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

ХАБАРЛАРЫ

ИЗВЕСТИЯ

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

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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.

ЧФ «ХАЛЫҚ»

В 2016 году для развития и улучшения качества жизни казахстанцев был создан частный Благотворительный фонд «Халык». За годы своей деятельности на реализацию благотворительных проектов в областях образования и науки, социальной защиты, культуры, здравоохранения и спорта, Фонд выделил более 45 миллиардов тенге.

Особое внимание Благотворительный фонд «Халык» уделяет образовательным программам, считая это направление одним из ключевых в своей деятельности. Оказывая поддержку отечественному образованию, Фонд вносит свой посильный вклад в развитие качественного образования в Казахстане. Тем самым способствуя росту числа людей, способных менять жизнь в стране к лучшему – профессионалов в различных сферах, потенциальных лидеров и «великих умов». Одной из значимых инициатив фонда «Халык» в образовательной сфере стал проект Ozgeris powered by Halyk Fund – первый в стране бизнес-инкубатор для учащихся 9-11 классов, который помогает развивать необходимые в современном мире предпринимательские навыки. Так, на содействие малому бизнесу школьников было выделено более 200 грантов. Для поддержки талантливых и мотивированных детей Фонд неоднократно выделял гранты на обучение в Международной школе «Мирас» и в Astana IT University, а также помог казахстанским школьникам принять участие в престижном конкурсе «USTEM Robotics» в США. Авторские работы в рамках проекта «Тәлімгер», которому Фонд оказал поддержку, легли в основу учебной программы, учебников и учебно-методических книг по предмету «Основы предпринимательства и бизнеса», преподаваемого в 10-11 классах казахстанских школ и колледжей.

Помимо помощи школьникам, учащимся колледжей и студентам Фонд считает важным внести свой вклад в повышение квалификации педагогов, совершенствование их знаний и навыков, поскольку именно они являются проводниками знаний будущих поколений казахстанцев. При поддержке Фонда «Халык» в южной столице был организован ежегодный городской конкурс педагогов «Almaty Digital Ustaz.

Важной инициативой стал реализуемый проект по обучению основам финансовой грамотности преподавателей из восьми областей Казахстана, что должно оказать существенное влияние на воспитание финансовой грамотности и предпринимательского мышления у нового поколения граждан страны.

Необходимую помощь Фонд «Халык» оказывает и тем, кто особенно остро в ней нуждается. В рамках социальной защиты населения активно проводится работа по поддержке детей, оставшихся без родителей, детей и взрослых из социально уязвимых слоев населения, людей с ограниченными возможностями, а также обеспечению нуждающихся социальным жильем, строительству социально важных объектов, таких как детские сады, детские площадки и физкультурно-оздоровительные комплексы.

В копилку добрых дел Фонда «Халык» можно добавить оказание помощи детскому спорту, куда относится поддержка в развитии детского футбола и карате в нашей стране. Жизненно важную помощь Благотворительный фонд «Халык» оказал нашим соотечественникам во время недавней пандемии COVID-19. Тогда, в разгар тяжелой борьбы с коронавирусной инфекцией Фонд выделил свыше 11 миллиардов тенге на приобретение необходимого медицинского оборудования и дорогостоящих медицинских препаратов, автомобилей скорой медицинской помощи и средств защиты, адресную материальную помощь социально уязвимым слоям населения и денежные выплаты медицинским работникам.

В 2023 году наряду с другими проектами, нацеленными на повышение благосостояния казахстанских граждан Фонд решил уделить особое внимание науке, поскольку она является частью общественной культуры, а уровень ее развития определяет уровень развития государства.

Поддержка Фондом выпуска журналов Национальной Академии наук Республики Казахстан, которые входят в международные фонды Scopus и Wos и в которых публикуются статьи отечественных ученых, докторантов и магистрантов, а также научных сотрудников высших учебных заведений и научно-исследовательских институтов нашей страны является не менее значимым вкладом Фонда в развитие казахстанского общества.

С уважением,
Благотворительный Фонд «Халык»!

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HYDROTHERMALLY ALTERED ROCKS OF THE AKMAYA-QATPAR ORE ZONE AND THEIR REFLECTION IN GEOPHYSICAL FIELDS

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Abstract. Establishment of geophysical criteria for forecasting promising areas for rare metal manifestations within the Akmay-Katpar ore zone. To achieve this goal, the mineralogical composition of the ore-containing medium of the Akmaya deposit was studied, and their changes due to the functioning of hydrothermal solutions, leading to changes in the petro physical characteristics of the ore deposition medium. At the same time, three-dimensional models of the deposit built in the MicroMine program were used and analyzed, as well as geophysical cartographic and geological materials for this deposit. We considered the mineralogical composition of hydrothermally altered and unchanged rocks of the deposit in question (hornfels, skarns), as well as their density and magnetic properties. The mineralogical composition and their petrophysical characteristics formed the basis for the analysis of geophysical anomalies associated with hydrothermally altered rocks of the Akmaya deposit. The results obtained allowed: 1) explain the nature of the geophysical anomalies created by zones of hydrothermally altered rocks based on the analysis of their mineralogical composition with petrophysical characteristics; 2) outline the ore stock and the area of distribution of the main ore-bearing veins and veins based on the analysis of magnetic exploration data. The practical significance lies in the use of geophysical criteria for predicting the areas of hydrothermally altered cities as a prospecting sign of the discovery of ore deposits.

