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

4 (460)

JULY – AUGUST 2023

THE JOURNAL WAS FOUNDED IN 1940

PUBLISHED 6 TIMES A YEAR

ALMATY, NAS RK

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»!

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 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 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/

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 4. Number 460 (2023), 176–186
https://doi.org/10.32014/2023.2518-170X.320

IRSTI: 38.57.17

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FORECASTING RARE METAL PEGMATITE DEPOSITS OF THE KALBA REGION

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Abstract. The features of geotectonic development, deep structure and rare metal metallogeny of the Kalba region of the Greater Altai, which is part of the general system of the Central Asian mobile belt, are considered. The main rare-metal structure of the region is the Kalba-Narym granitoid belt of the northwestern direction, formed during the Hercynian cycle in a post-collision (orogenic) geodynamic setting. The spatial-genetic relationship of the leading geological-industrial type of deposits of rare-metal pegmatites (Ta, Nb, Be, Li, Cs, Sn) with medium-coarse-grained biotite granites of phase I of the Kalba complex P_1 (285 Ma), of the normal series of sodium-potassium alkalinity is emphasized and moderate basicity. The predominant concentration of rare-metal pegmatite deposits in the Central Kalba block of increased tectonic disturbance is substantiated. In the distribution of pegmatite fields and deposits, the leading ore-controlling role is given to the regmatic system of latitudinal deep faults of ancient origin, renewed in the Hercynian cycle. A geological and genetic model of rhythmically pulsating rare-metal pegmatite formation is presented, reflecting the zonal development of mineral complexes from oligoclase-microcline (barren) to albite, greisen, spodumene containing and pollucite-bearing (ore) with increasing concentration of mineralization.

According to laboratory studies (mass spectrometry, scanning electron microscopy, atomic absorption analysis, etc.), new information was obtained on the material composition of pegmatite ores with the release of typomorphic minerals (clevelandite, lepidolite, colored tourmalines, spodumene, pollucite, ixiolite, etc.) and geochemical elements-indicators of rare-metal pegmatite formation (Ta, Nb, Be, Li, Cs, F, P, etc.). The developed geotectonic, geological-structural, petrological and mineralogical-geochemical predictive-search criteria are the basis for setting up further exploration work in order to strengthen the rare-metal mineral resource base of the region.

Keywords: Kalba region, granitoids, deposits, rare metals, modeling, forecasting

Funding: This research has been funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. AP19676805).

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ҚАЛБА АЙМАҚЫНДАҒЫ СИРЕКТІ МЕТАЛЛ ПЕГМАТИТ КЕНДЕРІН БОЛЖАУ

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Аннотация. Орталық Азия жылжымалы белдеуінің жалпы жүйесіне кіретін Үлкен Алтайдың Қалбі аймағының геотектоникалық даму ерекшеліктері, терең құрылымы және сирек металдар металлогениясы қарастырылады. Облыстың негізгі сирек-металл құрылымы - соқтығысудан кейінгі (орогендік) геодинамикалық жағдайда герциндік циклде қалыптасқан солтүстік-батыс бағыттағы Қалба-Нарым гранитоидты белдеуі. Сирек-металлдық пегматиттердің (Ta, Nb, Be, Li, Cs, Sn) жетекші геологиялық-өндірістік типті кен орындарының Қалба кешені P_1 фазасының орташа ірі түйіршікті биотитті граниттерімен кеңістіктік-генетикалық байланысы (285 Ма), қалыпты қатардағы натрий-калий сілтілігі және орташа негізділігі атап өтіледі. Тектоникалық бұзылыстың

