Prospects and priorities for the reconstruction and development of lithium mining production on the basis of domestic raw materials

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Abstract. The prospects of lithium as a component of new energy are considered. Provides data on the resources of lithium mineral raw materials. Variants of the reconstruction of lithium production facilities in Russia from domestic raw materials are evaluated in order to solve the problem of import substitution. Attention is focused on the choice of objects of priority industrial development and the need to create modern technologies for processing lithium raw materials. It is shown that the restored Zabaikalsk mining and processing plant can be a reliable source of lithium when using new technological solutions for extracting lithium and associated useful components from primary ores and waste of spodumene ores.

Lithium is one of the most demanded rare metals in the modern world by the military and civilian industries. It is concentrated to the maximum extent in the residual products of acid magma differentiation rare-metal granite pegmatites, where it is a mineral-forming and rock-forming rare element. The main carrier of lithium in granite pegmatites is the spodumene mineral \(\text{LiAl}[\text{Si}_2\text{O}_6]\), containing on average 6.5–7.5\% \(\text{Li}_2\text{O}\), although its theoretical content is 8.1\%.

The prevalence and specific properties of lithium are due to its industrial value, as well as the scale of production and use, incommensurate with other rare metals. At present, its global production has exceeded 32.5 thousand tons / year (in terms of metal). The global demand for lithium products was estimated in the period 2015–2020 in 150–300 thousand tons, and by 2025 it is predicted to be 550 thousand tons.

Lithium retains the role of the leading component of nuclear energy and, at the same time, increases the innovative industrial importance as a structure-forming component of the new battery energy: lithium-ion batteries determine the increasing worldwide consumption of lithium in energy production and storage systems [1, 2].

The fastest growing in recent years in the foreign world has been the consumption of lithium in the energy sector of the economy in the production of lithium-ion batteries for hybrid and electric cars, the release of which on the market is constantly growing.

In Japan, a 60 MWh lithium-ion battery has been created for storing and distributing electricity from solar panels at a cost of $ 204 million [1]. The replacement of internal combustion engines with
electric ones and the creation of large-scale energy storage systems for renewable energy sources will be the basis of the IV industrial revolution. This will strengthen the global role of lithium as a strategically important component of new industrial energy.

In Russia, the most capacious consumers of lithium products are enterprises that use Li-Al and Li-Mg alloys in aviation and aerospace technology. In this direction, Russia is traditionally ahead of other countries. In particular, the MiG-29M fighter was created using Li-Al alloy 1420 containing 2% lithium, which made it possible to reduce its weight by 20%. Weldable Li-Al alloy 1460, containing 2–2.4% Li, has been created for fuel tanks of new-generation aircraft using liquid natural gas. It is distinguished by its high strength in the temperature range +20–253 °C. Its use reduces the weight of the structure by 25–30%. The alloys under consideration were used in the creation of the cabin module of the space shuttle "Buran".

In 1990, the USSR ranked second in the world after the United States in terms of lithium production 1.4 thousand tons / year in terms of metal. However, world consumption at that time already amounted to 7.6–8.2 thousand tons, and subsequently it continuously increased by 30% annually only due to the growth in the production of lithium-ion batteries.

In Russia, under the conditions of the "transitional period", a paradoxical situation has developed: the presence of industries producing final products, and the absence of mining enterprises that provide these industries with their own lithium raw materials. If the country has its own mineral resource base of spodumene ores in pegmatite deposits, corresponding in terms of reserves and quality to average world standards. The situation that has developed during the 30-year "transitional period" seems unacceptable from both geo-economic and geopolitical positions. Of the largest deposits of rare-metal granite pegmatites with approved reserves of lithium and associated Ta (with Nb), Cs (with Rb), Be and Sn, which were explored in detail in the 1960s–1970s, not a single one was put into operation.

The world reserves of lithium are estimated by the US Geological Survey (USGS) at more than 14 million tons, and resources in the range of 40-60 million tons. Most of the reserves (76%) are represented by brines and brine of drainless salt lakes ("salar") with contents 0.06–0.5% Li2O. They are explored and exploited in the highland (Andes) arid regions of Chile, Argentina, Bolivia. Therefore, the modern world production of lithium products is based on the processing of hydromineral raw materials from the richest brines of lakes in the Atacama Desert in South America. The cost of their processing and the production of lithium carbonate is significantly lower than the processing of spodumene raw materials.

Cuprus Foot Minerals (USA), FMC (USA), Minsal SA (Chile) and SQM (Chile), which use sodium chloride brines as a raw material source, are recognized as leaders in the production of lithium products from lithium-bearing hydromineral raw materials. type of salar of the Atacama desert.

