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ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
РЕСПУБЛИКИ КАЗАХСТАН
Satbayev University

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LI-BEARING PEGMATITES OF THE KALBA-NARYM METALLOGENIC ZONE (EAST KAZAKHSTAN): MINERAL POTENTIAL AND EXPLORATION CRITERIA

Abtsract. The paper focuses on the formation patterns of Li-bearing pegmatites in the Kalba-Narym metallogenic zone in East Kazakhstan, with exploration implications. The main types of rare-metal (Ta, Nb, Be, Li, Cs, Sn, W, TR) mineralization are structurally and genetically related with Permian postcollisional granitoids of the Kalba-Narym belt. According to the suggested geological model simulating multistage evolution of mineral assemblages from oligoclase-microcline to albite varieties, mineralization at the Bakennoye, Yubileinoe, and other deposits is related with 285 Ma Kalba alkaline granites and occurs in Cs-bearing spodumene pegmatites located in the upper part of the ore zone. The distribution of pegmatite fields has been controlled by a large-scale system of old regional W-E faults which were rejuvenated during the collisional activity. Rare-metal pegmatite mineralization can be traced from the presence of cleavelandite, lepidolite, spodumene, pollucite, color tourmalines, ixiolite, and other indicator minerals. In addition to the classical pegmatitic deposits associated with granites, older (305 Ma) plagiogranites and dikes of the Kunush complex host Li-bearing albite-spodumene pegmatites with secondary Sn, Ta, and Li mineralization (Akhmetkino, Tochka, Aldai, and other deposits). The indicators for this mineralization type include albite, cleavelandite, spodumene, cymatolite, and tantalite-columbite. Albite-spodumene pegmatites in the region can provide additional Li resources and are worth of further investigation.

Key words: Kalba-Narym zone, rare metals, granite, plagiogranite, pegmatite, Li resources, mineral exploration.

Introduction. The Kalba-Narym metallogenic zone is located in the Irtysh-Zaisan fold system in East Kazakhstan within the Great Altai, a part of the Central Asian Orogenic Belt [1]. The Great Altai region is remarkable for its complex geological structure and extremely rich mineralization, with abundant and diverse massive sulfide deposits of base, rare, and precious metals (Fe, Cu, Pb, Zn, Ag, Au, Ta, REE, etc.) which make basis for developed mining and metallurgical industries. As old shallow deposits are being depleted, advanced exploration of deep-seated mineral resources, including rare metals (Ta, Nb, Be, Li, Cs, etc.) demanded in the high technology sector, becomes the main challenge [2].

Estimating the potential of the region as to the l*ithium resources* for future energy production operations is of special importance in this respect. Previously, spodumene pegmatites in East Kazakhstan were mined mainly for *Ta and Sn*, with associate microcline and muscovite (Bakennoye, Yubileinoye, Belaia Gora, Upper Baimurza, and other deposits), while other metals (Be, Li, Cs) were neglected and put out to tailings. However, the growing world demand for lithium and other rare metals requires additional exploration of spodumene pegmatite resources and reappraisal of some small deposits and occurrences in terms of *Ta-Be-Sn-Cs-Li mineralization* using new approaches and technologies. This study aims at gaining more insights into the formation patterns and mineral potential of spodumene pegmatites in the Kalba-Narym zone, for the case of the *Tochka area,* with implications for exploration and subsequent mining operations.

Materials and methods. Geological and metadological backrgound. Additional exploration of Li pegmatites in the *Tochka area* can proceed from a wealth of available data collected since 1955 [3].

Mineralization occurs in the *Karagoin-Saryozek* ore zone which spans more than 200 m in the vertical dimension and stores several underexpolred Ta, Nb, Be, Sn, Li albite-spodumene pegmatite deposits associated with small intrusions and dikes of the Kunush complex (Fig. 1). The zone includes a 5.4 m thick blind vein of albite-spodumene pegmatite discovered recently at a drilling depth of 303 m (Kenebay site), which boosts its potential. Economic amounts of lithium may exist at the reference *Akhmetkino deposit*, which has to be studied in detail and evaluated in response to the growing *Li* demand [4].

