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To cite this article: L N Morozova 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **302** 012047

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The Kolmozero deposit: a unique Li source in the European Arctic of Russia

L N Morozova

Geological Institute of the Kola Science Centre of the Russian Academy of Sciences, Apatity, Russia

morozova@geoksc.apatity.ru

Abstract. Tens to hundreds of pegmatite veins can accumulate within a pegmatite field. However, only a limited number of pegmatite veins can be practically valued. Hence, there is a problem of identifying rare metal pegmatites at the stage of geological prospecting and appraisal. Geochemical indicators are most impartial, reproducible and highly informative for these purposes. The Kolmozero lithium deposit is located in the Neoarchaeon metagabbro-anorthozites of the Patchemvareksky massif in the junction zone of the two major regional structures of the Archaean age, i.e. the Murmansk block and the Kolmozero-Voronya Greenstone Belt of the Kola Peninsula. It is shown that pegmatites of the Kolmozero deposit with industrially valued rare metal mineralization (Be, Ta, Nb, Li) are poor in large-ion lithophile elements (LILE) (Sr and Ba) and in high charged high field strength elements (HFSE) (REE, Th, Zr). They also have low values of fractionation indexes – Mg/Li and Zr/Hf. The defined geochemical indicators have been applied to estimate feldspar pegmatites and muscovite-feldspar pegmatites that are spatially associated with rare metal pegmatites of the Kolmozero lithium deposit. The feldspar (beryllium-bearing) and muscovite-feldspar (beryllium-niobium-tantalum) pegmatites have rare metal mineralization and, like albite-spodumene pegmatites, are rich in Li, Nb, Ta, Be and depleted by Sr, Ba, Zr, Y, REE. Contents of ore elements (Li, Nb, Ta, Be) content increases from feldspar to muscovite-feldspar and albite-spodumene pegmatites. It is accompanied by a decrease in values of fractionation indexes of Zr/Hf and Mg/Li, as well as a decrease in contents of light, medium and heavy lanthanoids Zr, Ba and Sr.

1. Introduction

Lithium is a silver white metal, one of the lightest among metals with a low density, high heat capacity and an exclusive reactivity. It easily produces alloys with magnesium, beryllium, aluminum, lead and copper. Metallic Li and its compounds are widely used in different industries, such as aluminum, aviation, aerospace, electrotechnical industries, production of ceramics, glass, lubricants, synthetic rubber, power supplies for automobile industry, etc.

Lithium is a strategic mineral. Raw materials for its production are imported to Russia. Under expanding Western sanctions, increased world's demand in lithium and the import substitution policy taken by the president of Russia, the nation's supply of lithium raw materials is expected to be provided by domestic deposits of rare metal pegmatites, if necessary. This is due to the fact that lithium reserves in lithium deposits can amount to first millions of tons [1]. The Kolmozero lithium deposit is the Russia's first-rank object of this kind. It accounts for 26% of the total lithium reserves in



the country [2]. Therefore, the complex study of the Kolmozero lithium deposit in the Arctic region of Russia has particular scientific and practical importance.

2. Introduction

The Kola Peninsula hosts a major pegmatite belt that stretches 130 km from the north-west (Voronya River) to the north-east (Kal'mozero Lake). This belt comprises major deposits of rare metal pegmatites, i.e. the Vasin-Mylk, Oleny Ridge, Okhmylk, Polmostundra, Kolmozero deposits [3]. Among the listed sites, the Kolmozero deposit is a unique source of lithium in the European Arctic of Russia. Geologically, the Kolmozero deposit rests in Neo-Archaean metagabbro-anorthosites of the Patchemvaretsky massif in the junction zone of two regional Archaean structures, i.e. the Murmansk Block and the Kolmozero-Voronya Greenstone Belt. Rare metal veins of the Kolmozero deposit occur mostly in metagabbro-anorthosites of the Patchemvaretsky massif as 12 major and numerous minor plate-like bodies that lie unconformably with host rocks. Major veins are ~ 1400 m long, 5 to 65 m thick and traced at the depth of more than 500 m. The veins have apophyses, swells and pinches. Ore minerals in pegmatites are represented by spodumene, minerals of the columbite group and beryllium [4, 5] (Figure 1).

