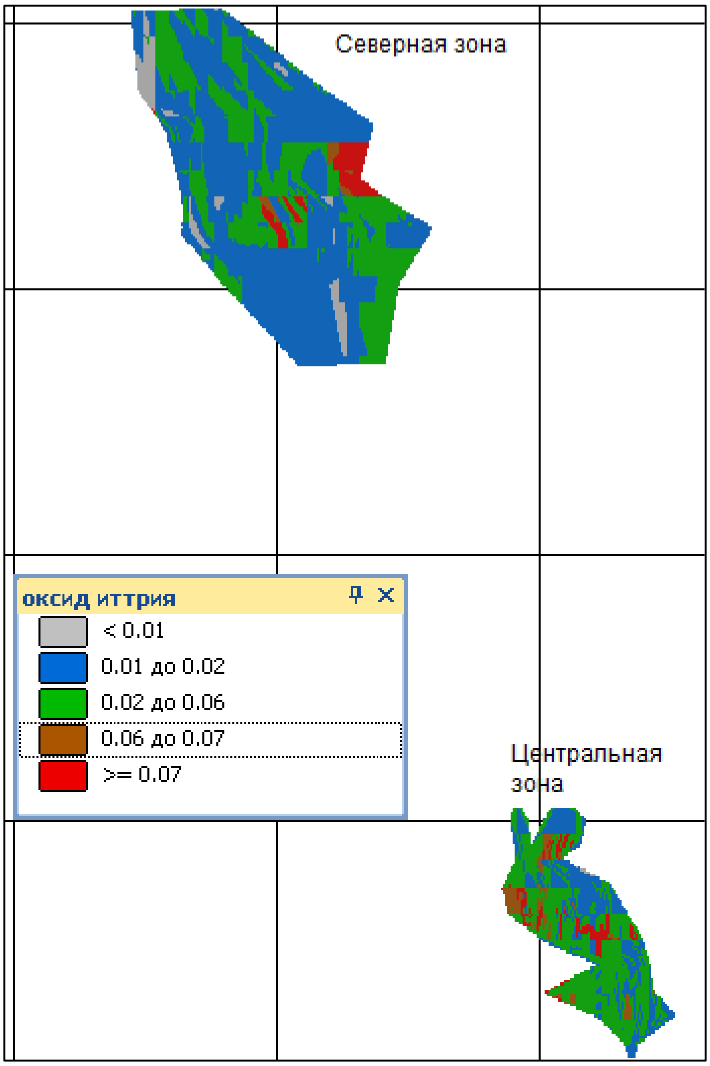

Figure 6. The block model of the Akbulak site. Plan view

The central zone of the Akbulak site has mainly zones with yttrium oxide contents between 0.02 and 0.06 %. Such zones of mineralisation above the lateral content are of relatively even distribution throughout the horizon. In addition, zones with elevated yttrium oxide concentrations of 0.06 to 0.07 % and higher occur in the upper and lower horizons (Fig. 6).

The central zone belongs to alluvial placers in Mesozoic weathering crusts over gneiss-granites and, according to geological materials, has the following parameters:

- area 1.0 km^2 ;
- average thickness 14.2 m;
- average yttrium oxide content is 272 g/t;
- average content of the sum of rare earth oxides 790 g/t;
- average linear stripping ratio 1.5

According to geological data, the depth of the roof occurrence of the Central Zone ore deposit in the Akbulak site varies from 0 to 33.0 m, the bottom from 4.0 m to 64.5 m. The average thickness of the deposit across the ore occurrence was 13.2 m. The average content of yttrium oxide across the ore occurrence was *272 g/t* (with lateral content of 100 g/t) and the sum of rare earth oxides was 790 g/t.

The Northern Zone, compared to the Central Zone, has the ore-promising halo with elevated contents of up to 400 g/t. At that, distribution of silver in boreholes is uniform at contents from 1 to 10 g/t with sharp increases to hundreds of g/t. Elevated contents are observed both in upper and lower parts of the section. According to mineralogical analysis, silver is in native form (Tishhenko, 1994: 246).