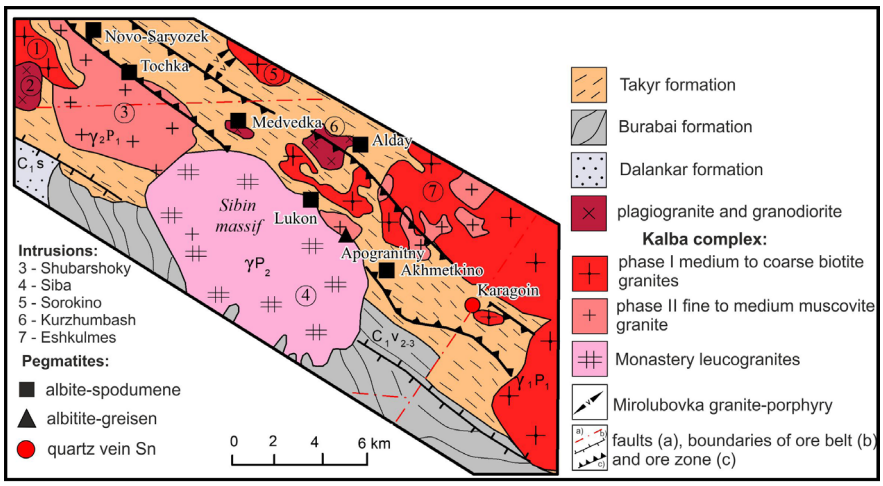

Figure 1 - Simplified local geology of the Karagoin-Saryozek ore zone (performed by Oitseva T. A.) [5]

The orebodies are mainly localized in faulted and metamorphozed black shales of the Takyr Fm. (D_3) and in plagiogranite intrusions (Fig. 2). The Kalguty garnet-biotite granitoids identified in previous models of magmatism [6] rather belong to the Kunush complex [2, 7]. The Kunush plagiogranites, which constitute a particular element in the magmatism of the Kalba area, have a collisional origin and host gold in the West Kalba zone or *secondary rare-metal mineralization* (Ta, Nb, Be, Sn, Li, W) in the Kalba-Narym zone [8, 9]. Plagiogranites are gray equigranular medium-grained varieties consisting of 59-62% plagioclase, 26-28% quartz, and small amounts of feldspar (2-4%), biotite (6.5%), and accessories (amphibole, apatite, zircon, arsenopyrite, etc., 0.3-0.6% in total). Their compositions differ in sodic alkalinity (Na2O/K2O>4), a relatively low agpaitic index (Ka=0.89) corresponding to the plumaistic series, and high contents of mafic components [10]. The rocks have elevated contents of Cu, Pb, and Zn and contain Au, Ag, Pd, and Sb: Ag in galena (6.3 ppm), monazite (1.6 ppm), and greisen quartz (37.31 ppm); PGE in apatite (4.17 to 13.84) and sferosiderite (2.31 ppm). The contents of Sn are 11.43 ppm, while rare alkalis (275.5 ppm ∑Li+Rb+Cs) are twice as low as in phase I granites of the Kalba complex. According to high Sr contents (up to 686-815 ppm) and isotope systematics, the Kunush plagiogranites are of crust-mantle adakite type [11, 12].