күшеюі Орталық Қалба блогында сирек металды пегматит кен орындарының басым шоғырлануы дәлелденді. Пегматитті кен орындары мен кен орындарының таралуында герциндік циклде жаңарған көне текті ендіктік терең жарықтардың регматикалық жүйесіне жетекші рудалық бақылаушы рөл беріледі. Минералдану концентрациясының жоғарылауымен олигоклазды-микроклиннен (тақыр) альбит, грейзен, сподумен және ластануы бар (руда) минералды кешендердің аймақтық дамуын көрсететін ырғақты пульсирленген сирек металды пегматит түзілуінің геологиялық-генетикалық моделі ұсынылған. Зертханалық зерттеулерге сәйкес (масс-спектрометрия, сканерлеуші электрондық микроскопия, атомдық абсорбциялық талдау және т.б.) типоморфты минералдар (клевландит, лепидолит, түрлі-түсті турмалиндер, сподумен, поллюцит, ексолит) бөлінетін пегматитті кендердің материалдық құрамы туралы жаңа мәліметтер алынды. және т.б.) және геохимиялық элементтер-сирек-металлдық пегматит түзілу көрсеткіштері (Ta, Nb, Be, Li, Cs, F, P және т.б.). Әзірленген геотектоникалық, геологиялық-құрылымдық, петрологиялық және минералогиялық-геохимиялық болжамдық-іздестіру критерийлері өңірдің сирек-металл минералдық-шикізаттық базасын нығайту мақсатында одан әрі барлау жұмыстарын жүргізу үшін негіз болып табылады.

Түйін сөздер: Калбинск облысы, гранитоидтар, кен орындары, сирек металдар, модельдеу, болжау

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ПРОГНОЗИРОВАНИЕ РЕДКОМЕТАЛЛЬНЫХ ПЕГМАТИТОВЫХ МЕСТОРОЖДЕНИЙ КАЛБИНСКОГО РЕГИОНА

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Аннотация. Рассматриваются особенности геотектонического развития, глубинного строения и редкометалльной металлогении Калбинского региона Большого Алтая, входящего в общую систему Центрально-Азиатского

подвижного пояса. Главной редкометалльной структурой региона является Калба-Нарымский гранитоидный пояс северо-западного направления, сформированный в герцинский цикл в постколлизионной (орогенной) геодинамической обстановке. Подчеркивается пространственно-генетическая связь ведущего геолого-промышленного типа месторождений редкометалльных пегматитов (Ta, Nb, Be, Li, Cs, Sn) со средне-крупнозернистыми биотитовыми гранитами I фазы калбинского комплекса P_1 (285 млн. лет), нормального ряда натриево-калиевой щелочности и умеренной основности. Обосновывается преимущественная концентрация редкометалльных пегматитовых месторождений в Центрально-Калбинском блоке повышенной тектонической нарушенности. В размещении пегматитовых полей и месторождений ведущая рудоконтролирующая роль придается регматической системе широтных глубинных разломов древнего заложения, подновленных в герцинский цикл. Приводится геолого-генетическая модель ритмично-пульсационного редкометалльного пегматитообразования, отражающая зональное развитие минеральных комплексов от олигоклаз-микроклиновых (безрудных) до альбитовых, грейзеновых, сподуменсодержащих и поллуцитоносных (рудных) с возрастающей концентрацией оруденения. По данным лабораторных исследований (масс-спектрометрия, растровая электронная микроскопия, атомно-абсорбционный анализ и др.) получена новая информация о вещественном составе пегматитовых руд с выделением типоморфных минералов (клевеландит, лепидолит, цветные турмалины, сподумен, поллуцит, иксиолит и др.) и геохимических элементов-индикаторов редкометалльного пегматитообразования (Ta, Nb, Be, Li, Cs, F, P и др.). Разработанные геотектонические, геолого-структурные, петрологические и минералого-геохимические прогнозно-поисковые критерии являются основой для постановки дальнейших геологоразведочных работ с целью укрепления редкометалльной минерально-сырьевой базы региона.