Keywords: ore zone, mineralogical composition, petrophysical characteristics, geophysical anomalies, gravitational field, magnetic field

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АҚМАЯ-КАТПАР КЕН АЙМАҒЫНЫҢ ГИДРОТЕРМАЛЫҚ-ӨЗГЕРГЕН ЖЫНЫСТАРЫ ЖӘНЕ ОЛАРДЫҢ ГЕОФИЗИКАЛЫҚ ӨРІСТЕРДЕ КӨРІНІСІ

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Аннотация. Ақмая-Катпар кен аймағы шегінде сирек кездесетін кенбілінімдерге перспективалы алаңдарды болжаудың геофизикалық ерекшеліктерін белгілеу. Қойылған мақсатты орындау үшін Ақмая кен орнының кенсиыстырушы ортасының минералогиялық құрамы және олардың кен шоғырлану ортасының петрофизикалық сипаттамаларының өзгеруіне әкелетін гидротермиялық ерітінділердің жұмыс істеуі есебінен өзгеруі зерттелді. Бұл сәтте MicroMine бағдарламасында салынған кен орнының үш өлшемді модельдері, сондай-ақ осы кен орны бойынша геофизикалық картографиялық және геологиялық материалдар пайдаланылды және талданды. Біз қарастырылып отырған кен орнының гидротермиялық өзгерген және өзгермеген жыныстарының минералогиялық құрамын (мүйізтұмсықтар, скарндар), сондай — ақ олардың тығыздығы мен магниттік қасиеттерін қарастырдық. Минералогиялық құрамы және олардың петрофизикалық сипаттамалары Ақмая кен орнының гидротермиялық-өзгерген жыныстарымен байланысты геофизикалық ауытқуларды талдауға негіз болды. Алынған нәтижелер: 1) петрофизикалық сипаттамалары бар минералогиялық құрамын талдау негізінде гидротермиялық-өзгертілген жыныстар аймақтары құрған геофизикалық ауытқулардың табиғатын түсіндіруге; 2) рудалық штокверкті және магнитті барлау деректерін талдау негізінде негізгі рудалық тамырлар мен тамырлардың таралу алаңын контурлауға мүмкіндік берді. Практикалық маңыздылығы кен орындарын анықтаудың іздеу белгісі ретінде гидротермиялық өзгерген жыныстардың аудандарын болжаудың геофизикалық критерийлерін қолдану болып табылады.

Түйін сөздер: кен аймағы, минералогиялық құрамы, петрофизикалық сипаттамалары, геофизикалық ауытқулары, гравитациялық өрісі, магнит өрісі

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ГИДРОТЕРМАЛЬНО-ИЗМЕНЕННЫЕ ПОРОДЫ АКМАЯ-КАТПАРСКОЙ РУДНОЙ ЗОНЫ И ИХ ОТРАЖЕНИЯ В ГЕОФИЗИЧЕСКИХ ПОЛЯХ

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Аннотация. Установление геофизических критериев прогнозирования перспективных площадей на редкометальные проявления в пределах Акмая-Катпарской рудной зоны. Для выполнения поставленной цели изучен минералогический состав рудовмещающей среды месторождения Акмая, и их изменения за счет функционирования гидротермальных растворов, приводящих к изменению петрофизических характеристик среды рудоотложения. При этом были использованы и анализированы трехмерные модели месторождения, построенные в программе MicroMine, а также геофизические картографические и геологические материалы по данному месторождению. Нами рассматривались минералогический состав гидротермально- измененных и неизмененных пород рассматриваемого месторождения (роговики, скарны), а также их плотностные и магнитные свойства. Минералогический состав и их петрофизические характеристики легли в основу анализа геофизических аномалий, связанных с гидротермально-измененными породами месторождения Акмая. Полученные результаты позволили: 1) объяснить природу геофизических аномалий, созданных зонами гидротермально-измененных пород на основе анализа их минералогического состава с петрофизическими характеристиками; 2) оконтурить рудный штокверк, и площадь распространения основных рудоносных жил и прожилков на основе анализа данных магниторазведки. Практическая значимость заключается в использовании геофизических критериев прогнозирования площадей гидротермально-изменённых пород как поискового признака обнаружения рудных месторождений.

Ключевые слова: рудная зона, минералогический состав, петрофизические характеристики, геофизические аномалии, гравитационное поле, магнитное поле

Introduction

The Akmaya-Katpar ore zone coincides with the central part of the Assumption synclinorium and is composed of volcanogenic-sedimentary and terrigenous-carbonate formations of Famennian age.

The main importance for the formation of the structure of the area was the deep faults of long-term development, which are a reflection of the Zhaksy-Tagalinsky deep fault, which played an important role in the placement of granitoids of four complexes:

1. Late Devonian-Early Carboniferous – , D_3-C_1
2. Late Carboniferous – C_3 C_3 C_3
3. Early Permian – $_1P_1$, $_2P_2$
4. Late Permian – $_1P_2$, $_2P_2$

A number of stratiform iron-manganese ore occurrences in the region are associated with this structurally metallogenic zone, most of the large and small deposits that are localized in the central part of the zone. Copper ore occurrences, which belong to the hydrothermal type, are located to the west of the described zone.

