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Lithium capacity of Kazakhstan mineral resource base

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Abstract. Relevance. Weak knowledge of the territory of the Republic of Kazakhstan on lithium raw materials previously mined in the East Kazakhstan region. **Aim.** To study lithium raw material base in the Republic of Kazakhstan and prospects for the extraction of lithium raw materials. **Methods.** Content analysis of all information on the subject of the mineral resource base of lithium in the Republic of Kazakhstan. **Results.** Within the Republic of Kazakhstan, ore deposits of scapolite pegmatites and lithium-bearing greisens-hydrothermal growths are known along alkaline granites. Residual lithium reserves from previously developed rare metal deposits that are equivalent to 36.3 thousand tons of Li₂O, predicted resources of known lithium occurrences are estimated at 140 thousand tons of Li₂O. It is possible to develop known rare metal deposits with the extraction of tantalum, niobium, beryllium and associated extraction of spodumene concentrate. GRK «Ognevsky Mining and Processing Plant» is already planning to put back to mining of tantalum and beryl (with the associated extraction of spodumene concentrate – up to 2.5 thousand tons/year) at the Bakenoe deposit and processing the resulting ore concentrates at the operating Ulba metallurgical plant of Kazatomprom. With regard to lithium-bearing hydro-mineral resources of the Republic of Kazakhstan, the situation is more complicated, due to the data limitations on the completeness of formation water testing and the reliability of data on surface waters of stagnant lakes. Such oil and gas fields as Karachaganak (up to 196 mg/l Li₂O), Kolkuduk (up to 130 mg/l Li₂O), Teplovskoe (up to 82.5 mg/l), Urikhtau (up to 52 mg/l) and Western Opak (up to 45 mg/l) are known for high concentration of lithium in formation waters. First two deposits are ready for oil and gas development and production with an annual extraction of up to 1 thousand tons of lithium carbonate. With regard to the lithium content of stagnant lakes of the Republic of Kazakhstan, it should be noted almost total lack of reliable information on sampling their surface waters. Given the fact of finding industrially significant lithium-bearing hydro-mineral lake deposits in adjacent regions of China and Mongolia, it is necessary to intensify the thematic works to assess the lithium content of endorheic lakes throughout the Republic of Kazakhstan, with sampling not only of surface waters, but also of natural brine, lake mud, saline clayey rocks of solonchaks and takyrs.

Keywords: strategic raw materials, lithium, spodumene pegmatites, rare metal greisen-hydrothermalite formations, hydromineral deposits, Republic of Kazakhstan

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Литиевый потенциал минерально-сырьевой базы Республики Казахстан

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Аннотация. Актуальность работы обусловлена слабой изученностью территории Республики Казахстан на литиевое сырье, ранее добываемое в Восточно-Казахстанской области. **Цель:** изучение сырьевой базы лития Республики Казахстан и перспектив добычи литиевого сырья. **Методы:** контент-анализ всей информации по тематике минерально-сырьевой базы лития Республики Казахстан. **Результаты.** В пределах Республики Казахстан известны рудные месторождения скаполитовых пегматитов и литиеносных грейзен-гидротермальных образований по щелочным гранитам. Остаточные запасы литиевого сырья разрабатываемых ранее редкометалльных месторождений составляют 36,3 тыс. т Li₂O, прогнозные ресурсы известных литиевых проявлений оцениваются в 140 тыс. т Li₂O. Возможна разработка известных редкометалльных месторождений с добычей тантала, ниобия, бериллия и попутным извлечением сподуменового концентрата. ГРК «Огневский ГОК» уже планирует работы по возобновлению добычи тантала и берилла (с попутным извлечением сподуменового концентрата – до 2,5 тыс. т/год) на Бакенном месторождении и переработкой полученных рудных концентратов на действующем Ульбинском металлургическом заводе Казатомпрома. В отношении литиеносных гидроминеральных ресурсов Республики Казахстан ситуация более сложная ввиду ограниченности данных опробования околонефтяных вод и достоверности данных поверхностных вод бессточных озер. Известны высокие концентрации лития в околонефтяных водах нефтегазовых месторождений Карачаганак (до 196 мг/л Li₂O), Колькудук (до 130 мг/л Li₂O), Тепловское (до 82,5 мг/л), Урихтау (до 52 мг/л) и Западный Опак (до 45 мг/л), на первых двух возможна организация промыслов с годовым извлечением до 1 тыс. т карбоната лития. В отношении литиеносности бессточных озер Республики Казахстан следует отметить практически полное отсутствие достоверных данных опробования их поверхностных вод. Учитывая факт обнаружения промышленно значимых литиеносных гидроминеральных озерных месторождений в смежных районах Китая и Монголии, следует активизировать тематические работы по оценке литиеносности бессточных озер на всей территории Республики Казахстан с опробованием не только поверхностных вод, но и придонной рапы, ила озер, засоленных глинистых пород солончаков и такыров.