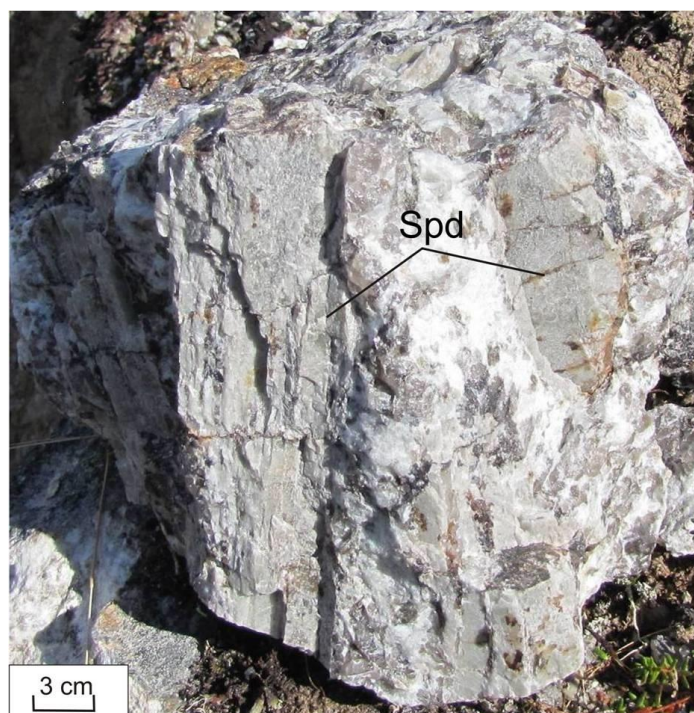


Figure 1. Spodumene (Spd) in rare metal pegmatites of the Kolmozero lithium deposit.

Rare metal pegmatites are studied in different ways; in particular, sources of rare metal mineralization, tectonic settings of their formation, time of rare metal magmatism activation, exclusive geochemical features of rare metal pegmatites, etc. are defined. As a rule, pegmatites never occur as individual bodies. There can be from tens to hundreds of pegmatite veins within one pegmatite field. Only few pegmatite bodies can be practically valued. Therefore, there is a problem of detecting rare metal pegmatites at the stage of geological prospecting and appraisal. Geochemical indicators are most impartial, reproducible and highly informative for these purposes.

This study aims at defining geochemical criteria typical of pegmatites of the Kolmozero lithium deposit that can be applied to estimate the potential of pegmatite bodies for the rare metal mineralization. The geochemical criteria have been obtained based on new data on the distribution of rare and rare earth elements in pegmatites. The defined geochemical indicators have been applied to

estimate feldspar and muscovite-feldspar pegmatites that are spatially associated with rare metal pegmatites of the Kolmozero lithium deposit.

Analysis of the geochemical data showed that albite-spodumene pegmatites of the Kolmozero deposit had relatively high SiO_2 and Al_2O_3 contents and low MgO and CaO contents, as compared to a granite clark. Na_2O content is higher than K_2O content. P_2O_5 content (0.15 wt. %) is close to a granite clark (0.16 wt. %; [6]), while F content (0.01 wt. %) is lower (0.08 wt. %; [6]). Such a composition of volatile components provides the presence of apatite and the absence of topaz in the rocks. The concentration of boron (6.53 ppm) is 2.3 times lower than that of a granite clark (15 ppm; [6]). The content of lithium, niobium, tantalum and beryllium in samples of albite-spodumene pegmatites (12244, 81, 59 and 142 ppm) is higher than the content of these ore elements in a granite clark. Maximal concentrations of lithium in albite-spodumene pegmatites are up to 17326 ppm.

Albite-spodumene pegmatites are poor in rare earth elements ($\Sigma\text{REE} = 1.87$ ppm) and characterized by weakly fractionated spectrum of lanthanides distribution ($(\text{La}/\text{Yb})_N = 6.86\text{--}27.69$) with a distinct negative Eu-anomaly ($\text{Eu}/\text{Eu}^* = 0.39\text{--}0.65$). Cerium anomaly is either slightly negative, or absent ($\text{Ce}/\text{Ce}^{**} = 0.49\text{--}1.07$). The presence of a negative europium anomaly under low concentrations of Sr indicates fractioning of the plagioclase, when the melt was enriched by incompatible components [7].

The content of highly charged high field strength (HFSE) elements (REE, Th, Zr, Y) and large-ion lithophile elements (LILE) (Sr and Ba) in albite-spodumene pegmatites is lower than in a granite clark. Normalized to a granite clark, multi-component spectra of incompatible elements of the studied pegmatite types have the same configuration and show positive anomalies of Cs, Rb, U, Nb-Ta, Hf, Li, Be and negative anomalies of Ba and Th (Figure 2).