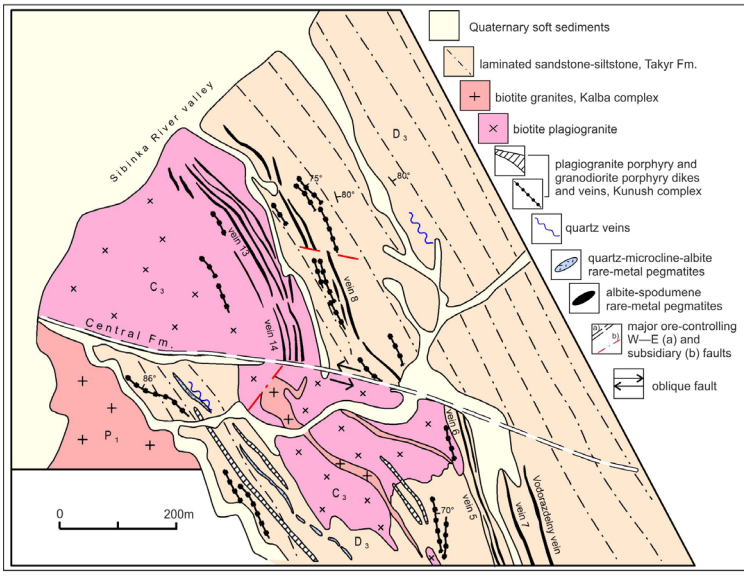

Figure 2 - Simplified local geology of Tochka deposit (northern part), after Osipova et al. (1990) [3]

Plagiogranites occur as two relatively large bodies separated by a W-E fault (Fig. 2) and are mainly buried under soft sediments in the northwest. Boreholes in the black shales strip individual offshoots and protrusions of plagiogranite (Barrier intrusion, etc.). The ore field comprises a system of the Kunush dike-shaped plagiogranite, granodiorite, and quartz porphyry alternated with the Kalba vein granites, aplites, aplite-pegmatites, pegmatites, and quartz veins [13]. The veins are 20-30 cm to 3-5 m thick (0.2-1 m in late quartz veins) and 250-300 long, strike in the NW direction (315-330°) concordantly with the host black shales, and dip mostly to the northeast at 70-85°.

The pegmatite veins are of (1) microcline, (2) microcline-albite, (3) albite, or (4) albite-spodumene types, or locally bear quartz-microcline-muscovite (greisen) assemblages. The albite-spodumene pegmatites that formed in the conditions of epidote-amphibolite metamorphism (500-600°C; 2-8 kbar) [14] have the highest Li potential.

The ore field is of supra-intrusion linear morphological type, with staircase veins in plagiogranites [3]. There are three NW pegmatite formations emplaced one below another: the Eastern (hanging wall), Central (axial), and Western (footwall) units. The mineralization is controlled mainly by the W-E Central zone which splits the deposit into the Northern and Southern blocks displaced for 380 m one relative to another (Fig. 2).

The *Central Fm.* appears to have the best prospects. It is composed mainly of albite-spodumene pegmatites occurring in two clusters of closely spaced veins, 170-200 m of total thickness, which form a single ore body. Pegmatite veins 13, 14, and some others crop out, while the mineralization as a whole is unevenly distributed and traceable to depths of 200-300 m or more. The contents of Li_2O in the veins reach at least 1 wt.%. Previous flame photometry data for pegmatite core samples [3] showed the relatively high contents of 1.050-1.111 wt.% Li_2O at 292 m core depth and 0.631 wt.% Li_2O at 335 m in borehole No. 19, etc, as well as at depths 140-316.5 m in boreholes at the Kenebay and Alday sites [15]. These data have been confirmed by more precise recent analyses of the Tochka albite-spodumene pegmatite samples at the IRGETAS (D. Serikbayev East Kazakhstan Technical University) and VNIItsvetemet laboratories (Ust`-Kamenogorsk). The Li contents vary from 0.62 to 1.43 wt.% in samples of vein 13 (0.98 wt.% average over 6 specimens) and reach 1.60 wt.% in those of trench 203. The vein interior parts accommodate stacked nests (>1 m) of spodumene which exceeds 50 vol.% (Fig. 3).

Lithium enrichment was also found in greisen *pegmatites and in xenoliths* of the host biotite-garnet-sericite shales (>0.1-0.3 wt.% Li_2O). The Li contents measured in lens-shaped Chudskaya and No. 9 veins are 0.63wt.% Li_2O for albite-spodumene pegmatite and as low as 0.019 wt.% Li_2O for greisen and albitite pegmatites.

Figure 3 - Nest of albite-spodumene pegmatite

Of special interest is the NE staircase-like Barrier vein located in a small NE plagiogranite intrusion in the southeastern flank of the ore field (Fig. 4). The vein encloses a long zone of albite-spodumene pegmatites in its interior part, with 0.22 to 0.79 wt.% Li_2O (0.35% on average over 8 analyses).