Inexhaustible reserves of hydromineral raw materials with a high lithium content are also available on the Eurasian continent in the form of lacustrine brines of magnesium chloride type in the Qinghai province (China) and deep brines of calcium chloride type in the Irkutsk region, Krasnoyarsk Territory and the Republic of Sakha (Russia). The concentrations of useful components in them are shown in Table 1.

However, due to the high content of calcium and magnesium, these types of raw materials are unconventional. Attempts to process them into lithium products by reagent methods, which have been repeatedly carried out by Russian and Chinese specialists, have not yet led to positive results.

At the same time, rare metal pegmatite raw materials in a number of foreign countries continue to remain not only competitive, but also the leading raw material source of lithium [2].

Table 1. Average contents of useful components in brines in promising areas of the halogen-carbonate formation in the south of the Siberian platform [1].

| Site         | Average content of components, mg / L |
|--------------|---------------------------------------|
|              | Li         | Mg         | Sr         | Br         | B      | I       |
| Znamensky    | 366        | 28000      | 2770       | 10620      | 92.4   | –       |
| Kosmichesky  | –          | 12000      | –          | 5130       | –      | –       |
In the USSR, as the only source of lithium from 1941 to 1997. The Zavitinskoe deposit of spodumene pegmatites in the Eastern Transbaikalia was exploited by the open-cut method. The ore was enriched at the Zabaikalsky GOK plant. It included decryption of spodumene at a temperature of 1100 °C with its transfer to the β-modification and subsequent flotation of the ore mass with the release of spodumene concentrate. Over 55 years of operation, the average lithium content in the ore has decreased from 0.69% to 0.5% and 0.3% in the residual off-balance raw materials and mining and processing waste. No analogues of processing such poor spodumene raw material are known abroad. The enterprise, created to meet the needs of the special services during the period of the forced participation of the USSR in the nuclear arms race, in the conditions of the creation of a new Russian economy, was closed as unprofitable.

The spodumene concentrate was processed by the Krasnoyarsk Chemical Plant using lime technology for lithium hydroxide with the release in 1990–1992. 1450–1650 tons / year and metallic lithium in volumes of 30–50 tons / year. This plant, according to specialists from the Institute of Mineralogy and Geochemistry of Rare Elements, controlled half of the sales of lithium in Russia, and then began to process imported raw materials, exporting part of its products. The Novosibirsk plant of chemical concentrates specializes in deep purification of lithium from impurities and produces metal products, lithium batteries, Lidos disinfectant, etc. at a capacity of ~ 1 thousand tons / year in terms of metal. Both plants are part of the TVEL concern.

On April 21, 2016, the Committee of the Council of Federations on Agrarian and Food Policy and Environmental Management held a seminar-meeting "On Legislative Regulation of the Extraction of Rare Metals and Losses in the Primary Processing of Solid Minerals", which was attended by representatives of the Rare Zemli magazine. In the materials of the meeting, in particular, it was noted that from the Government program № 328 of April 15, 2014 "Development of industry and increasing its competitiveness" within the framework of the rare earth subprogram № 15, "for some unknown reason, such important rare elements as lithium and beryllium dropped out." The unsuccessful implementation experience in 2002–2005 was also mentioned. Federal target program "LIBTON" (lithium, beryllium, tantalum, tin, niobium), the implementation of which in Eastern Transbaikalia was planned under the auspices of "Rosatom". This program encouraged many specialists in rare metal, but did not take place due to a combination of internal and external reasons due to the lack of a state strategy for the development of domestic rare metal deposits.

As a partial compensation for the cessation of production of lithium raw materials, Russia is importing chemical lithium products from hydromineral raw materials from Chile and Argentina. It is also proposed to resume the processing of Transbaikal off-balance raw materials and production wastes with a content of 0.2–0.3% Li₂O. All these options are still regarded as manifestations of private initiatives without the necessary feasibility studies and the creation of pilot projects.

The authors at the Joint Institute for High Temperatures of the Russian Academy of Sciences are developing fundamentally new pyrochemical methods for direct processing of spodumene concentrates (RFBR grant № 20-08-00017). To date, melting spodumene with additions of sulfates and fluorides at a technologically acceptable temperature (≥1000°C) has proven the possibility of using the immiscibility (liquation) of the silicate and salt parts of the melt with subsequent leaching of lithium fluoride as a particularly valuable chemical product with a yield of 60%. The treatment of spodumene with sodium acetate followed by reagent sintering at T = 220–240°C also obtained lithium fluoride with a yield of 85–90%. These results of exploratory laboratory and technological experiments make it possible to count on the creation of an innovative physicochemical technology for
processing spodumene concentrates and ores with low lithium contents, similar to the wastes of the former Zabaikalsk mining and processing plant.