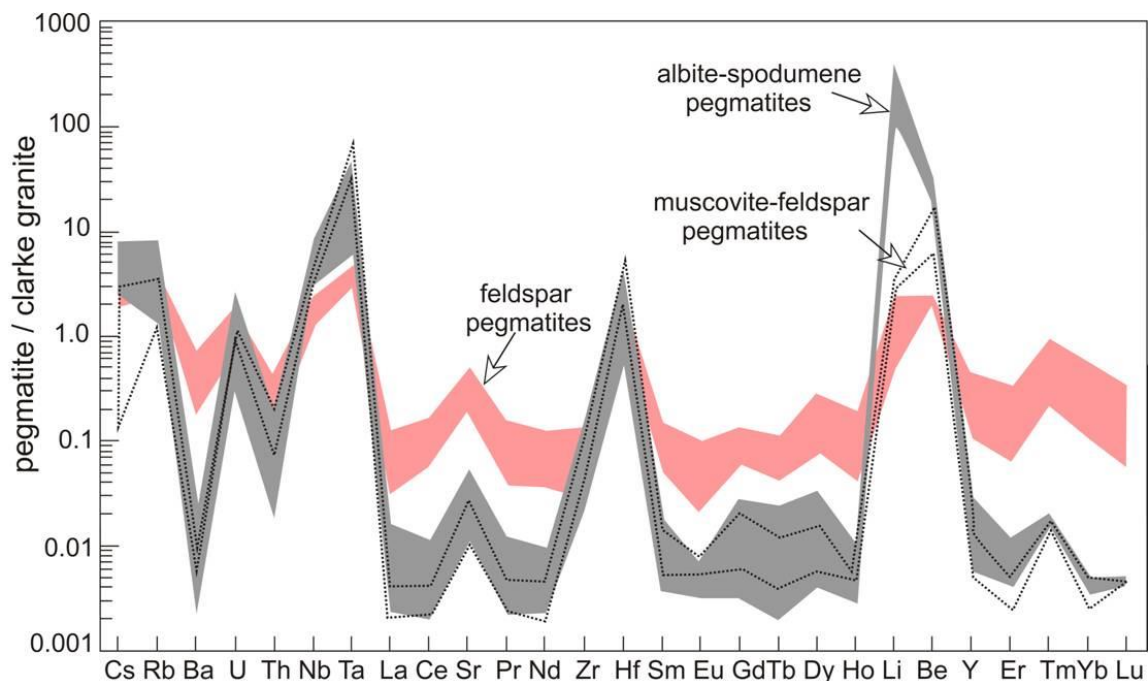


Figure 2. Distribution of rare elements in pegmatites of the Kolmozero pegmatite field. Normalized to a clarke granite, after [6].

Values of Mg/Li (0.04) and Zr/Hf (6.12) ratios in the studied pegmatites are low. It indicates a highly differentiated granite melt under the formation of albite-spodumene pegmatites. The index of rare metal content (Ir) has been considered to estimate the pegmatites mineralization. The index has

been estimated, using the formula ($Ir = F \cdot (Li + Rb + Cs) / (Sr + Ba)$) [8]. The Ir value in albite-spodumene pegmatites is defined to be 167321.

Therefore, albite-spodumene pegmatites of the Kolmozero lithium deposit with a high fractionation value and the best economic potential regarding the rare metal mineralization have the following geochemical characteristics: high contents of Li, Ta, Nb and Be regarding a granite clark; low contents of large-ion lithophile elements ($Ba \leq 20$ ppm; $Sr \leq 15.4$ ppm) and highly charged elements ($Y \leq 0.46$ ppm, $Th \leq 2.5$ ppm, $\Sigma REE \leq 3$ ppm), low values of fractionation indexes ($Mg/Li \leq 0.05$, $Zr/Hf \leq 7.4$) and a high value of the index of rare metal content ($Ir = 167321$). Rare metal pegmatites all over the world have the same geochemical characteristics [9, 10, 11, 12, 13, 14].

Rare metal pegmatites of the Kolmozero lithium deposit are spatially confined to feldspar pegmatites with beryllium and muscovite-feldspar pegmatites with beryllium and minerals of the columbite group. The study of composition of the feldspar and muscovite-feldspar pegmatites indicated that those pegmatites also had geochemical features typical of rare metal pegmatites, but were less economically valued in terms of the rare metal mineralization. The value of the index of rare metal content for feldspar pegmatites is 143 and increases up to 7341 towards muscovite-feldspar pegmatites. Contents of ore elements (Li, Nb, Ta, Be) and the index of the rare metal content increases from feldspar to muscovite-feldspar and albite-spodumene pegmatites. It is accompanied by a decrease in values of fractionation indexes of Zr/Hf and Mg/Li , as well as a decrease in contents of light, medium and heavy lanthanoids Zr, Ba and Sr (Figure 2, 3). These data can show that all types of pegmatites formed from a single granite source at different stages of the pegmatite genesis. At its early stage feldspar pegmatites formed from a less differentiated granite source. Albite-spodumene and muscovite-feldspar pegmatites formed at the final stage of the pegmatite genesis, but under different concentrations of lithium in a pegmatite melt. Muscovite-feldspar pegmatites formed, when concentrations of lithium in a pegmatite melt were relatively low. Albite-spodumene pegmatites formed, when concentrations of lithium increased.