Ключевые слова: стратегическое сырье, литий, сподуменовые пегматиты, редкометалльные грейзено-гидротермалитовые образования, гидроминеральные месторождения, Республика Казахстан

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Introduction

Lithium raw materials are used to ensure the production of lithium products for the aluminum industry (in the alumina electrolysis, aluminum alloying) [1–3], in nuclear power engineering (coolant, hydrogen accumulation) [4–6], in glass ceramics (lithium metasilicates) [7–9], in lubricants [10–11], in electric batteries (electrolytes and anodes) [12–15]. The latter usage of lithium products is the fastest growing in terms of consumption [16–18].

Global lithium consumption in the early 1990s was 9–10 thousand tons/year of 100% Li, followed by a smooth increase in consumption to 26 thousand tons of 100% Li in 2015. Then there has been an explosive increase in lithium product demand, primarily for the production of electric batteries up to 180 thousand tons of 100% Li by 2023 [8, 11, 17–20]. The commodity flows of lithium raw materials from producing countries to their consumers have changed [18–20], new suppliers

have appeared, new lithium mining and exploration projects for these raw materials are being financed. The resumption of lithium raw materials production in the Republic of Kazakhstan is also becoming relevant.

Manifestations of lithium mineral raw materials were recorded on the territory of the Republic of Kazakhstan for carrying out geological exploration in the 1950s and 1970s. However, due to the presence of an operating mining production at the large and rich Zavitskiy deposit of spodumene pegmatites in Russia [21] relatively lithium-poor rare metal deposits of the Irtysh province [22] at that time were of interest only for the extraction of tantalum and tin. Lithium mineralization manifestations and lithium-containing groundwaters in the territory of the Republic of Kazakhstan were only recorded and not studied further. The explosive growth of the world consumption of lithium products in the manufacture of electric batteries, which began in 2015 [23], led to a significant increase in average annual prices for raw lithium carbonate from 6.5 USD/kg in 2015 to 37.0 USD/kg in 2022 [24]. As a result, interest in investment projects of exploration and extraction of lithium raw materials with a reassessment of their technical and economic indicators such as revenue and profitability has resumed. So, several issues focused on the reevaluation of the state of the lithium raw material base of the Republic of Kazakhstan in the new economic conditions are overdue.

Methods

The data of lithium ore mineralization findings on geological exploration for rare metal raw materials in the territory of the Republic of Kazakhstan for previous years, laboratory analyses of underground industrial and formation waters, surface waters of lakes, as well as factual and analytical information in literary sources devoted to the mineral resource base of lithium of the Republic of Kazakhstan were collected. The information was verified from the standpoint of reliability and generalized throughout the country.

Mineral resource base of lithium raw materials of the Republic of Kazakhstan

Deposits and manifestations of lithium on the territory of the Republic of Kazakhstan are represented by two types of raw materials – ore and hydromineral. They differ in technologies of minerals processing and logistics of location.

Lithium ore mineralization on the territory of the Republic of Kazakhstan is represented by two geological types – spodumene-containing rare-metal pegmatites and lithium-bearing greisenized alkaline granites [25], deposits and manifestations of which are concentrated within the Irtysh rare-metal zone [22] (Fig. 1).

Rare-metal pegmatites are concentrated in the Kolba-Narym ore zone (belt) within the Karagoin-Saryozek, Asubulak and Ognevsky pegmatite fields

[22, 26, 27]. At the Bakennoe, Yubileynoe, Verkhne-Baymurzinskoe, and Akhmetkino fields (Fig. 1), lithium raw materials were considered as a passing component when calculating reserves. Bakennoe deposits (residual reserves of 8.9 thousand tons of Li_2O with an average content of 0.119% Li_2O), Yubileynoe, Belaya Gora, Verkhne-Baimurzinskoe and Kwartsevoe were developed by the Belogorsky Mining and Processing Plant for tantalum-niobium, tin and beryllium raw materials in the 1950s and 1990s, the associated spodumene was not extracted during ore enrichment. As a result, lithium-bearing technogenic formations, including 15.8 thousand tons of Li_2O with a content of 0.28–0.32% Li_2O , accumulated in the tailings dumps of the processing plants of Belogorsky GOK, and another 16 thousand tons of Li_2O with a content of 0.1% Li_2O in the dumps of its mines [28]. At the proved rare metal deposits of pegmatites of the Central Flank, 36.3 thousand tons of residual balance reserves of Li_2O were taken into account, including 23 thousand tons of Li_2O at the reserve Akhmetkino deposit with a content of 0.35% Li_2O [28].