Ключевые слова: Калбинский регион, гранитоиды, месторождения, редкие металлы, моделирование, прогнозирование

Introduction

The Kalba region is located in East Kazakhstan and, in terms of geotectonic zoning, is included in the general geostructure of the Great Altai (hereby GA) which is part of the Central Asian mobile belt. In the north-east it is limited by the Irtysh zone of crumpling, in the south-west along the Terekta fault it is separated from the West Kalba. The southeastern flank of the structure continues to China; in the northwest it is mainly overlain by a cover of loose deposits of the Kulunda depression. In metallogenic terms, this is the major rare metal structure of East Kazakhstan, the prospects of which have not yet been exhausted. At present, the most important task is to forecast and search for new rare metal objects in order to strengthen the raw material base for rare metal production enterprises. Kalba granitoid belt of the northwestern direction is formed in the Hercynian cycle in a post-collisional (orogenic) geodynamic setting. The spatial-genetic relationship of the leading geological-industrial type of rare-metal pegmatites deposits (Nb, Ta, Be, Cs, Li, Sn) with medium-coarse-grained biotite phase I granites of the Kalba complex (P_1, 285 million years), normal series of sodium-potassium alkalinity is emphasized and moderate basicity.

Methodology

Based on geological, geochemical and mineralogical studies, information was obtained on the composition of pegmatite ores with the release of typomorphic minerals (clevelandite, lepidolite, colored tourmalines, spodumene, pollucite, ixiolite, etc.) and main geochemical elements of rare metal ore formation (Nb, Ta, Be, Cs, Li, F, P, etc.).

The study of the mineralogical composition of Kalba pegmatites was greatly contributed by A.I. Ginzburg, V.D. Nikitin, S.G. Shavlo, N.A. Solodov, V.I. Kuznetsov, Yu.A. Sadovsky, V.A. Filippov and others. New studies of the material composition of pegmatites were carried out by the authors using electron microscopy to study typomorphic minerals and geochemical elements of rare metal pegmatite formation. Rare metal pegmatites were formed as a result of the multistage development of metasomatic processes:

1) *microclinization*, accompanied by the formation of block microcline pegmatites and mineral paragenesis (block quartz and microcline, large-lamellar muscovite, columbite and beryl);

2) *albitization*, which is associated with the formation of albite-microcline and albite mineral complexes, which are the matrix of rare-metal pegmatite veins with ordinary beryllium-tin-tantalum ores;

3) *greisenization*, fixed by a quartz-albite-muscovite complex, in the inner parts of pegmatite veins; typomorphic minerals - green lithium-bearing muscovite, fluorapatite, verdelite, tantalite-columbite, and cassiterite;

4) *spodumenization*, manifested by the new formation of the most productive mineral complexes (quartz-spodumene, quartz-spodumene-clevelandite, quartz-clevelandite-spodumene-lepidolite, etc.). The general evolution of the process of pegmatite formation was accompanied by a more complex shape and an increase in the thickness of pegmatite veins, an increase in the amount of ore and accompanying minerals, a concentration of rare metal mineralization (Ta, Li, Sn) and an increase in the contents of Zr, Hf, U, TR.

The characteristics of the leading mineral complexes are given in the article.

Results.

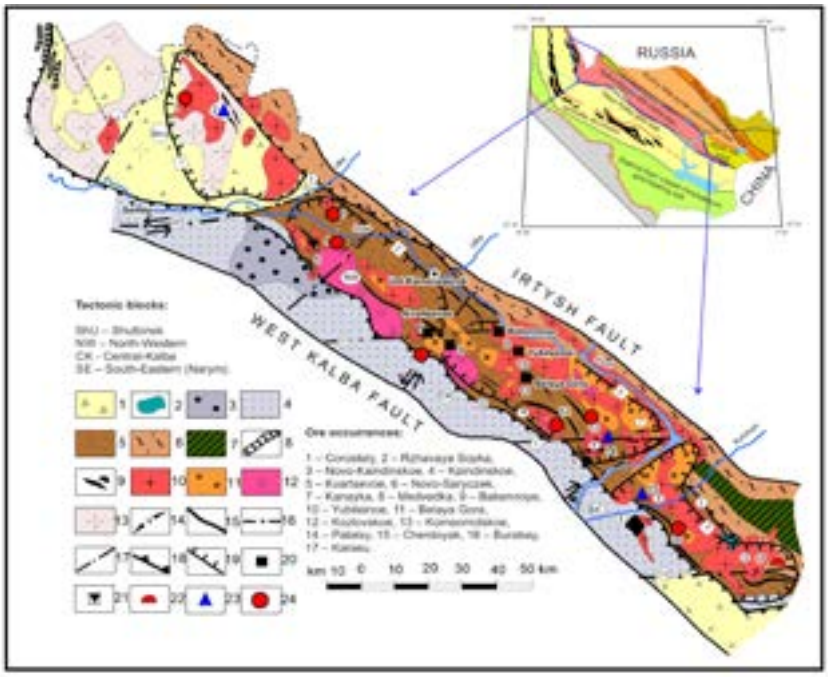
Features of geotectonic development and depth structure.