The most numerous manifestations of rare metals within the Akmaya-Katpar ore zone are the deposits of Northern Katpar and Akmaya, the ore occurrences of Western Katpar, Northeastern Katpar, Bibigul.

Deposits and ore occurrences of rare metals in the Akmaya-Katpar ore zone belong to the molybdenum-tungsten ore formation, spatially and genetically related to the apical parts of the leucocratic granites of the Late Permian age that do not come out on the surface of the Akmain pluton. In terms of chemical and mineral composition, granites belong to alaskite differences and are represented by plagioclase (7,87 %), KPS (51,3 %), quartz (40,55 %), dark-colored (0,96 %) and accessory (1,32 %) minerals.

According to the interpretation of geophysical fields, the Akmain pluton is stretched in the northeastern direction. Its apical part, where rare-metal ore objects are localized, has undergone a greisenization process, manifested in the form of a series of low-power veins of a stockwork nature with various ore mineral associations. Around these veins, there are rejuvenating halos of metasomatic transformations- silicification, etc.

For example, at the North Katpar deposit, the ores are closely related to the greisenization process, the richest mineralization refers to fluorite and quartz-fluorite metasomatites. At the Akmaya deposit, industrial ores are associated with early quartz and quartz-feldspar veins and veins with wolframite, and the host rocks for them are hydrothermally altered skarns and hornfels (Ablessenova, 2023: 7; Subbotin, 1952: 50; Omirserikov, 2016 a: 6).

These factual data indicate that rare-metal ore bodies in this ore zone are confined to zones of metasomatically altered rocks.

Tasks of this kind were solved by a number of researchers, where they studied petrophysical properties of hydrothermally transformed rocks of the White Mountain of Far East. The patterns they obtained determined the geophysical characteristics of the White Mountain deposit, where the hydrothermal alteration of rocks of the pre-ore and ore period is associated with: 1) decrease of magnetic susceptibility; 2) decreasing polarizability; 3) increase electrical resistivity within this deposit.

As can be seen, hydrothermally altered rocks greatly differ in petrophysical properties from unaltered rocks developed in the area of this deposit.

In this regard, petrophysical anomaly appears in the area of the ore object, and it creates anomaly in its geophysical fields (Nosyrev, 2022: 17).

Previously, we analyzed and systematized petrophysical characteristics of unaltered rocks and created its petrophysical model for the Akmaya-Katpar ore zone. The results were correlated with geophysical anomalies, thus geophysical signs of rare-metal ore-bearing Akmaya-Katpara ore zone were determined in the form of combining zones of negative minima of gravity and zones of positive magnetic anomalies with geochemical anomalies (Ablessenova, 2023: 7).

It should be noted that petrophysical properties of hydrothermally altered rocks of Akmaya-Katpar ore zone were not analyzed, although all known rare-metal ore objects are confined to them.

Considering that the western part of the buried Akmain intrusion remains understudied, such studies are relevant for the search of new promising rare-metal sites in this ore zone.

We chose Akmaya deposit for solving the set task, as the rare-metal stockwork is confined to the zones of hydrothermal-altered rocks.

The deposit was discovered by A.K. Kayupov and V.M. Popov in 1936, and was explored from 1941 to 1952. In parallel with exploration, diligent mining was carried out at the deposit (1941–1949), about 160 tons of 60% tungsten concentrate were extracted, and the ore reserves were completely exhausted. Then, in the early 1980s, additional exploration was carried out and scheelite was discovered. In 1992 the revision of the available factual material (Y.G. Toiskin, R.N. Torchinyuk) was carried out, as a result of which the expected reserves of tungsten trioxide at the deposit can increase up to 30 thousand tons at its average content of 0,22–0,2 5%.

The mineralogy of this deposit was studied in detail by F.V. Chukhrov and L.P. Ermilova.

The systematized material on mineralogy allows us to analyze the mineralogical composition of unaltered (hornfels and skarns) and hydrothermally altered (oxidized, sericitized) rocks in the area of the Akmaya deposit. The petrophysical characteristics of rocks (density, magnetic susceptibility) that create geophysical anomalies depend on their mineralogical composition. Therefore, we analyze the mineralogical composition of unaltered and altered rocks developed in the area of Akmaya deposit with linkage to magnetic and gravity anomalies.

Research Methods and Materials

The Akmaya deposit is compact and it has been studied sufficiently by geological and geophysical as well as innovative methods (borehole technology) by different researchers in different years from 1936 to 2017 (Subbotin, 1952: 50; Omirserikov, 2016 a: 6).

The materials required for the task are categorized into three groups:

1. Geological structure, mineralogy, and stages of ore formation at the Akmaya deposit.

The field is located in the western part of the Uspenskaya Confusion Zone and is characterized by a complex geological structure. The area includes sedimentary and volcanogenic formations of Lower Silurian age, effusives of the Middle and Lower Devonian, a complex of sedimentary and sedimentary-volcanogenic rocks of the Upper Devonian and Lower Carboniferous, volcanic formations of the undivided Upper Paleozoic, intrusives and Tertiary and Quaternary sediments. There are no outcrops of intrusive rocks within the deposit. Rare-metal mineralization is associated with the Permian Akmaya intrusion, which has not yet been uncovered by erosion.