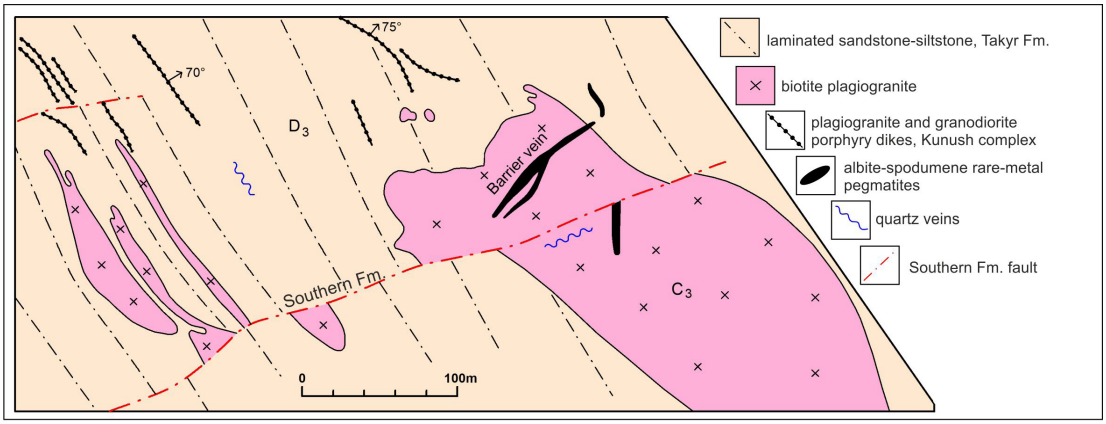

Figure 4 - Simplified local geology of Tochka deposit (southern part), after Osipova et al. (1990) [3]

The *Western Fm.* encompasses albite-spodumene pegmatites of vein 2, as well as albite and albite-microcline pegmatites of veins 1 and 3. The veins have shallow erosion cutout and dip at 20° in the NW direction. Vein 2 has the highest Li grades with 10,800-17,800 ppm or 1.08-1.78 wt.% Li_2O (Table 1, samples T-1, T-1a). These results were confirmed by AAS data (1.66-2.87 wt.%).

The *Eastern Fm.* is the most strongly eroded. It has 10-30 m long and 1.5-4 m thick lens-shaped bodies of albite-spodumene pegmatites in its northern part and lens- or plate-shaped veins, up to 5-6 m thick, in the Southern block. The albite-spodumene pegmatites of Vodorazdelny vein contain up to 0.63 wt.% Li_2O.

Table 1 - Trace element abundances (ppm) in Tochka rocks

Sample	Rock	Ta	Nb	Be	Li	Rb	Cs	Sn	W	Mo
T-1	Spodumene pegmatite	36.71	61.6	177.2	17800	80.00	12.87	29.43	1.43	1.58
T-1a	Spodumene pegmatite	37.99	75.5	137.9	10800	52.50	10.81	36.00	1.30	1.73
T-2	Quartz- muscovite-tourmaline hornfels	9.02	26.7	45.30	3130	961.0	308.6	101.4	2.08	1.98
T-3	Hornfels with thin pegmatite veins	32.26	56.9	58.20	1362	608.0	128.5	129.9	4.14	1.78
T-6	Quartz with spodumene	2.72	3.37	3.41	425	45.7	12.72	7.78	0.40	211.56
T-7	Quartz in a muscovite coat	16.69	14.87	5.40	622	159.9	26.90	50.90	1.85	1.17
T-8	Plagiogranite	0.57	0.81	1.33	413	41.20	22.19	9.57	0.75	1.37
T-9	Fine albitite	2.58	1.92	14.96	104.3	71.00	10.55	14.20	0.74	1.22
T-10	Greisen albitite	22.05	26.32	52.40	903	789.0	77.70	215.2	20.64	1.46
T-11	Streak of albite-tourmaline pegmatite	10.57	12.96	25.78	307.3	227.2	20.22	99.10	1.13	1.91
T-13	Sugar-like albitite	0.80	0.77	71.50	183.4	45.50	9.42	206.0	1.02	1.05