Within the *southern part of* the Akbulak site, 4 ore deposits was identified with average contents of yttrium oxide *from 190 to 424* g/t (with lateral content of 100 g/t) and the sum of rare earth oxides of 829-1863 g/t. Ore deposit depths vary from 7.2 to 13.8 m. The linear stripping ratio is 0.6-1.6 (Tishhenko, 1994: 246).

The block model of the southern part of the Akbulak site shows that here, in all 4 ore deposits, zones with yttrium oxide content of 0.02 to 0.06 % have the highest occurrence. They are distributed relatively evenly horizontally and vertically. Zones with yttrium oxide content within the lateral content are also distributed evenly in ore deposits, while mineralization zones with elevated yttrium oxide content ranging from 0.06 to 0.07 % and higher are concentrated mainly in the upper horizons of ore deposits (Fig. 7).

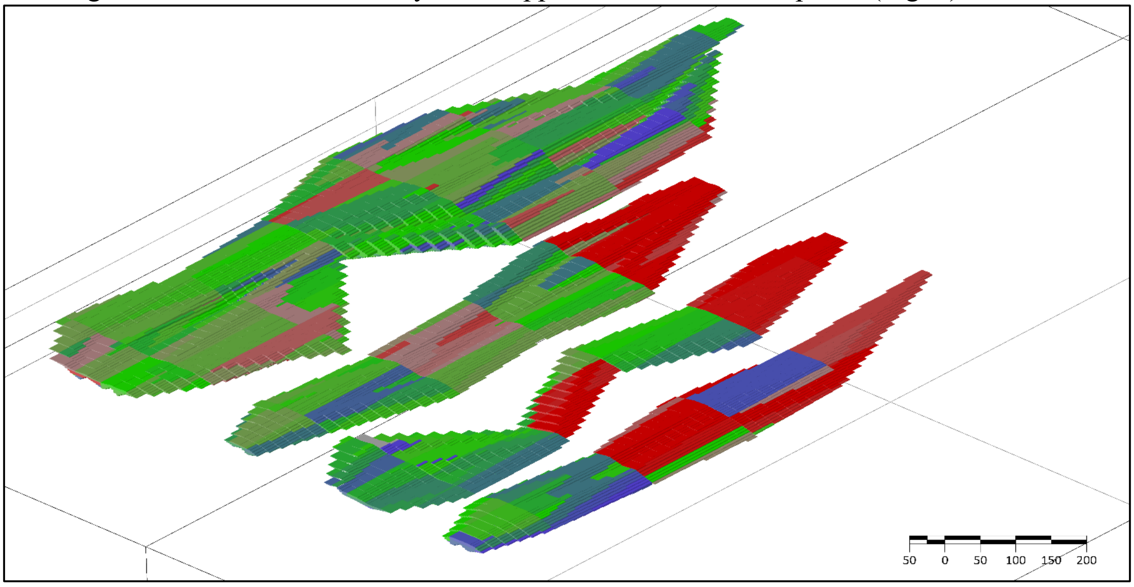

Figure 7. The block model of the Southern part of the Akbulak site. Side view

The geostatic analysis obtained during the 3D modelling of the Akbulak site shows that the average yttrium oxide content is 280 g/t, when its value for the Central Zone was determined to be within 272 g/t (Fig. 8). This small discrepancy, or conversely overlap, means that the geological materials used to compile the borehole database carry a number of inaccuracies.