The Akmaya ore field is confined to the carbonate rock sequence (60–70m thick), among shales and sandstones, and partially extends beyond this sequence (Figure 1).

The deposit shows pre-mining, ore and post-mining stages.

Pre-metamorphism processes of general metamorphism of rocks of the ore zone are manifested at the deposit, the agents are thermal energy of ore-bearing Akmain intrusion, where limestones are partially metamorphosed, partially hornblende and skarned. The hornfels are characterized with the formation of bimineral metasomatites consisting of quartz and pyroxene and they compose about 50 % of the rocks of the deposit area. The skarns are characterized with the formation of essentially pyroxene-garnet rocks with vesuvian, wollastonite, calcite and potassium feldspar, and they constitute about 30 % of the rocks composing the deposit.

In the *ore* stage, the main following stages of mineralization are distinguished:

1. Quartz and quartz-feldspar veins and veins with wolframite;

2. Chalcopyrite-pyrrhotite-molybdenite-chlorite veins.

The *post-mining* stage includes quartz-zeolite and zeolite veins and veinlets.

The first ore stage with quartz-feldspar-wolframite veins and veins, which determined the industrial value of the deposit, was the most powerful. Near these veins, the host skarns and hornblende underwent sericitization at a distance of 1 to 5 cm and more.

The main ore minerals of the deposit are wolframite with impurities of niobium and scandium, molybdenite, nugget bismuth.

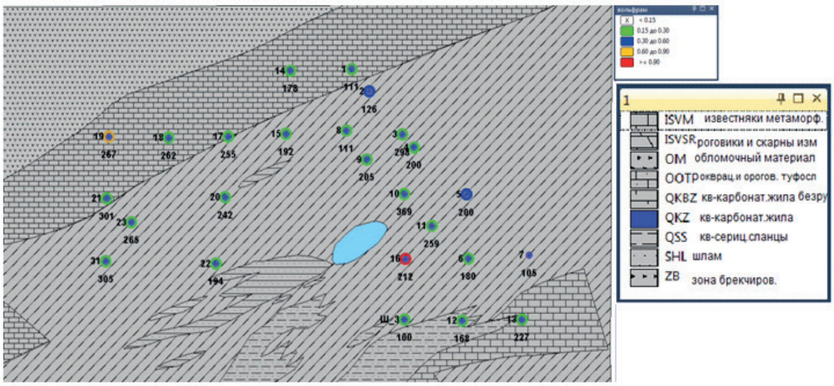

Figure 1 - Geological map of the Akmaya deposit with mapped exploration wells, Scale. 1:10,000

2. Geological and geophysical cartographic materials of the field area of scale 1:10000,1:50000.

3. Computer models of the deposit in 3D format. In the MicroMine program, a group of researchers and we have built 3D wireframe and block models of the Akmaya deposit, on the side tungsten trioxide content of 0,15 % (Omirserikov, 2016 a: 6).

a) Based on the wireframe model, the morphology of the ore stockwork was visualized (Figure 2).

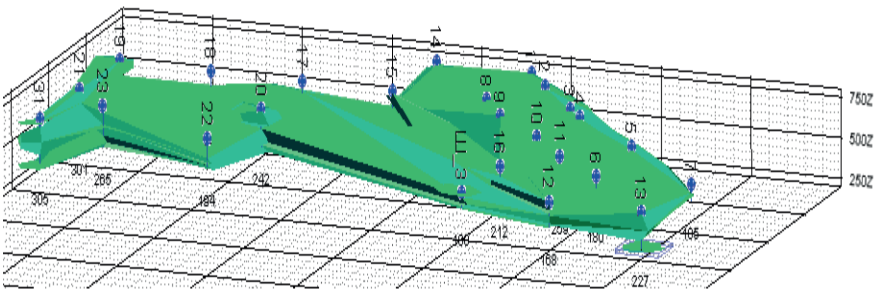

Figure 2 - Three-dimensional wireframe model of the ore body at the Akmaya deposit with exploratory wells mapping

The intervening rocks of the Akmaya deposit (hornfels, skarns, marbles) are practically ore-free. In this regard, the morphology of the ore stockwork is determined by the spatial location of ore-bearing veins. According to geological data, the area where about 250 ore veins are concentrated has an elongated shape.