Results. Spodumene is the main metallic mineral reaching rock-forming percentages of 3-5 to 20-25% or more in albite-spodumene pegmatites from the Tochka area. White and pink spodumenes, within 3-5 cm in size, typically occurs in transverse bands across plate-shaped veins, while coarser crystals, up to 5-10 cm or longer and 1-3 cm wide, form nests in veins (Fig. 3) and are often replaced by eucryptite and cymatolite. Some spodumenes are as long as 1 m. Spodumene coexists with microcline (15-20%), sugar-like albite, cleavelandite, muscovite, gilbertite, or rarely with lepidolite, verdelite, etc. The Tochka pegmatites also contain 2-4 mm platy crystals of tantalite-columbite associated with quartz-albite-gilbertite assemblages. Furthermore, SEM images reveal rare-metal minerals (cassiterite, columbite, tantalite, microlite) and micrometer lumpy fluorapatite (Fig. 5), as well as microinclusions of galena, pyrite, apatite, and drop-shaped native irons.

Discussion. The existence of exposed and buried albite-spodumene pegmatite veins provides motivation for further exploration in the Tochka area. The veins were discovered in the course of previous surveys but have not been properly characterized, for several reasons.

First of all, the exploration in the Kalba-Narym zone from 1955 to 1994 targeted mainly at Ta and Sn ores, according to the demand of that time, but neglected other trace elements like Be, Li, Cs, or Rb. On the other hand, the potential of Li-bearing pegmatites in the area was estimated on sparse drilling networks (200 m × 150-200 m and 200 m × 400 m). That drilling coverage was insufficient for correlation of interceptions and for evaluation of albite-spodumene percentages in pegmatite veins and over the deposit as a whole, given the short length of the veins and their heterogeneity in morphology, thickness, and composition. Thus, the contours of the pegmatite veins remained poorly constrained along the flanks and at larger depths.

The Li grades in the available reports [3, 15] appear to be underestimated because of averaging over both barren and albite-spodumene pegmatites. Namely, the Li_2O contents at the Tochka site were reported to be 0.033 wt.% for the Western Fm. and 0.063 wt.% for the Central Fm., but flame photometry showed higher values in a range of 0.219 to 1.132%. The low average Li contents rather represent the bulk composition of mixed mineral assemblages in the pegmatites.

The methods of flame photometry and semi-quantitative spectral analyses used earlier failed to ensure sufficient analytical quality. Thus, the results call for revision on the basis of ICP-MS and AES data for the Tochka albite-spodumene pegmatites, which give 0.22 to 2.87 wt.% Li_2O. This range is comparable with the respective contents in the economic deposits of the Kalba-Narym zone (0.306 wt.% at Yubileinoye, 0.119 wt.% at Bakennoye, 0.76 wt.% at Akhmetkino) and in other countries (up to 2.9 wt.% at Green Bushes in Australia; 1.06 wt.% at Vishnevskoye in Russia, etc.) [4, 14, 16].