All previously identified rare metal pegmatites of the Kolba-Narym ore zone were found in areas of massive exposure of the Earth's surface (14% of the territory), while the rest areas of the belt are covered by loose sediments, including the cover of the Zaisan Depression. The fund of easily discovered deposits in the region is actually exhausted. That is why geophysical and geochemical research methods, which allow identifying overlapped and uncovered geological objects with ore mineralization, will be effective for searching new rare metal deposits. For example, geochemical anomalies of lithium have been identified in the southeastern extension of the Kolba-Narym ore zone (Cherdoyakskaya, Burabayaskaya, Kalgutinskaya, Karasuiskaya), which can be objects of search and evaluation of new lithium deposits [29], as well as a new area of spodumene pegmatites distribution, a point southwest of the Bakennoe deposit [30].

Manifestations and rare metal deposits *greisen-hydrothermalites formations* with tin, tin-tungsten, used tantalum-niobium and lithium mineralization is denominated throughout the Irtysh rare metal zone. Lithium mineralization in the form of spodumene, zinnwaldite and lepidolite identified for niobium-zirconium-rare earth deposits in the Upper Espe, Karasu and Kokkol river, the manifestation of Azutau and many other ore objects [31] (Fig. 1). Interest in grazenized granites as a promising lithium raw material appeared when the Alakhinskoe field of spodumene granite-porphry in the adjacent region of the Altai mountains (Russia) was discovered [33]. This led to the opening within the Bulb-Narym ore zones Novo-Akhmirovskoe deposits of lithium Topaz granites with zinnwaldite with the author's estimates of inferred resources of lithium raw materials from 32 thousand tons of Li_2O (data Altay geological-geophysical expedition) to 110 kt with Li_2O content of 0.2–0.4% Li_2O [33].