This spatial feature of the ore stockwork is clearly visualized by the framework model of the deposit, where the ore stockwork is located with a long axis along the strike of the calcareous rock pack, and its configuration does not change with depth (Figure 2) (Omirserikov, 2016 a: 6).

b) Based on the block model, the spatial distribution of tungsten grades across the ore stockwork is visualized, where its non-uniform spatial distribution is clearly observed. Tungsten grades vary from 0,15 to 0,60 % and above (Figure 3):

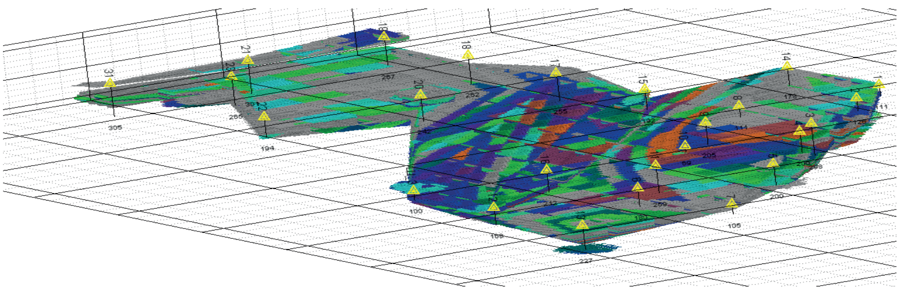

Figure 3 - Three-dimensional block model of Akmaya deposit

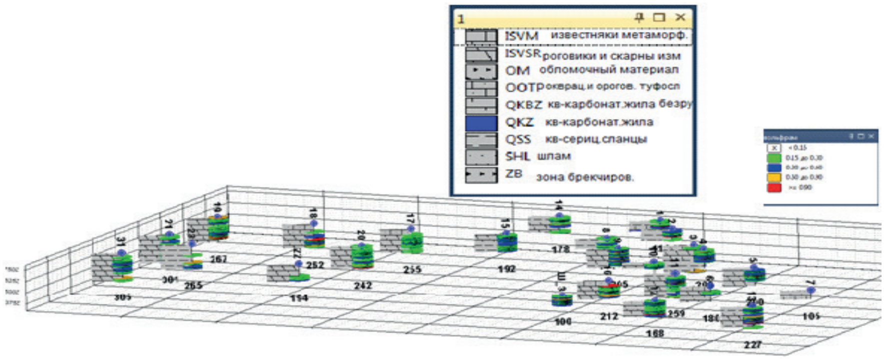

Figure 4 - Three-dimensional model of distribution of metasomatic rocks of the ore zone of the Akmaya deposit

c) visualized the lithological composition of rocks within the deposit and tungsten content by exploration wells. A three-dimensional model of the distribution of metasomatic rocks of the Akmaya deposit showed that the most common metasomatic rocks are hydrothermally altered skarns and hornfels, and the tungsten content in exploration wells varied from 0,15 to 0,9 %. (Figure 4).

So, the analyzed geological materials and the results of model constructions on the Akmaya deposit led to the fact that hydrothermal-altered rocks are the most common and are ore-bearing medium. Therefore, we consider their reflections in gravity and magnetic fields as the basis for the selection of geological and geophysical forecast criteria in the search for new areas for rare-metal ores within the Akmaya-Katpar ore zone.

Results and discussion

Gravity field. In the Akmai-Katpar ore zone, low-density intrusive formations are represented by two granite massifs: 1) the Katpar granite massif of Early Permian age, which is exposed in the north of the North Katpar deposit; 2) the Akmaya leucocratic granite massif of Late Permian age, which is uncovered by several wells at a depth of 400–600 meters in the central part of the North Katpar deposit. According to geological data, all rare-metal ore objects (deposits and ore occurrences) are spatially and genetically related to the "blind" Akmain granite massif and are concentrated in the intrusive-dedentrusive zone of its dome-shaped structures.

The above-mentioned granite massifs in the gravity field are distinguished by a single gravitational minimum with intensity of 0,2–0,3 mGal (milligal). Gravitational minimum is connected with negative value of excess density within -0,3 g/cm3 between densities of host rocks (orogenized and skarned) of ore zone (2,85 g/cm3) and above-mentioned granite massifs (2,55 g/cm3) (Ablessenova, 2023: 7).

In general, the area of the Akmaya-Katpar ore zone, where rare-metal ore manifestations are concentrated, is characterized by a negative gravity anomaly due to the low density of intrusive rocks (Figure 5).

However, these geophysical mapping materials of different scales, especially 1:10000 scale, show that the areas of some rare-metal sites, including the Akmaya deposit area, in the gravity field are distinguished by a positive gravity anomaly of intensity up to 0,4 mGal. (Figure 5,6).

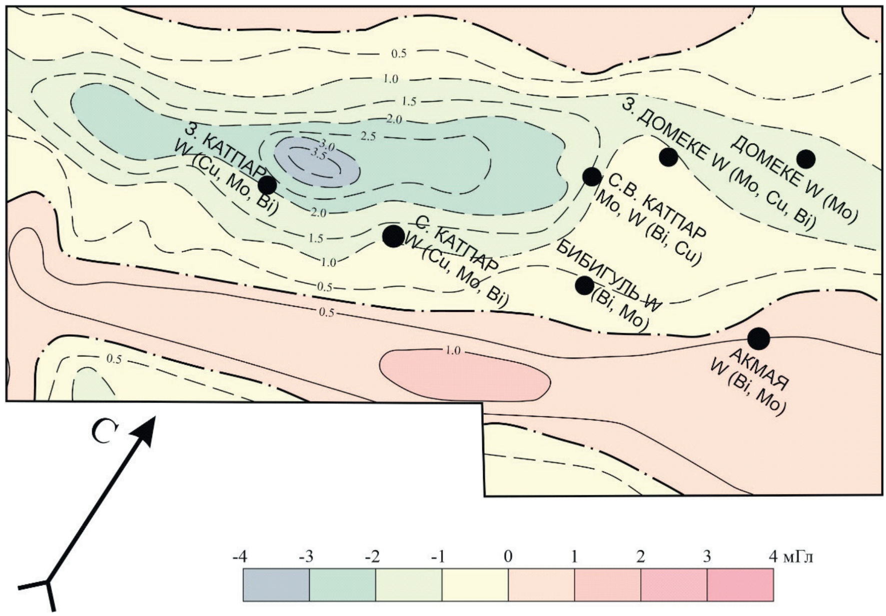

Figure 5 – Map of the gravity isanomal of the Akmaya-Katpar ore field.
Scale 1:50 000 (Agadir expedition, 1993)