An analysis of the state of the resource base of the Zavitinskoye spodumene deposit in Transbaikalia showed that at present, in its subsoil, in the contours of open mining operations there are approximately 210 thousand tons of balance reserves with an average content of 0.5–0.6% Li₂O and 51 thousand tons of off-balance ores located outside of them.

As a result of expeditionary and office work carried out in 2018–2019, laboratory of geochemistry and ore genesis INREK SB RAS, it was found that in the spodumene pegmatites of the Zavitinskoye deposit in the veins exposed in the side of the quarry and stored in ores stored in warehouses, industrial concentrations of lithium in spodumene, as well as columbite-tantalite, cassiterite and beryl, will be contained. The content of lithium and other components is quite high (table 2). The lithium content in terms of Li₂O is in the range of 1.95–5.98%, which is significantly higher than the average for the deposit.

**Table 2.** The content of main industrial components in spodumene pegmatite of the Zavitinskoye deposit.

| Sample number | Element and its content, wt % |
|---------------|-------------------------------|
|               | Li  | Be  | Cs  | Rb  | Ta  | Nb  | Sn  |
| ZV-1/1        | 0.949 | 0.0062 | 0.0225 | 0.0137 | 0.0023 | 0.0089 | 0.0057 |
| ZV-1/4        | 1.19  | 0.05  | 0.0092 | 0.135  | 0.004  | 0.0039 | 0.0068 |
| ZV-2/1        | 1.39  | 0.0006 | 0.0030 | 0.0227 | 0.0029 | 0.0184 | 0.0053 |
| ZV-2/2        | 1.34  | 0.0003 | 0.0032 | 0.0278 | 0.0014 | 0.0090 | 0.0055 |
| ZV-2/3        | 0.837 | 0.0057 | 0.0028 | 0.0201 | 0.0016 | 0.0074 | 0.0043 |
| ZV-3/1        | 0.933 | 0.0038 | 0.0030 | 0.0316 | 0.0014 | 0.0081 | 0.0038 |
| ZV-3/2        | 1.16  | 0.06  | 0.0081 | 0.0204 | 0.0008 | 0.0044 | 0.0032 |
| ZV-3/3        | 0.454 | 0.07  | 0.0059 | 0.117  | 0.0008 | 0.00570 | 0.0048 |

At the same time, the content of rubidium is quite high, which, subject to the development of an economically acceptable extraction technology, may be of industrial interest. A possible cost-effective source of lithium is the tailings of spodumene ores, accumulated from 1940 to 1993. The mass of technogenic raw materials is 11,760 thousand tons. As a result of sampling and analysis of spodumene ore dressing wastes, the data given in Table 3 were obtained.

**Table 3.** The average content of chemical elements in the tailing dump (technosoil) of the Zavitinskoye deposit.

| Sample number | Chemical element and its content, ppm, ppm |
|---------------|------------------------------------------|
|               | Li  | Be  | Sc  | Ta  | Nb  | Th  | U  | Sn  | La  |
| T.1 x         | 892 | 78.7 | 405 | 3.2 | 20.7 | 43.2 | 5.5 | 2.6 | 26.7 | 8.4 |
| T.2 x         | 581 | 36  | 369 | 3.2 | 14  | 31.4 | 5.6 | 3.1 | 21.5 | 13.4 |
| T.3 x         | 1230 | 100 | 588 | 0.9 | 40.3 | 80.4 | 4.1 | 2.6 | 40.4 | 2.9 |
| T.4 x         | 637 | 52.1 | 779 | 0.7 | 21  | 47.3 | 3.1 | 9.3 | 35  | 3.1 |
| T.5 x         | 613 | 39.9 | 762 | 0.9 | 26.8 | 54.9 | 3.8 | 4.7 | 40.2 | 1.9 |
| T.6 x         | 744 | 26.2 | 735 | 0.6 | 42  | 99.1 | 3.2 | 1.6 | 32.2 | 3.9 |

Analysis of the table 3 shows that the content of the main industrial ore element lithium in the concentration waste is quite high (581–1230 ppm or 0.25–0.53% Li₂O). They can reach values only 2–4 times lower in the original ores. The content of beryllium is also quite high (26.6–100 ppm), 6–25 times higher than the clarke. The same applies to tantalum and tin. Therefore, if it is necessary to recycle these production wastes, it is possible to profitably extract all these chemical elements. The
content of uranium and thorium in enrichment wastes is comparable to Clarke, therefore the probability of their negative impact on the environment is small.