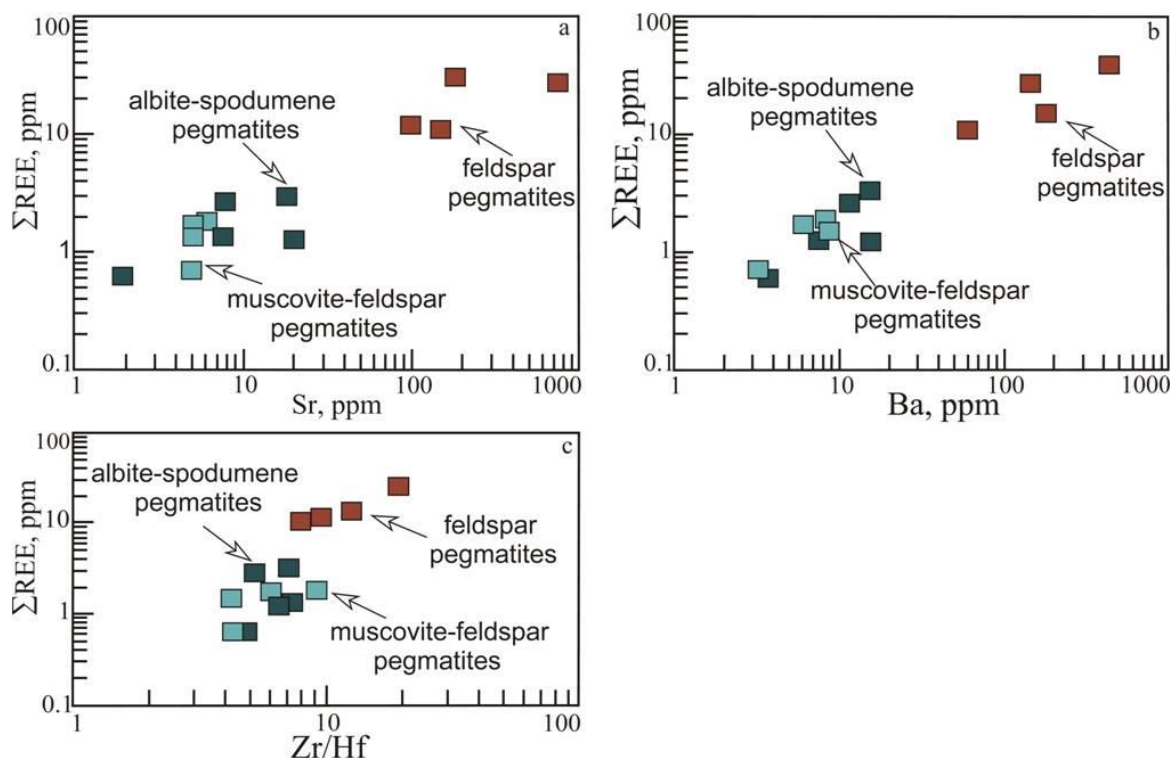


Figure 3. Diagrams: $\Sigma REE-Sr$ (a); $\Sigma REE-Ba$ (b), $\Sigma REE-Zr/Hf$ (c), after [5]

3. Introduction

Ore bodies of albite-spodumene pegmatites of the Kolmozero lithium deposit with industrially valued rare metal mineralization (Be, Ta, Nb, Li) are poor in Sr, Ba, REE, Th, Zr. They have low Mg/Li (≤ 0.05) and Zr/Hf (≤ 7.4) ratios and a high value of index of rare metal content ($Ir = 167321$). These geochemical features can be used as criteria to estimate the potential of pegmatite bodies for the rare metal mineralization in the Kola region.

Muscovite-feldspar (beryllium-niobium-tantalum) and feldspar (beryllium-bearing) pegmatites also have typical features of the rare metal-type pegmatites. The value of the index of rare metal content for feldspar pegmatites is 143. It increases up to 7341 in case of muscovite-feldspar pegmatites.

Acknowledgements

The current research has been conducted in the framework of the State order on the topic of scientific research 0226-2019-0053 of Geological Institute of the Kola Science Centre of the Russian Academy of Sciences

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