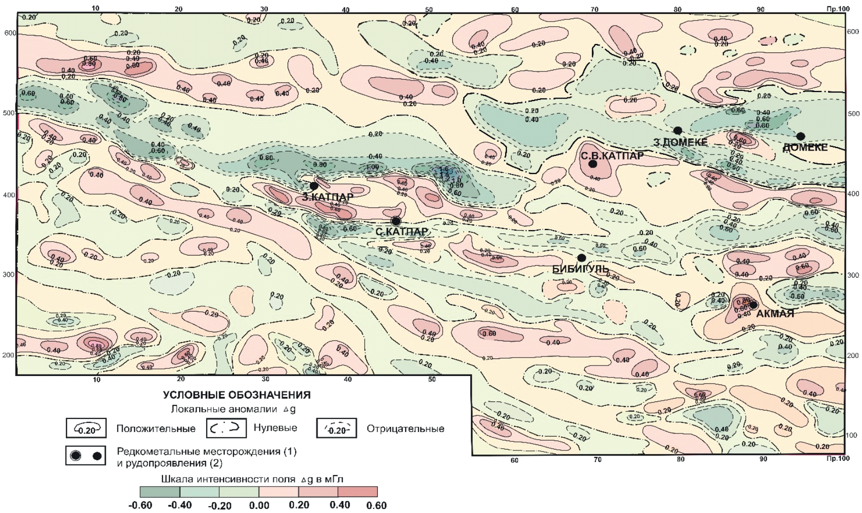

Figure 6 - Map of the gravity isanomal of the Akmaya-Katpar ore field.
Scale 1:10 000 (Agadir expedition, 1993)

The appearance of a positive gravity anomaly in the gravity field in the area of the Akmaya deposit is attributed to the existence of zones of hydrothermal-altered rocks that differ sharply in mineralogical composition from the rocks developed in the area of the deposit.

According to geological data in the area of this deposit are developed products of metamorphism of the pre-metamorphic stage of ore formation, they are hornblende and skarns, they are composed of such minerals as pyroxene, garnet (grossular), vesuvian, wollastonite. The densities of these minerals given in reference books are indicated by the following intervals of their values from 3,00 to 3,6 g/cm³ (Romanovsky, 2009).

Consequently, the main rocks composing the Akmaya deposit area are dense rocks. The average density of hornfels and skarns, according to some researchers, is determined in the range from 2,85 to 3,45 g/cm³ (Dortman, 1984; Pugin, 2019).

At the final stage of the pre-metallic stage of ore formation, the halo of skarned and hornblende rocks was overlaid by intensive oxy-quartzization, with it accompanied by hydrothermal sericitization. In this case the mineral composition of hornblende and skarns is changed due to replacement of the main rock-forming minerals, where pyroxene and garnet are replaced by chlorite, wollastonite and vesuvian by calcite, albite and biotite by sericite. The density of newly formed minerals in the hydrothermal-altered zone of the Akmaya deposit according to reference data ranges from 2,4 to 2,5 g/cm³ (Romanovsky, 2009).

Consequently, the replacement of high-density minerals with minerals of relatively low density will lead to a decrease in the density of hydrothermally altered rock zones. According to some researchers, the density of hydrothermally altered rocks is determined within the range from 2,43 to 2,20 g/cm³ (Romanovsky, 2009; Lidin, 2000: 480; Pugin, 2019: 110; Omirserikov, 2014 b: 12).

So, in the area of Akmaya deposit due to petro-density characteristic of zones of hydrothermal-altered rocks there appeared a positive excess density within 0,35 g/cm^3 between densities of Akmaya intrusion (2,55 g/cm^3) and zones of hydrothermal-altered rocks (2,30 g/cm^3). In this regard, the area of Akmaya deposit in the gravity field is characterized by a positive gravity anomaly of intensity up to 0,4 mGal.

In addition, in the Akmaya-Katpar ore zone, according to geophysical data, a positive gravity anomaly with intensity in the range of 0,20–0,4 mGal is observed in the area of the North-East Katpar ore occurrence. It is associated with greisenization of skarns and hornfels to which scheelite mineralization is confined (Figure 6).

According to geological data, more than 300 vein and greisen vein bodies have been identified at the North Katpar deposit. The main ore veins and greisen vein bodies were formed without near-surface hydrothermal alteration. Among them, only quartz ore veins (with feldspar, molybdenite, biotite) were accompanied by zones of weak greisenization of the host rocks. Therefore, the area of the North Katpar deposit, confined to the main dome structure of the Akmain granite massif, is distinguished by a negative gravity minimum with an intensity of 0,4 mGal. (Figures 5, 6).