In accordance with modern geotectonic concepts, the Kalba region (hereafter KNZ) is a fragment of a submerged Precambrian plate (terrane) that migrated separately in the Paleo-Asian Ocean and joined the Greater Altai at the stage of the Hercynian collision of the Kazakhstan and Gorny-Altai lithospheric plates and the degradation of the Irish Zaysan paleobasin (Buslov, 2011; Safonova, 2014). In its modern form, the KNZ is presented in the form of a linear complex-fold-granitoid belt bounded by deep faults. In terms of metallogenic zoning, the Kalba region corresponds to a rare metal belt bounded by the Irtysh copper-pyrrhotite-gold ore zone and the West Kalba gold belt (Fig. 1). According to the features of the deep structure, the KNZ belongs to the sialic type of the ZK section of increased thickness (45–50 km), differs in the increased thickness of the metagranite (granite-metamorphic) layer (up to 12 km) and metadiorite (up to 12–14 km), reduced metabasalt (up to 14–18 km).

Geological structure and metallogeny Kalba region. In the Kalba region, Precambrian formations are fragmentarily recorded in the Narym (Kurchum valley), near the border with the Irtysh shear zone, represented by a small tectonic plate of crystalline

shales and protrusions of serpentinized hyperbasites (PR?) among the deposits of the Takyr suite (D_3). The Caledonian formations are overlain by the Hercynian structural layer and are not exposed on the day surface; they are assumed to occur at depths of 4–8 km. Hercynian formations are widespread (Zimanovskaya et. al., 2022), fig. 1.

In the early riftogenic stage, there were accumulated carbonaceous-calcareous-terrigenous deposits (Kystav-Kurchum Formation, D_2gv) and thin-bedded black shale sandstone-siltstone sediments of the slate formation (Takyr Formation, D_3). Later, the flyschoid carbonaceous-calcareous-terrigenous formation (Burabay Formation, C_1v_{2-3}) and graywacke siltstone-sandstone (Dalankarin Formation, C_1s) were formed. The middle stage is characterized by molasse strata (Tauba Formation, C_2) and small pre-atolithic intrusions and dikes of the C_3 Kunush Complex (D′yachkov et. al., 2021; Ponomareva et. al., 2021). In the postcollisional (orogenic) stage, the Kalba granitoid belt was formed, composed mainly of granites of the Kalba (P_1) and leucogranites of the monastery (P_2) complexes.



1 – Cenozoic cover; 2 – Kalgutinskaya volcano-plutonic rhyolite-dacite association (C_3); 3 – molasses of the Tauba Formation (C_2); 4 – flyschoid and graywacke silt-sandstone deposits (C_1); 5 – slate sandstone-siltstone formation (D_3); 6 – carbonate-terrigenous deposits and 7 – metamorphic rocks (PZ2-PR); 8 – hyperbasites; 9 – intrusive and dike (C_3); 10-11 – granites (P_1) (10 – granites of the I phase, 11 – II phase); 12 – leucogranites (P_2); 13 – hidden granite massifs according to geophysical data; 14 – dikes of the Mirolyubovsky complex (P_2); 15 – regional deep faults, longitudinal northwestern; 16 – latitudinal ore controlling and 17 – transverse northeastern; 18 – boundaries of belt and 19 – ore regions; 20 – 24 – ore formations (20 – rare-metal and 21 – chamber crystal-bearing pegmatites; 22 – albitite-greisen tin-tantalum, 23 – tin-tungsten; 24 – quartz-veined tin-tungsten and tin).