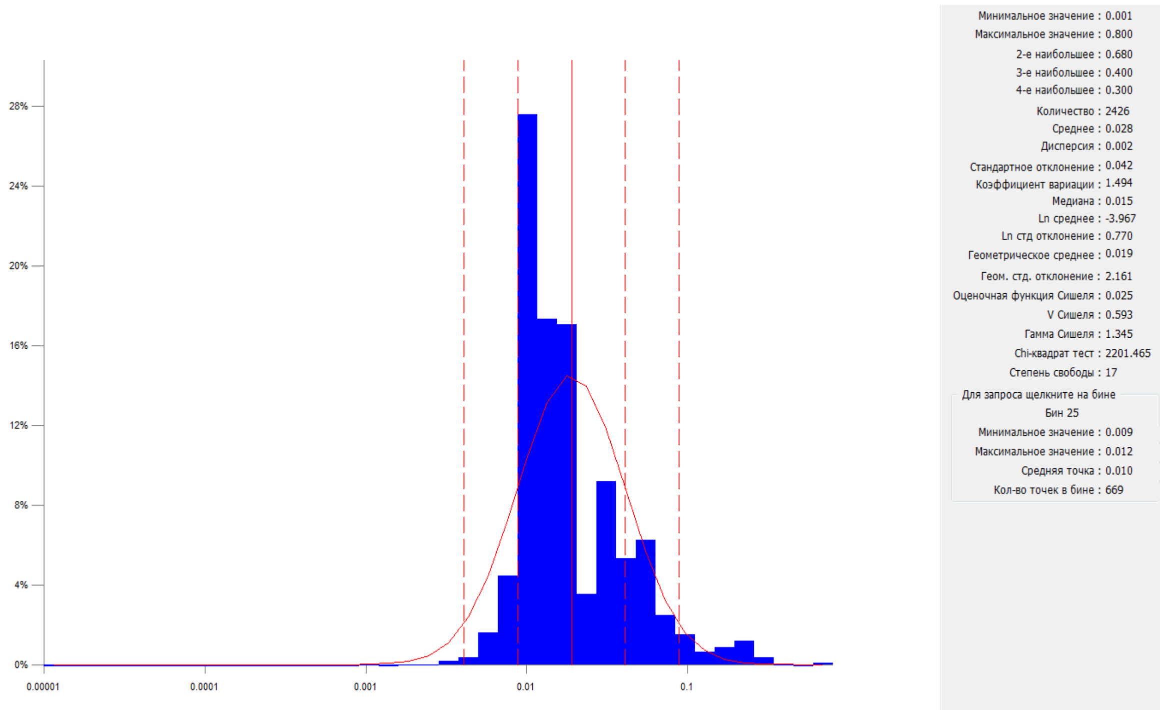

Figure 8. Statistics on the yttrium oxide J_2O_3 content

Interpretation of ore bodies by exploration profiles. Interpretation of ore bodies by exploration profiles was conducted for the Central Zone of the Akbulak site taking into account their reported boundaries ("The 1991–1994 report on prospecting works for rare elements within Akbulak site", Central prospecting geochemical party). In this case, the block model of the considered area was interpreted by exploration lines and it was conducted interactively by 10 exploration lines (Fig. 9). Each section was rendered for viewing in the MICROMINE Vise environment. The transects were displayed with the results of yttrium oxide percentage in the original samples in different colours. The results of interpreting the sections by exploration profiles were tabulated, where prevailing zones with different content of yttrium oxide were evaluated.