It should be concluded that the reflection of hydrothermally altered rocks in the gravity field depends on their spatial distribution and intensity of manifestation of metasomatic processes. In this regard, the peripheral greisenized rocks in the North Katpar deposit due to the weak intensity of manifestation and limited prevalence were not reflected in the gravity field. At the Akmaya deposit, the widespread and intensive occurrence of hydrothermally altered rocks was clearly reflected in the gravity field in the form of a positive anomaly.

Magnetic field. The intensity of magnetic anomalies is associated with the magnetic susceptibility of rocks of the Akmaya-Katpar ore zone (Trukhachev, 2008; Kurskeev, 1983: 286; Smelov, 1985: 123; Benevolenski, 1960).

On medium scale magnetometric maps the ore zone is distinguished by a positive magnetic anomaly with intensity from 1,5 to 4 nT. The positive sign of the magnetic anomaly is associated with the intrusive ore-bearing Akmain granite massif, its magnetic susceptibility is determined within 60*10^{-6} GHS.

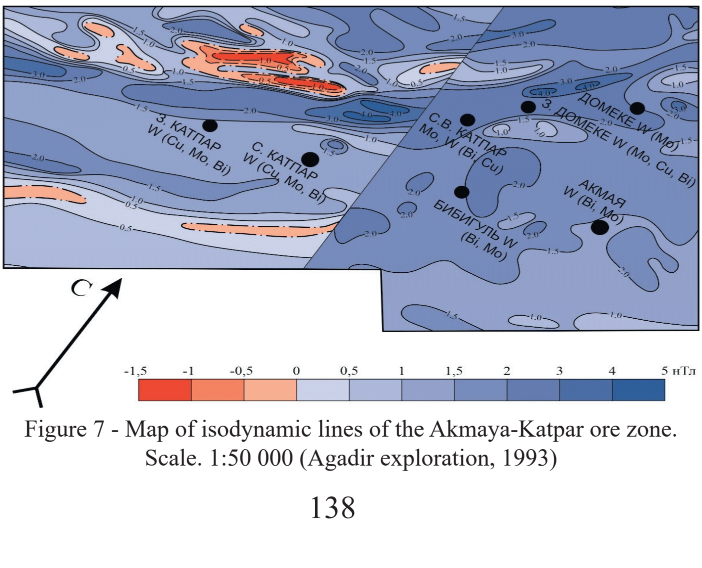

Figure 7 - Map of isodynamic lines of the Akmaya-Katpar ore zone.
Scale. 1:50 000 (Agadir exploration, 1993)

The positive sign of magnetic anomaly for this ore zone is preserved on magnetometric maps of larger scale. All rare-metal objects (except Akmai deposit) associated with Akmai massif and localized in carbonate environment (with magnetic susceptibility in the range of 12–15*10^{-6} GHS) are concentrated in the area of positive magnetic anomaly with intensity from 50 to 100 nT (Figure 8).

On the 1:10000 scale magnetometric map of the Akmaya deposit area is highlighted by a negative magnetic anomaly with intensity from -50 to -100 nT (Figure 8).

We analyze the change in the sign of the magnetic anomaly in the area of the deposit:

1) The primary main reason for the change in the sign of the magnetic anomaly in the area of the Akmaya deposit may be the morphology of the ore body, according to the morphology of the deposit is classified as a stockwork deposit. As is known, stockwork deposits are confined to intensely dislocated areas, i.e. in areas with a large number of differently oriented small ore-bearing fractures. This structural feature of ore body formation will lead to the appearance of a negative magnetic anomaly over the deposit. Therefore, on magnetometric fields the zones of ore stockwork development are well distinguished by a negative magnetic anomaly of -50 nT intensity.

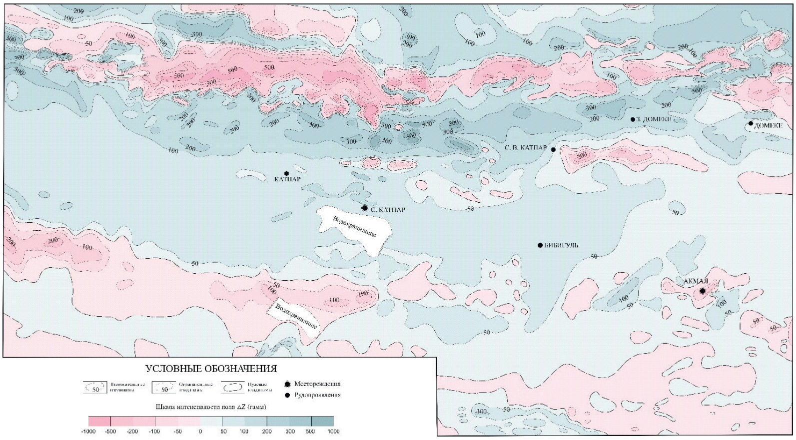

Figure 8 - Map of isodynamics of the Akmaya-Katpar ore zone.
Scale. 1:10,000 (Agadir exploration, 1993)