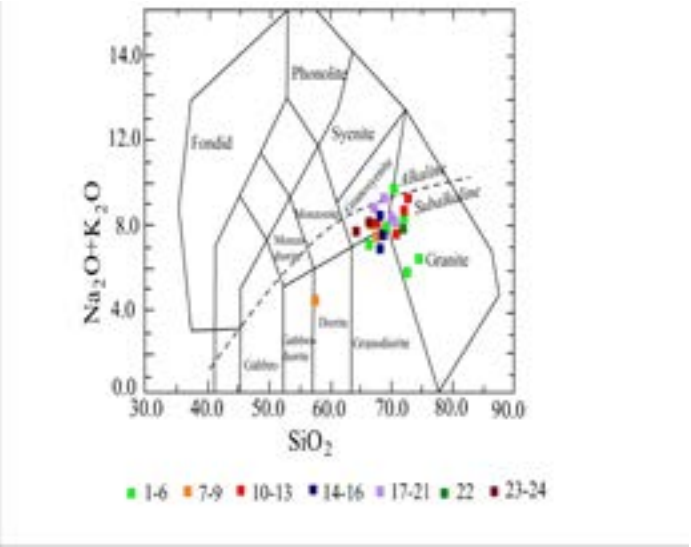
Fig. 1 - Scheme of the geological structure of the Kalba-Narym belt (compiled by B.A. Dyachkov, T.A. Oitseva).

Rare metal mineralization is represented by deposits of pegmatite, albitite-greisen, greisen-quartz vein and other ore-formational types. There are four ore regions (Shulbinsk, North-West-Kalba, Central-Kalba and Narym), two ore zones (Gremyachinsko-Kiinsky, Karagoin-Saryozeksky) and 22 ore clusters. Rare metal pegmatites deposits (Nb, Ta, Be, Cs, Li, Sn), located mainly in the Ognevsko-Bakenny and Asubulak-Belogorsky ore clusters (Bakennoye, Yubileinoye, Belogorskoye and Verkhne-Baimurzinskoye), were of major industrial importance.

Forecasting criteria and perspective assessment. As a result of the study, further development was given to the idea of the belt distribution of ore deposits in Rudny Altai, Kalba-Narym zone, Western Kalba and Zharma-Saur. The general pattern consists in the formation of deposits in the Hercynian cycle in various geodynamic settings, the concentration of ore objects in the ore belts of the northwestern direction, a considerable length (500-800 km) and high ore productivity (Buslov, 2011; Tkachev, 2011; D′yachkov et. al., 2021; Ponomareva et. al., 2021; Zimanovskaya et. al., 2022; Oitseva et. al., 2022). New data have been obtained on the formation patterns, features of the material composition of ores of rare-metal pegmatite deposits and geological structure with the development of predictive and prospecting criteria for their assessment.

The geotectonic position of rare metal deposits is determined by their confinement to the Kalba granitoid belt, formed in the Hercynian cycle in the postcollisional (orogenic) geodynamic setting of the Permian time. New studies determine the later age of the rare-metal belt relative to the West Kalba gold-ore belt, the collisional geodynamic setting (London, 2018). The confinement of rare-metal ore fields and deposits to thickened parts of granite massifs is emphasized, which is one of the search criteria. In the location of ore fields and deposits, the leading importance is given to longitudinal northwestern deep faults (Kalba-Narymsky, Terektinsky and their feathering structures), which were the largest magma conduits. The main pegmatite deposits (Bakennoye, Yubileinoye, etc.) were formed in the Central Kalba block of increased tectonic mobility, thrust over the Irtysh zone of collapse. The ore-controlling role of latitudinal faults is clearly manifested in other objects of the KNZ, as well as in the gold fields of Western Kalba and in Rudny Altai, and should be taken into account in predictive metallogenic works (Le Bas et. al., 1986; Safonova, 2014; Kuznetsova, 2018; Kotler et. al., 2021; Zimanovskaya et. al., 2022).