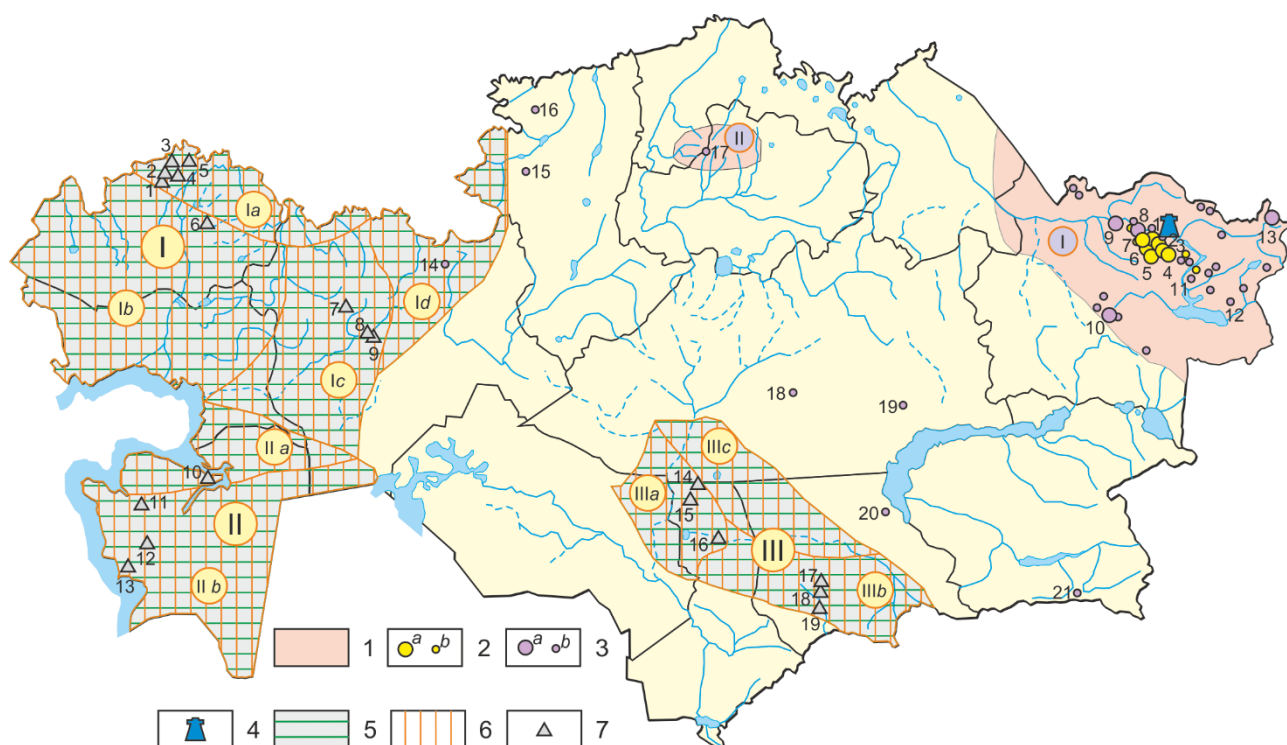


Fig. 1. Lithium mineral raw materials of the Republic of Kazakhstan: 1–3 – ore lithium mineralization: 1 – rare metal provinces (I – Irtysh, II – Kokchetav), 2 – deposits (a) and manifestations (b) of spodumene pegmatites (1 – Bakennoe, 2 – Yubileynoe, 3 – Verkhne-Baymurzinskoe, 4 – Belaya Gora, 5 – Ognevskoe, 6 – Akhmetkino, 7 – Tochka), 3 – deposits (a) and manifestations (b) of rare-metal greisen-hydrothermalite formations (8 – Novo-Akhmirovskoe, 9 – Kvarcevoe, 10 – Verkhnee Espe, 11 – Cherdayak, 12 – Karasu, 13 – Kokkol, 14 – Verkhne-Irgizskoe, 15 – Drozhzhilovskoe, 16 – Smirnovskoe, 17 – Totoguz, 18 – Karaobinskoe, 19 – Zhanet, 20 – Maykol, 21 – Karagailyaktas); 4 – enterprise for processing rare metal raw materials – Ulba Metallurgical Plant, 5–7 – hydromineral raw materials of near-oil waters: 5 – oil and gas provinces (I – Caspian, II – Mangystau-Ustyurt, III – Shu-Sarsu), 6 – oil and gas regions (Ia – North Caspian, Ib – East Caspian, Ic – East-Emben, Id – Aktobe-Priuralskaya, IIa – Buzachin-North-Ustyurt, IIb – South-Mangystau-Ustyurt, IIIa – Kokpansor, IIIb – Moyinkum, IIIc – Tesbulak), 7 – oil and gas fields with lithium-bearing formation waters (1 – Tokarevskoe, 2 – Tsyganovskoe, 3 – Ulyanovskoe, 4 – Gremyachinskoe, 5 – Teplovskoe, 6 – Karachaganak, 7 – Urikhtau, 8 – Kenkiyak, 9 – Zhanazhol, 10 – Komsomolskoe, 11 – Ozen, 12 – Asar, 13 – Bekturly, 14 – Ortalyk, 15 – West Opak, 16 – Pridorozhnoe, 17 – Kolkuduk, 18 – Airakty, 19 – Amangeldy)

Рис. 1. Литиевое минеральное сырье Республики Казахстан: 1–3 – рудная литиевая минерализация: 1 – редкометалльные провинции (I – Прииртышская, II – Кокчетавская), 2 – месторождения (a) и проявления (b) сподуменовых пегматитов (1 – Бакенное, 2 – Юбилейное, 3 – Верхне-Баймурзинское, 4 – Белая Гора, 5 – Огневское, 6 – Ахметкино), 3 – месторождения (a) и проявления (b) редкометалльных грейзено-гидротермалитовых образований (7 – Ново-Ахмировское, 8 – Кварцевое, 9 – Верхнее Эспе, 10 – Чердак, 11 – Карасу, 12 – Кокколь, 13 – Верхне-Иргизское, 14 – Дрожжиловское, 15 – Смирновское, 16 – Тотозу, 17 – Караобинское, 18 – Жанет, 19 – Майколь, 20 – Карагайлыктас); 4 – предприятие по переработке редкометалльного сырья – Ульбинский металлургический завод, 5–7 – гидроминеральное сырье околонефтяных вод: 5 – нефтегазоносные провинции (I – Прикаспийская, II – Мангыстау-Устюртская, III – Шу-Сарсуйская), 6 – нефтегазоносные области (Ia – Северо-Прикаспийская, Ib – Восточно-Прикаспийская, Ic – Восточно-Эмбенская, Id – Актобинско-Приуральская, IIa – Бузачинско-Северо-Устюртская, IIb – Южно-Мангыстау-Устюртская, IIIa – Кокпансорская, IIIb – Мойынкумская, IIIc – Тесбулакская), 7 – нефтегазовые месторождения с литиеносными околонефтяными водами (1 – Токаревское, 2 – Цыгановское, 3 – Ульяновское, 4 – Гремячинское, 5 – Тепловское, 6 – Карачаганак, 7 – Урихтау, 8 – Кенкияк, 9 – Жанажол, 10 – Комсомольское, 11 – Озен, 12 – Асар, 13 – Бектурлы, 14 – Орталык, 15 – Западный Опа, 16 – Придорожное, 17 – Колькудук, 18 – Айрақты, 19 – Амангельды)

In addition to the Irtysh rare metal zone lithium mineralization was recorded on a separate deposits and manifestations of rare metal greisen-hydrothermalites formations: upper-Irgiz in Aktobe region [34], Smirnoff and Druzhilovskiy in Kostanay region [35], Totopos in Akmola region [36], Carabinae and Zhanet

in Karaganda region [37], Mycol in Zhambyl region and Karacailyas in Almaty region [38] (Fig. 1).