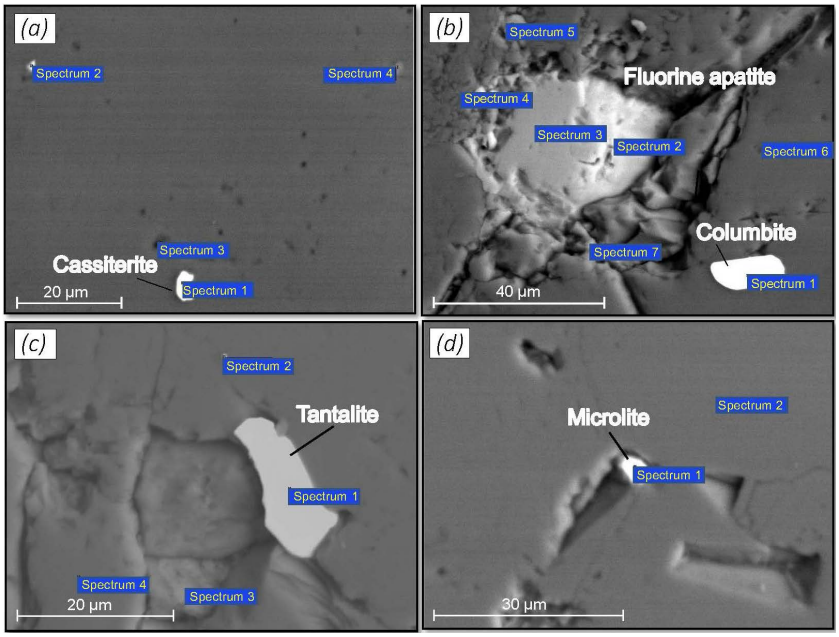

Figure 5 - Mineral microinclusions in albite-spodumene pegmatites from Tochka area.

Conclusion. Main types of mineralization in East Kazakhstan, mostly located within the Kalba-Narym granitoid belt, formed during the Late Paleozoic postcollisional events. Of special importance are rare-metal pegmatite deposits (Ta, Nb, Be, Li, Cs, Sn) related to the Kalba granites (P_1). However, a number of deposits operated previously by the Belgorod Mining and Processing Works (Bakennoye, Yubileinoe, Belaya Gora, etc.) have been tied up. Originally, the mining was targeted at Ta and Sn resources while other components, including Li, went to tailings. Currently, the interest to rare-metal pegmatites as a resource of lithium has been rekindled with growing demand for Li in the world markets.

Rare-metal mineralization developed mainly in the heavily deformed Central Kalba block in the conditions of tectonic activity. Li-bearing rocks are mostly located in the Ognevo-Bakennoye, Asubulak, and Belogorsk-Baimurza ore fields controlled by regional-scale W-E faults. Among these, albite-spodumene pegmatites are the youngest rocks occurring in the upper part of the ore zone. They are as rich in unique mineral species as world-known pegmatite deposits like Koktoay, Bernic Lake, Zimbabwe, etc. [17-22], though having lesser extent of mineralization, for different reasons.

The NW Karagoin-Saryozek ore zone in the southwestern flank of the Kalba-Narym rare-metal belt accommodates orebodies with secondary rare-metal mineralization (Ta, Nb, Be, Li, etc.), which are associated with small intrusions and dikes of the Kunush complex. [3, 4]. Economic potential can be expected from albite-spodumene pegmatites in supra-intrusion zones, offshoots, and staircase-like veins in small plagiogranite intrusions (Akhmetkino, Tochka, Aldai, Lukon, Novo-Saryozek, etc.). The mineralization can be traced from the presence of albite, cleavelandite, cymatolite, tantalite-columbite, and other indicator minerals. New SEM data for these pegmatites reveal relatively high lithium contents (>1 wt.% LiO_2). The albite-spodumene pegmatite bodies are worth further investigation for potential Li resources.

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ҚАЛБА-НАРЫН АЙМАҒЫНЫҢ (ШЫҒЫС ҚАЗАҚСТАН) ЛИТИЙЛІ ПЕГМАТИТТЕРІН БОЛЖАУ ЖӘНЕ БАҒАЛАУ ӘДІСТЕМЕСІ