In the Kalba region, the spatial-genetic relationship of the main types of rare-metal-deposits with phase I granitoids of the Kalba complex was determined (Zimanovskaya et. al., 2022). Granitoids are characterized by inconsistent facies composition, petrochemically refer to the normal series of sodium-potassium alkalinity, calc-alkaline and low-plumazite agpaiticity (Ka = 0.63), very high-alumina and moderate basicity. In the diagram of silicic acidity-alkalinity, they occupy an intermediate position between granites and granodiorites, Fig. 2.



1–6 – medium-coarse-grained biotite granites (Ognevsko-Bakennoe ore field); 7–9 – contaminated granites and granodiorites Karmen-Kuus ore occurrence, Yubileinoe deposit); 10–13 – porphyritic biotite granites of the Krasny Kordon ore occurrence and 14–16 – Ungursai ore occurrence; 17–21 – medium-coarse-grained weakly muscovitized granites (Belogorskoe ore field); 22 – microclinized and 23, 24 – contaminated granites of the Jubilee deposit.

Fig. 2 - Diagram of silicic acidity and alkalinity of phase I granitoids of Central Kalba with the line of separation of rocks into subalkaline and alkaline after (Le Bas et. al., 1986). Performed by T.A. Oitseva. ICP-MS results, analyst S.N. Polezhaev.

Geochemically, the granitoids are enriched in rare alkalis (Li+Rb+Cs=480 grams per ton) and Sn, an increased Ta content is found in biotite (26.14 grams per ton) and accessory minerals, and is found in dispersed form in quartz and feldspars. New radiological data of the Ar/Ar method (for biotite, muscovite, and lepidolite) additionally confirm the close absolute age of phase I granitoids (285.1 ± 2.7 million years) and rare metal pegmatites (283 ± 2.7 million years), which reflects the synchronicity of the formation of granites and processes of pegmatite formation (Kotler et. al., 2021).

The geological-genetic model of rare-metal pegmatite formation is presented in the form of a single ore-magmatic system, reflecting the synchronization of the arrival of the initial granitoid melts, pegmatite-forming solutions-melts and fluid gas-liquid solutions associated with common deep magma chambers of the crustal type. By the nature of ore content, these granitoids are close to the tin-tantalum geochemical type and ore-bearing granite systems of normal alkalinity (Gonçalves et. al., 2019).

Characteristics of the leading mineral complexes. The zonal distribution of mineral complexes in pegmatites is clearly manifested in the Asubulak ore field (Fig. 1), which was noted in the works of N.A. Solodov, V.A. Filippov, D.Ya. Aizderzis, E.P. Pushko, A.M. Smirnov and other researchers. The characteristics of the leading mineral complexes are given.

The *albite complex* is widely developed. It is composed mainly of albite (95%) with

an insignificant admixture of quartz (up to 5 %), muscovite, tourmaline, garnet and other minerals. Outwardly, it is a rock of massive appearance, white, composed mainly of fine-grained and sugary albite. They contain tantalite-columbite in the form of fine dissemination (up to 0.5 mm in size), prismatic crystals of dark brown and black color. Less commonly, cassiterite crystals of a dipyramidal-prismatic appearance of various colors from reddish-brown and pale green to colorless are observed. A distinctive feature of the complex is its enrichment with phosphates of Li, Mn, Fe, forming nests, lenses and black spots.

The *quartz-albite-muscovite (greisen) complex* occurs locally in different parts of the veins. In the inner zones, it is associated with the albite-spodumene complex. Outwardly, it is a coarse-grained greisen of greenish color, consisting mainly of muscovite (more than 50 %), quartz and albite.

Spodumene-bearing complexes are the main concentrators of rare-metal mineralization. New research results show that the most productive are quartz-clevelandite-spodumene-lepidolite (colored) and quartz-clevelandite-lepidolite-pollucite complexes and their varieties (Kotler et. al., 2021). Similar pegmatites are widespread in other rare-metal provinces (Zhang et. al., 2016; Yong et. al., 2018; Dittrich et. al., 2019; Fei et. al., 2021; Tramm et. al., 2021). The main feature is the complexity of the composition of pegmatites containing unique minerals of several generations (clevelandite, lepidolite, spodumene, petalite, amblygonite, pollucite, colored tourmalines, cassiterite, tantalite-columbite, manganotantalite, microlite, etc.) and rich complex ores (Sn+Ta+Cs+Li). The following minerals are among the most leading indicators of rare metal pegmatite formation.