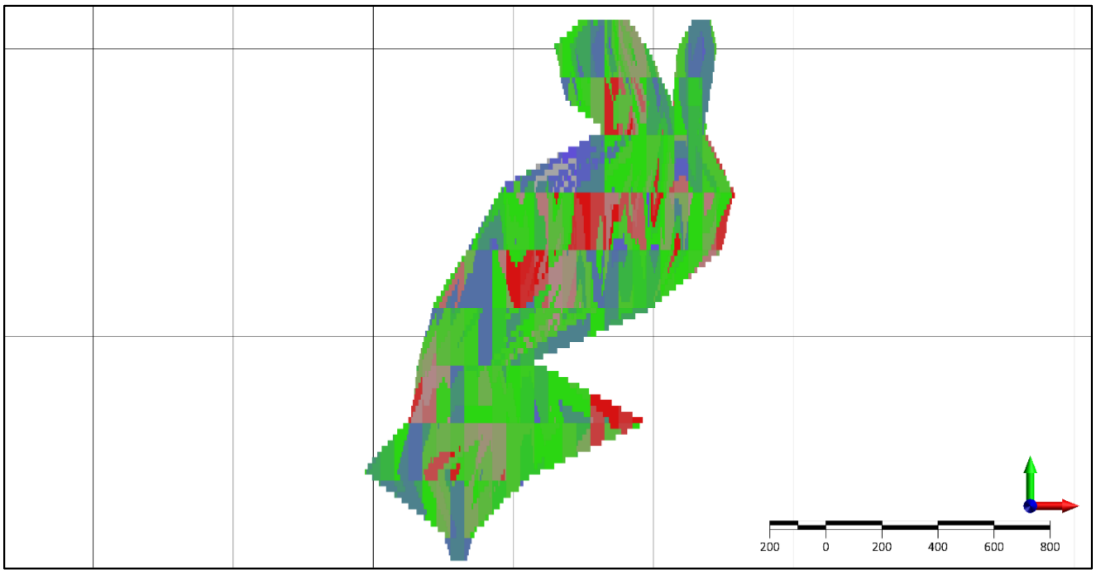

Figure 9. The block model of the Central Zone at the Akbulak site. Top view

Table 1. Exploration profile sections with visualisation of yttrium oxide contents of the Central Zone at the Akbulak site

	Grey < 0.01 %; blue 0.01–0.02 %; green 0.02–0.06 %; brown 0.06–0.07 %; red => 0.07 %	Qualitative interpretation of the section
1132		The section in the northern part of the ore body, zones with lateral yttrium oxide content occupy both the upper and lower horizons of the section, zones with relatively moderate content occupy the upper and middle horizons
1129		In the lower and middle horizons of this section there are zones with elevated levels of yttrium oxide
1128		Zones with average yttrium oxide contents and zones with lateral contents are common throughout the section. In the middle and lower parts of the section, there are zones with elevated yttrium oxide content
1127		Zones with moderate to elevated yttrium oxide concentrations as well as zones with lateral contents are common throughout the section
1125		Zones with moderate to elevated yttrium oxide concentrations as well as zones with lateral contents are common throughout the section
1123		There is a uniform distribution of zones with lateral content of yttrium oxide, as well as zones with its average content.
1121		There is a uniform distribution of zones with lateral content of yttrium oxide, as well as zones with an average content of yttrium oxide
1119		A section in the southern part of the ore body: zones of elevated yttrium oxide content are encountered
1117		There is a uniform distribution of zones with lateral content of yttrium oxide, as well as zones with its average content

1115		The central part of the section has concentrated zones with lateral yttrium oxide content, while the marginal parts have zones with medium yttrium content

Visualisation of the sections in terms of yttrium oxide content has established the following pattern:

– vertically and horizontally in the sections, there is no definite pattern in distribution of zones with certain yttrium oxide contents;

– the northern part of the ore body contains zones with higher contents of yttrium oxide, while the southern part mainly contains zones with lateral and medium contents of yttrium oxide.

Conclusion

As noted above, almost all of the weathering crust is contaminated with yttrium and rare earth elements within the site. The following conclusions are drawn from the Akbulak site 3D models:

1) the wireframe model of the site showed that:

- the ore deposits in the prospective areas have an elongated shape, inheriting the strike of the basement rocks;
- the ore deposit contours depend on value of the lateral content of yttrium oxide;
- geometric parameters of the ore deposits correspond to geological data.

2) the block model and its 2D slices along exploration lines showed that:

- no definite pattern is observed in the horizontal and vertical variation of yttrium and rare earth oxides within the given area;
- zones with high levels of yttrium oxide are common in the Central and Southern zones of the area;
- the Northern zone of the Akbulak site is distinguished by the fact that here distributed are mainly ittrium oxide zones with lateral content;
- the geostatic analysis for building the deposit's block model shows that the average content of sums of yttrium and rare earth oxides in the Akbulak site is 280 g/t, when its value according to geological data was determined to be within 272 g/t (Fig.10).

In general, the obtained results of computer modelling clarify the spatial location of different REM contents, their relationships in three-dimensional environment, as well as provide an opportunity to select areas of ores by the most important parameters, such as elevated content of useful component, their location in a particular geological and lithological setting.

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www:nauka-nanrk.kz
http://www.geolog-technical.kz/index.php/en/
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Заместитель директор отдела издания научных журналов НАН РК *Р. Жәлиқызы*
Редакторы: *М.С. Ахметова, Д.С. Аленов*
Верстка на компьютере *Г.Д.Жадыранова*

Подписано в печать 14.04.2023.
Формат 70x90$^{1}/_{16}$. Бумага офсетная. Печать – ризограф.
20,0 п.л. Тираж 300. Заказ 1.

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