Hydromineral lithium raw materials in the territory of the Republic of Kazakhstan are known as part of underground industrial waters and surface waters of saline closed lakes, but have not been evaluated for its industrial value.

Table. Results of testing the formation waters on Li of the oil fields of the Republic of Kazakhstan

Таблица. Результаты опробования околонефтяных вод месторождений Республики Казахстан на литий

Oil and gas taxa/Нефтегазовые таксоны			Li content, mg/l	
Province Провинция	Region Область	Field Месторождение	Содержание Li, мг/л	
Caspian Прикаспийская	North Caspian Северо-Прикаспийская	Токаревское Токаревское	13–39* 25,1	
		Тсыгановское Цыгановское	2–40 20,6	
		Ульяновское Ульяновское	1,5–25,8 13,5	
		Гремуаченское Гремяченское	2,2–30,0 13,4	
		Тепловское Тепловское	27,3–82,5 42,9	
		East Caspian Восточно-Прикаспийская	Карачаганак Карачаганак	5–196
		East-Emben Восточно-Эмбенская	Урихтау/Урихтау	2,5–52,0 29,2
	Кенкияк, Жаназхол Кенкияк, Жанажол		0,4–10,2 5,8	
	Mangystau-Ustyurt Мангыстау-Устыуртская	Buzachin-North-Ustyurt Бузачинско-Северо-Устыуртская	Комсомольское Комсомольское	6,5–18,8 10,7
			Ozen/Озен	4,4–5,6 5,0
South-Mangystau-Ustyurt Южно-Мангыстау-Устыуртская		Асар/Асар	7,0–12,4 9,5	
		Бектурлы/Бектурлы	10,2	
Shu-Sarsu Шу-Сарсуская	Kokpansor Кокпансорская	Орталык/Орталык	30,0	
		West Opak Западный Опак	12–45 28,5	
		Придорожное Придорожное	4,5–10,5 7,5	
	Moyinkum Мойынкумская	Колькудук Колькудук	60–130 77,9	
		Айракты/Айракты	16,0	
		Амангельды Амангельды	12,0–37,5 31,0	
	Tesbulak Тесбулакская	Тесбулак Тесбулакская	30–67	

* – the numerator – the interval of the lithium content, the denominator – the simple average.

* – в числителе – интервал содержаний лития, в знаменателе – среднearифметическое значение.

Lithium-containing industrial waters were recorded during exploratory drilling for oil and gas (Fig. 1, Table), with maximum concentrations observed within the Caspian, Mangystau-Ustyurt and Shu-Sarysu oil and gas provinces [39–43].

It is noteworthy that in the Orenburg oil-bearing region adjacent to Kazakhstan North Caspian region (where lithium concentrations of 2–82 mg/l are recorded), lithium concentrations in formation waters reach in the nearest to Kazakhstan areas: Chinarevskaya – 172 mg, Tashilinskaya – 99 mg/l, Mustaevskaya – 660 mg/l and Irtek – 744 mg/l [44], and in the pro-

duced water treating facility – up to 500 mg/l [45]. This may indicate the lack of representativeness of testing near the oil waters of Kazakhstan oil and gas fields for the detection of an industrially significant hydromineral lithium component.

Because of the relatively low lithium concentrations in near-oil waters, occasionally exceeding 100 mg/l, industrial waters of oil and gas fields were not evaluated for their industrial value.

Manifestations of *potentially lithium-bearing hydromineral surface waters* are a high brine concentration objects: the Aral Sea brine; the brine of salt marshes and drying lakes of the Caspian lowland, the Chu River basin and other arid regions of the Republic of Kazakhstan. There has been no dedicated study to assess the lithium content of surface waters of closed lakes in the territory of the Republic of Kazakhstan. There is scant information based on the results of studies of the Aral Sea brine on the presence of lithium in the closed lakes (up to 65 mg/l) [46] and surface waters of Inder lakes (8.4 mg/l) [47], Arys (up to 6.8 mg/l), Kakshetau [48]. For most lakes of the Republic of Kazakhstan, there is no information on lithium concentration in surface waters.

In the 1970–1990s, mass testing of lithium mineralization in the waters of drainless lakes and brine of salt marshes was carried out in neighboring countries. As a result, lithium-rich lakes were discovered in China, where its industrial extraction was later organized: Taijinyer (203 mg/l Li₂O) and Daitan (161 mg/l Li₂O) in the Caidam intermountain depression, Tsabue (896–1527 mg/l Li₂O) and Dansunzo (430 mg/l Li₂O) on The Tibetan Plateau [49]. Mineralized lakes in Western Mongolia Davsan-Nur (16.5–51.9 mg/l Li₂O) and Takhim-Nur (97.9 mg/l Li₂O) have been identified [50], and industrial lithium extraction has begun on the latter. In Russia, there was a small amount of work to assess the lithiosity of lakes, but due to natural-climatic conditions it was concluded that their detection was hopeless [21].