Discussion

In East Kazakhstan, according to the analysis of geological materials of past years and new results of research work, ideas about the belt distribution of ore deposits (Fe, Cu, Pb, Zn, Au, Ta, TR and other metals) were further developed with the formation of ore belts of regional rank. Known rare metal and rare earth deposits (Nb, Ta, Be, TR, Li, etc.) were formed in a postcollisional (orogenic) geodynamic setting, accompanied by a powerful development of Permian granitoid magmatism, typical for many regions of the Central Asian belt (Buslov, 2011; Safonova, 2014; Fei et. al., 2021; Kotler et. al., 2021). In the regional plan, a regular spatial confinement of rare-metal objects to large granitoid belts has been determined.

A positive factor in the rare-metal metallogeny of Kalba is the substantiation of the synchronism of the age of the ore-hosting granitoids of the Kalba complex and the rare-metal pegmatites by modern isotope-geochronological methods — 283–286 million years. For the Kalgutinskaya Mo-W deposit in Gorny Altai, the duration of ore-magmatic processes is more than 20 million years. In the Kalba region, the time interval of the ore-magmatic system is limited by the age of the ongonite dikes of the Mirolyubovsky complex and amounts to about 10 million years (Safonova, 2014).

As a result of detailed mineralogical and geochemical studies, new information was obtained on the composition of rare metal pegmatites, mineral parageneses and geochemical indicator elements reflecting the fluid regime of ore formation were

determined (Gamyanin et. al., 2008). The leading generators of rare-metal mineralization are multistage processes of metasomatic replacement of pegmatites (microclinization, albitization, greisenization, etc.), accompanied by the formation of a complex of unique minerals (clevelandite, lepidolite, spodumene, pollucite, amblygonite, tantalite-columbite, microlite concentrations) metals during the evolution of the pegmatite process. According to these features, the Kalba rare-metal pegmatite objects approach large pegmatite deposits of foreign countries: Kings Mountain, Bernik Lake, Koktogay, Zimbabwe, Angola, etc. (Dittrich et. al., 2019; Wang et. al., 2020; Fei et. al., 2021; Levashova et. al., 2022). The differences lie in the unequal geological conditions of their formation: Kalba pegmatites were localized in environments similar in chemical composition (quartz-feldspar-mica schists, granites), and foreign deposits were formed mainly in rocks of increased basicity (gneisses, diabases, andesites, plagioamphibolites and altered gabbroid etc.), have a more ancient age of the host rocks. This is one of the possible reasons for the low scale of the volumes of rare metal ores of the Kalba deposits.

Conclusion

The regularities of the formation of rare-metal pegmatite deposits of the Kalba granitoid belt have been clarified from modern theoretical positions. The developed geotectonic, geological-structural, magmatic and mineralogical-geochemical forecasting and prospecting criteria are the scientific basis for further exploration. The studies carried out show that the prospects for discovering new deposits of rare metals remain in the Kalba region. The most promising are the flanks of the Kalba granitoid belt, over-intrusive and apical zones of hidden granite massifs, identified according to geological and geophysical data.

In order to increase the efficiency of prospecting work, it is necessary to sharply increase the depth of geological study of the territory with the establishment of deep geological mapping and deep mineragenic mapping, conducting more detailed prospecting work in promising areas using modern scientific and methodological technologies. The revealed features of the formation and mineral composition of pegmatite deposits on a modern analytical basis make a certain contribution to the knowledge of the processes of pegmatite ore formation.

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

Подписано в печать 16.08.2023.
Формат 70x90 1/16. Бумага офсетная. Печать – ризограф.
20,0 п.л. Тираж 300. Заказ 4.

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