2) The next reason is the change in the mineralogical composition of the ore-bearing medium due to hydrothermal-metasomatic alteration. It led not only to the change of rock density, but also to the change of magnetic susceptibility of hornblende and skarns. The decrease in magnetic susceptibility is due to the process of sericitization of rocks, as the newly formed minerals in the zone of hydrothermally altered rocks are diamagnetic (quartz, calcite, fluorite, feldspars) or weakly paramagnetic (chlorite, mica), and their magnetic susceptibility is of the order of 0-50*10^{-6} GHS. They do not make an appreciable contribution to the magnetic susceptibility of hydrothermally altered rocks, so the value of magnetic properties of rocks subjected to hydrothermal-metasomatic transformations is approximately 23–26*10^{-6} GHS (Kurskeev, 1983: 286; Smelov, 1985: 123; Benevolenski, 1960).

When interpreting the magnetic exploration materials, many researchers with lowered values of the magnetic anomaly intensity compared to the surrounding unaltered rocks highlight the outline of ore stockworks (Benevolenski, 1960; Isayeva, 2013: 12).

In this regard, the intensity of the negative magnetic anomaly in the range of up to -50 nT allows us to identify the contour of the ore stockwork at the Akmaya deposit. In plan, the morphology of the highlighted contour on the magnetometric fields coincides with the contour of the framework model of the deposit in plan (Omirserikov, 2016 a: 6).

3) In this area, where the intensity of the negative magnetic anomaly down to -50 nT is reduced, the area with increased negative values of the magnetic anomaly intensity up to -100 nT is highlighted.

This magnetic anomaly can be associated with the mineralogical composition of the second ore stage of mineralization. The only minerals of this stage are pyrrhotite and sharply subordinate to it chalcopyrite. Both these minerals are represented by fine-grained aggregates fulfilling cracks in vein quartz. Aggregates of continuous pyrrhotite and chalcopyrite reach up to 5 cm. In addition to vein quartz, pyrrhotite with chalcopyrite is also observed in fractures of peroxal hornblende. Pyrrhotite is known to be a ferromagnetic with high magnetic susceptibility in the range of $(7–20)\cdot 10^{-3}$ GHS.

Other ore minerals of the deposit such as wolframite and scheelite, bismuthite and molybdenite, pyrite are paramagnetic. Among them, pyrite is the second most abundant after quartz, where it is found in all veins and veins (Subbotin, 1952: 50; Omirserikov, 2016 a: 6).

Consequently, it can be stated that the area of distribution of pyrrhotite-chalcopyrite-molybdenite mineralization at this deposit is distinguished by a negative magnetic anomaly with intensity up to -100 nT due to the concentration of ore minerals with magnetic properties.

The following conclusions can be drawn from the results obtained from the analysis of the magnetic field of the Akmaya-Katpar ore zone:

1) the change in the sign of the magnetic field intensity in the area of the Akmaya deposit is related to the structural features of the ore body;

2) the decrease in the intensity of the positive magnetic anomaly is associated with a change in the mineralogical composition of the hydrothermally altered rocks of the deposit and this position delineates the ore stockwork;

3) increase in the intensity of the magnetic anomaly inside the stockwork contour is associated with the concentration of such ore minerals as pyrrhotite, pyrite, chalcopyrite.

Conclusion

During the ore stage hornblende and skarns of the Akmaya deposit underwent hydrothermal-metasomatic changes, with a change in mineralogical composition, where all more dense minerals in their composition were replaced by less dense minerals - sericite, chlorite, calcite. This led to a decrease in the density of hydrothermally altered hornblende and skarn varieties and reflected in the gravity field by a positive gravity anomaly due to positive excess mass within 0,35 g/cm^3.

Hydrothermal-metasomatic altered rocks also differed in magnetic properties from unaltered hornblende and skarns. Magnetic susceptibility of orogenic rocks in rare-metal deposits of Central Kazakhstan, according to researchers, reaches up to $1100*10^{-6}$ GHS, and it is associated with pyroxene, which is the main iron-bearing mineral in its composition. The magnetic susceptibility of pyroxene reaches up to $300*10^{-5}$ GHS, but in hydrothermally altered rocks, as it was already noted, chlorite develops along pyroxene, and this will lead to a decrease in the magnetic susceptibility of ore-bearing rocks to $50*10^{-6}$ GHS, as well as to a decrease in the negative intensity of the magnetic field in the area of the Akmaya deposit to -50 nT.

In this case, it should be noted that metamorphic and hydrothermal-metasomatic processes affect the magnetic properties of rocks in the Akmaya-Katpar ore zone, where the process of orogenization sharply increases magnetic susceptibility, and hydrothermal processing of rocks will lead to a decrease in their magnetic properties.

So, hydrothermal-metasomatic altered rocks of Akmaya-Katpar ore zone in geophysical fields are reflected as follows:

1) with positive gravitational anomaly due to the appearance of positive excess mass;

2) with a negative magnetic anomaly due to structural features of the ore stockwork;

3) with decreasing negative values of the magnetic anomaly intensity the contours of the ore stockwork are defined, and with increasing intensity of the negative magnetic anomaly the area of distribution of chalcopyrpit-pyrrhotite-pyrrhotite-molybdenite-chlorite veins in the ore stockwork is reflected.

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