Processing of lithium raw materials

Earlier, during the development of rare metal raw material deposits in the Irtysh rare metal province, lithium raw materials were not the subject of research for its extraction, despite the high manufacturability of the existing Ulba Metallurgical Plant (Ust-Kamenogorsk, East Kazakhstan region) processing radioactive and rare metal ores with the extraction of commercial products of uranium, thorium, tantalum, niobium and beryllium. In the context of a sharp increase in the price of lithium products after 2015 the question arose about the organization of lithium product production in the Republic of Kazakhstan [28] and in addition to the need for determination of state of the national mineral resource base of lithium, the technical possibilities and difficulties of processing lithium raw materials into marketable products are being considered.

A serious problem is the low efficiency of existing technologies for processing the initial lithium mineral raw materials.

Processing of ore mineral lithium raw materials. Thermal decrepitation enrichment technology is mainly used for the enrichment of spodumene ores, the disadvantage of which is significant technological losses, and it is practically not suitable for lithium-poor ores [51]. It is for poor lithium ores that it is possible to use the lime method of processing unenriched spodumene ores or spodumene-containing tailings of the enrichment of rare metal raw materials to obtain lithium carbonate and cement [52, 53]. Ores of rare metal deposits of the Kolba-Narym belt are complex and, in this case, the most effective methods for obtaining selective concentrates of tantalite, beryl, cassiterite and spodumene can be X-ray radiometric [54], gravity and flotation [55] enrichment methods. Optimized sulfate processing technology is possible for selectively enriched spodumene concentrate [28].

Processing of hydromineral lithium raw materials. Regarding the lithium extraction from hydromineral raw materials, it is on the one hand an easy process (low-energy hydrometallurgy technologies) and on the other hand a complex one (the presence of harmful impurities in the solution that interfere with the extraction of lithium compounds). Currently, in the processing of hydromineral lithium raw materials, solar halurgic technology is used, including natural evaporation of brine and precipitation of lithium-enriched sediment, which is difficult to apply in the relatively cold climate of Kazakhstan [43, 55, 56]. Lithium extraction schemes using extraction, sorption and electrolysis from underground and surface waters with a Li_2O concentration of more than 10 mg/dm^3 are also proposed [57–59]. Cation exchange resins are offered as lithium sorbents, both in protonated and sodium forms [59], aluminum hydroxide and hydrated manganese oxide [60–62], as well as strong acid cationites [63]. At the same time, the problem of exposure to high concentrations of magnesium salts that prevent lithium extraction is also solved. Sorption technologies for extracting lithium from natural solutions have been developed for a long time at the Institute of Solid-State Chemistry and Mechanochemistry of the SB Academy of Sciences of the USSR, but they have found real application not in the CIS, but in the processing of lithium-bearing brines of Lake Davsan-Nur in Mongolia (Chinese company Lan-Ke-Lithium Co., Ltd) [64].

Results and discussion

Against the background of a sharp increase in world prices for lithium products after 2015, the government authorities of the Republic of Kazakhstan set tasks to assess the capabilities of the country's mineral resource complex for the availability and value of mineral re-

sources of lithium raw materials, as well as the possibility of organizing a full cycle of its extraction and processing with the release of commercial lithium products directly in the Republic of Kazakhstan [28, 65].

Full-scale specialized studies on the assessment of lithium resources have not been conducted in the Republic of Kazakhstan before. No work was also carried out to identify new lithium deposits or to determine the significant content of this element as a by-product in the products of processing of other types of mineral raw materials.

The Geological Committee of the Ministry of Industry and Infrastructure Development of the Republic of Kazakhstan plans to study the mineral resource base of rare metals, including lithium, in particular, thematic works on verification of mineral reserves on the balance sheet, assessment of mineral resources of promising territories, financing of prospecting and exploration of the most promising subsurface areas. Nevertheless, the volume and scope of work are still clearly insufficient to quickly solve the creation of a full-cycle industry for the extraction and processing of lithium raw materials.

It is necessary to carry out revision thematic work on known rare metal ore deposits and manifestations (Akhmetkino, Yubileynoe, Ognevskoe, Bakennoe, Karasu, Tochka, Verkhne Espe, Iysor, Biesimas, etc.) [26, 31, 66, 67], as well as prospecting work near them, including those overlain by loose deposits using geochemical and geophysical methods [26, 29, 66, 67]. The subject of the search should be not only spodumene pegmatites (manifestations of Zhatysara, Red Cordon, Urunkhai, Karmen-Kuus, etc.) and zinvaldite-containing albitized granites (Novo-Akhmirovskoe, Apogranite, Muncha, etc.) within the Kolba-Narym rare metal belt, but also the peripheral flanks of the Irtysh rare metal province [38], as well as potentially lithium-bearing muscovite-albite and amazonite-albite granites of the Kokchetav massif [36] and the area around other manifestations of associated lithium mineralization in Aktobe, Kostanay, Karaganda, Zhambyl and Almaty regions.