In the loose sediments of the western and eastern edges of the sedimentation tank, high arsenic contents (577–1120 ppm) were revealed, which is associated with the superposition of sulfide mineralization on the pegmatites and spodumene of the Zavitinsky deposit. Along with it, the same samples contain antimony (47–4180 ppm) and lead (21.9–54.45 ppm). A feature of the loose sediments of the tailings of the Zabaikalsk mining and processing plant is their enrichment in thallium (1.51–5.49 ppm).

In the warehouses of the so-called off-balance ores there are about 9,029 thousand tons of ore with an average lithium oxide content of 0.55–0.60%, which is about 50 thousand tons of lithium oxide. They are mined and therefore the cost of obtaining the finished product will be significantly lower.

Apart from the Zavitinskoye deposit in Russia, lithium sources in spodumene ores can be 4 ore regions. The most important of them are the group of deposits of the Kola Peninsula and Kalarisky District in Northern Transbaikalia. The pegmatites of the Kola ore region are explored and contain 35% of the Russian lithium reserves approved by the State Reserves Committee with an average grade of 1–1.25% Li2O in the presence of rich blocks with contents ≥2.5% in the ore bodies. These reserves are localized in 3 deposits of the 30-km zone of the Voronya-Kolmozerskaya vein zone of rare-metal pegmatites. It extends in the NW direction.

Voronya-Kolmozerskaya zone of distribution of rare-metal granite pegmatites includes three deposits. The largest Kolmozerskoe is located in the southeast of the zone. It contains 23.7% of Russian lithium reserves with an average content of 1.14% Li2O.

At 60 km to the northwest, the Polmostundrovskoye field, average in terms of reserves, with a Li2O content of 1.25% has been explored. It is located closest to the river. Voronya and the dam of the Serebryanskaya hydroelectric power station. The Voronyetundrovskoye field (or Vasin-Mylk) is located 2 km from it to the southeast. It is small in terms of lithium reserves at 0.9% Li2O, but rich in accompanying cesium (0.4% Cs2O) with rubidium, tantalum (0.3% Ta2O) with niobium and beryllium. The reserves of all three fields have been calculated and approved.

The rare-metal pegmatites of Kolmozero and Polmostundra are represented by essentially lithium, microcline-sodumene-albite non-zonal veins with accompanying minerals Ta, Nb, and Be. The Vasin-Mylk deposit is represented by classic polyzonal veins (Li–Cs–Ta) and complex rich ores.

All these deposits can be developed by open pit mining to a depth of 100 m (Kolmozerskoe 65% of reserves). With the productivity of the future mine of 750 thousand tons of ore per year, the production of lithium (spodumene) concentrate can provide the output of 2 thousand tons of Li2O, which is 50% of the forecasted priority demand of Russia. Along the way, 30 tons of Ta2O5, 30 tons of Nb2O5, 50 tons of BeO can be obtained.

The enrichment technology of the Kola rare-metal pegmatite ores with the separation of spodumene concentrates and all associated concentrates was developed in the 1960s and needs to be re-evaluated from modern positions, i.e. in the directions of creation of processing and processing schemes with an emphasis on direct methods of deep processing of mineral concentrates and rich varieties of ores.

The industrial development of lithium deposits in the Voronya-Kolmozero zone, taking into account the complexity of rare-metal pegmatite ores and the high demand for such accompanying rare metals as tantalum, cesium and rubidium, is oriented towards design in this area of the Murmansk region. a large specialized rare metal cluster, whose activities for many decades can satisfy Russia's needs for leading strategic products.

Logistic accessibility and infrastructure support of the Kola lithium deposits are determined by the relative proximity to the Oktyabrskaya railway and the city of Murmansk. Nearby, in the area of the village of Tumanny, there is a Serebryanskaya hydroelectric power station on the river. Voronya and there is a power line connected to the railway and the highway. But the area where the deposits are located does not have transport communications and requires the construction of local roads as a determining infrastructural factor.
Another equally important source of lithium can be the Olondinskoe pegmatite field in the Kalarsky district of the Trans-Baikal Territory, located in close proximity to the Baikal-Amur Mainline and power lines with resources of about 110 million tons of spodumene ores [4].

The East Siberian lithium deposits in the Eastern Sayan Mountains and the South-East of Tyva are located, in contrast to the above, in hard-to-reach and undeveloped mountain taiga regions.

From the considered positions, it is recommended to draw up an R&D and R&D Program, a comparative feasibility study of the priority of the industrial development of Russian lithium deposits for the prospect of 2030 and the creation of an interdepartmental team of performers under the auspices of the Russian Academy of Sciences and Rostec.

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