Аннотация. Мақалада Шығыс Қазақстандағы Қалба-Нарым аймағының литийлі пегматиттерін қалыптастыру ерекшеліктері, болжау және бағалау критерийлері қарастырылады. Пермь уақытының коллизиядан кейінгі (орогендік) геодинамикалық жағдайында қалыптасқан Қалба-Нарым белдеуінің гранитоидтарымен сирек кездесетін металл кен орындарының (Ta, Nb, Be, Li, Cs, Sn, W, TR) жетекші түрлерінің құрылымдық-генетикалық байланысы атап өтіледі. Геологиялық-генетикалық модель басты сирек металды пегматитті кен орындарының (Бакенное, Юбилейное және т.б.) төменгі плюмазитті агпаиттілікпен және орташа негізділікпен натрий-калий сериясының қалыпты қатарындағы Қалба кешенінің граниттерімен (285 млн. жыл) кеңістік-генетикалық байланысын көрсетеді, аймақтық кен колоннасының жоғарғы бөлігінде құрамында сподумен және цезий бар пегматиттер орналасуы мен олигоклаз-микроклиннен бастап (кенді емес) микроклин-альбит және альбит (кенді) дейінгі минералдық кешендерінің кезеңдік дамуын көрсетеді. Пегматит өрістерінің орналасуында орогендік сатыға белсендірілген ежелгі құрылыстың аймақтық ендік ақауларының регматикалық жүйесіне жетекші рөл беріледі. Типоморфты бірегей минералдар және сирек металды пегматит түзілуінің геохимиялық индикатор-элементтері (клевеландит, лепидолит, сподумен, поллуцит, түрлі-түсті турмалиндер, иксиолит және т.б.) келтіріледі. Дәстүрлі гранит пегматит кен орындарынан басқа, құрылымдық-литологиялық тұзақтардың (Ахметкино, Точка, Алдай және т.б.) маңызы болған кунуш кешенінің (305 млн. жыл) бұрынғы плагиограниттерімен және дайкаларымен байланыстыратын альбит-сподумен салынған минералдануымен (Sn, Ta, Li) литийлі пегматиттердің перспективалы түрі ерекшеленеді. Кенденуіңің индикатор-минералдары: альбит, клевеландит, сподумен, циматолит, танталит-колумбит. Бұл нысандар литий шикізатының қосымша көзі ретінде қарастырылады және қосымша зерттеуді қажет етеді.

Түйінді сөздер: Қалба-Нарым аймағы, сирек металдар, граниттер, плагиограниттер, пегматиттер, литий шикізаты, болжау.

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К МЕТОДИКЕ ПРОГНОЗИРОВАНИЯ И ОЦЕНКИ ЛИТИЕНОСНЫХ ПЕГМАТИТОВ КАЛБА-НАРЫМСКОЙ ЗОНЫ (ВОСТОЧНЫЙ КАЗАХСТАН)

Аннотация. Рассматриваются особенности формирования, критерии прогнозирования и оценки литиеносных пегматитов Калба-Нарымской зоны Восточного Казахстана. Подчеркивается структурно-генетическая связь ведущих типов редкометалльных месторождений (Ta, Nb, Be, Li, Cs, Sn, W, TR) с гранитоидами Калба-Нарымского пояса, сформированными в постколлизионной (орогенной) геодинамической обстановке пермского времени. Геолого-генетическая модель отражает пространственно-генетическую связь главных редкометалльных пегматитовых месторождений (Бакенное, Юбилейное и др.) с гранитами калбинского комплекса (285 млн. лет) нормального ряда натриево-калиевой серии, низкоплюмазитовой агпаитности и умеренной основности, стадийное развитие минеральных комплексов от олигоклаз-микроклинового (безрудного) до микроклин-альбитового и альбитового (рудных) с размещением сподуменсодержащих и цезиеносных пегматитов в верхней части зональной рудной колонны. В размещении пегматитовых полей ведущая роль придается

регматической системе региональных широтных разломов древнего заложения, активизированных в орогенную стадию. Приводятся типоморфные уникальные минералы и геохимические элементы-индикаторы редкометалльного пегматитообразования (клевеландит, лепидолит, сподумен, поллуцит, цветные турмалины, иксиолит и др.). Кроме традиционных гранитных пегматитовых месторождений, выделяется перспективный тип литиеносных пегматитов с наложенной альбит-сподуменовой минерализацией (Sn, Ta, Li), ассоциирующих с более ранними плагиогранитами и дайками кунушского комплекса (305 млн. лет), которые имели значение структурно-литологических ловушек (Ахметкино, Точка, Алдай и др.). Минералы-индикаторы оруденения: альбит, клевеландит, сподумен, циматолит, танталит-колумбит. Эти объекты рассматриваются в качестве дополнительного источника литиевого сырья и заслуживают дополнительного изучения.

Ключевые слова: Калба-Нарымская зона, редкие металлы, граниты, плагиограниты, пегматиты, литиевое сырье, прогнозирование.

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