So far, according to available information, lithium raw materials in rare metal deposits are only a passing component in the composition of complex ores of tantalum, niobium, rare earths, previously of no interest due to small concentrations and low value. Nevertheless, due to changes in the marketable value of lithium products on the world market, it is possible to involve lithium-poor ore formations in operation precisely as an associated mineral, thereby increasing the profitability of processing complex rare metal ores.

Residual reserves of lithium raw materials of rare metal deposits of the Kolba-Narym ore belt in the amount of 36.3 thousand tons of Li_2O are reliably

known, including 23 thousand tons of Li_2O at the previously undeveloped Akhmetkino deposit. The resources of the spodumene in the technogenic deposits of tailings dumps and dumps of the Belogorsky GOK (32 thousand tons of Li_2O) are also considered, and the forecast resources of the Novo-Akhmirovskoe deposit of zinnvaldite-bearing granites (32–110 thousand tons of Li_2O) are estimated.

Currently known objects of lithium-bearing complex rare metal deposits of the Republic of Kazakhstan can be considered as objects of extraction, primarily tantalum, niobium and beryllium with associated extraction of spodumene concentrate. These are the Bakennoe, Ognevskoe, Akhmetkino and Yubileynoe fields, which need to be explored on the flanks and depth. At the Bakennoe field, work is already planned by GRK Ognevsky GOK LLP to resume production of tantalum and beryl with the associated extraction of up to 2.5 thousand tons/year of spodumene concentrate [68, 69]. Processing of the obtained ore concentrates is planned at the existing Ulba Metallurgical plant of Kazatomprom (Ust-Kamenogorsk, East Kazakhstan region).

With the resumption of work at the facilities of the Belogorsky GOK, it is possible to organize the processing of technogenic deposits of tailings dumps and refuse heaps in order to extract tantalite, beryl and spodumene concentrates, with their subsequent processing at the Ulba Ministry of Health of Kazatomprom.

To assess the development possibilities of the Novo-Akhmirovskoe deposit of zinnvaldite-bearing granites, it is required to conduct geological exploration with reserves calculation, as well as technological research on the enrichment of zinnvaldite ores and zinnvaldite processing into commercial lithium products.

With regard to hydromineral resources of the Republic of Kazakhstan, the situation is more complicated, there is clearly insufficient information on the completeness and reliability of testing of near-oil waters and brine of drainless lakes.

The highest concentrations of lithium were recorded in the near-oil waters of the Karachaganak oil and gas fields (up to 196 mg/l Li_2O) in the East Caspian oil and gas region, Kolkuduk (up to 130 mg/l Li_2O) in the Moyinkum region, Teplovskoe (up to 82.5 mg/l) in the North Caspian region, Urikhtau (up to 52 mg/l) in the East Embenskaya region, and the Western Opak (up to 45 mg/l) in the Kokpansorskaya region, however, their testing data are isolated and require verification. The assessment of lithium resources of near-oil waters based on a limited array of sampling data may lead to a formal conclusion that it is hopeless to detect large and rich hydromineral lithium-bearing groundwater sources, at a time when they exist in adjacent oil and gas regions of Russia [44, 45].

Systematic testing of underground waters of oil and gas fields for lithium should be resumed. At the same time, during the audit of near-oil waters of oil and gas fields at operating enterprises, it is necessary first of all to assess the concentration of lithium in the raw water of oil dewatering devices, in which lithium products accumulate 2–5 times higher compared to groundwater. For example, at the Orenburg NGCM, the concentration of lithium reaches 500 mg/l Li_2O , with its contents in near-oil waters 50–100 mg/l [45].

With regard to the lithium content of the closed lakes of the Republic of Kazakhstan, it should be noted that there is almost complete absence of reliable data on testing their waters. Lithium is concentrated in the bottom brine and sorbed in the bottom silt, and when testing the surface waters of lakes, a distorted (underestimated) assessment of their lithium content may be formed. Considering the fact of the discovery of lithium-bearing hydromineral lake deposits in adjacent areas of China and Mongolia, it is necessary to take very seriously the program for studying the lithium-bearing capacity of drainless lakes of the Republic of Kazakhstan. The assessment of the projected lithium resources in the drainless lakes of the Republic of Kazakhstan is still premature due to the lack of available information.

The Geological Committee of the Ministry of Industry and Infrastructure Development of the Republic of Kazakhstan is planning thematic work on assessing the lithicity of drainless lakes as objects with a high concentration of brines, namely: saline clay rocks of Takyr, brine of the Aral Sea, brine of salt marshes and dried or drying lakes of the Caspian lowland, the territory of the Chu River basin and other areas of the Republic of Kazakhstan with characteristic natural and geological conditions of possible formation of hydromineral lithium deposits.

Separately, it should be noted that in the quarry waters of the Zavitsinsky rare metal deposit (Russian Federation), the lithium concentration is 2607–3877 mg/l Li_2O [70] and similar lithium enrichment conditions may occur in mine and quarry waters at the closed Belogorsky GOK in the East Kazakhstan region. This is another possible area for the development of lithium-bearing groundwater in the Republic of Kazakhstan.

New sorption technologies for lithium extraction from natural solutions allow the development of lithium-bearing brines with relatively low lithium concentrations (Davsan-Nur Lake in Mongolia with a concentration of 16.5–51.9 mg/l Li_2O , operated by the Chinese company Lan-Ke-Lithium Co., Ltd [65]) and it is possible to implement it at lithium-bearing hydromineral facilities of the Republic of Kazakhstan.

Conclusion

The leadership of the Republic of Kazakhstan, after a sharp increase in world prices for lithium products,

has set the task of assessing the national mineral resource base of lithium raw materials in order to organize a full cycle of its extraction and processing with the release of commercial lithium products directly in Kazakhstan.

There are ore deposits of scapolite pegmatites and lithium-bearing greisen-hydrothermal formations on alkaline granites within the Republic of Kazakhstan. The residual reserves of lithium raw materials of previously developed rare metal deposits in the amount of 36.3 thousand tons of Li_2O are reliably known, the resources of spodumene in technogenic deposits of tailings (32 thousand tons of Li_2O) are also taken into account, and the authors' estimates of the forecast resources of the Novo-Akhmirovskoe deposit of zinc-bearing granites (32–110 thousand tons of Li_2O) are also given.

The well-known complex rare metal deposits of the Republic of Kazakhstan (Bakennoe, Akhmetkino, Ognevskoe and Yubileynoe) can be considered as objects of extraction, primarily as deposits of tantalum, niobium and beryllium with associated extraction of spodumene concentrate. GRK Ognevsky GOK is already planning to resume production of tantalum and beryl (with the associated extraction of spodumene concentrate – up to 2.5 thousand tons/year) at the Bakennoe deposit and processing of the ore concentrates obtained at the existing Ulba metallurgical plant of Kazatomprom.

With regard to the production of prospecting works for lithium, thematic and revision work is needed to search for spodumene pegmatites and lithium-bearing albitized granites within the Kolba-Narym rare metal belt and on the periphery of the Irtysh rare metal province, as well as lithium-fluoride muscovite-albite and amazonite-albite granites of the Kokchetav massif and other lithium manifestations in Aktobe, Kostanay, Karaganda, Zhambyl and Almaty regions.

With regard to lithium-bearing hydromineral resources of the Republic of Kazakhstan, the situation is more complicated, due to the limited data on the completeness of testing of near-oil waters and the reliability of data on surface waters of drainless lakes.

The highest concentrations of lithium were recorded in the near-oil waters of the Karachaganak oil and gas fields (up to 196 mg/l Li_2O), Kolkuduk (up to 130 mg/l Li_2O), Teplovskoe (up to 82.5 mg/l), Urikhtau (up to 52 mg/l) and Western Opak (up to 45 mg/l), on the first two from them, it is possible to organize fisheries with an annual extraction of up to 1 thousand tons of lithium carbonate. It is also necessary to resume systematic testing of underground waters of oil and gas fields for lithium, including with the testing of sub-standard waters, in order to detect the most lithium-rich underground industrial waters.

With regard to the lithium content of the drainless lakes of the Republic of Kazakhstan, it should be noted that there is almost complete absence of reliable data on testing their surface waters. Considering the fact of the discovery of industrially significant lithium-bearing hydromineral lake deposits in adjacent areas of China and Mongolia, thematic work should be intensified to assess the lithium-bearing capacity of drainless lakes throughout the territory of the Republic of Kazakhstan. When studying them, to test not only surface waters, but bottom brine and silt of lakes, saline clay rocks of salt marshes and takyr. The assessment of the projected lithium resources in the drainless lakes of the Republic of Kazakhstan is still premature due to the lack of available information.

The experience of developing lithium-bearing brines of Davsan-Nur Lake in Mongolia by the Chinese company Lan-Ke-Lithium Co., Ltd with relatively low lithium concentrations (up to 51.9 mg/l Li_2O) shows the possibility of organizing extractive fisheries at lithium-bearing hydromineral facilities of the Republic of Kazakhstan.

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