Kola Peninsula in solving problems of national arctic materials science

A I Nikolaev and S V Krivovichev

Federal Research Centre “Kola Science Centre of the Russian Academy of Sciences”
Apatity 14 Fersman street Russia

E-mail: nikol_ai@chemy.kolasc.net.ru, skrivovi@mail.ru

Abstract. The Kola Peninsula is one of the most developed Arctic regions in Russia and in the world. Its share in the Russian production of apatite, nepheline, loparite and baddeleyite concentrates is 100%. The region produces up to 45% of nickel, and 13% of copper, and the majority of rare-earth metals, niobium, and titanium compounds from the regional minerals. The ores mined from the existing deposits can be used for production of up to 30 various concentrates. The materials produced from the regional minerals include metal nickel, cobalt, copper, titanium, niobium, rare-earth metals, steel; sealants, components of electrode coatings and welding fluxes, sorbents for disposal of radioactive waste and wastewater containing heavy non-ferrous metals and other contaminants, high-porous heat insulation and fire-resistant materials for arctic application, cement, concretes with improved resistance to frost and sea water. In satisfying demand for new materials, the first and foremost objective is to establish a pilot engineering base for adaptation of process flowsheets, and collection of data for design and construction of new operations. Successive implementation of this objective requires concentrated efforts of scientists and engineers focused on implementation of the Kola Chemical and Technological Cluster Project, which enables to improve significantly the economy of minerals use by means of products of their deep processing. At the first stage of the Cluster operation, a process of new titanium sorbents production will be established to solve environmental issues — treatment of non-ferrous metals industry wastewater from heavy metals, and processing of liquid radioactive waste accumulated in the Arctic zone of Russian Federation.

1. Introduction

The Arctic zone of the Russian Federation (hereinafter — AZRF) is the largest zone in the world arctic sector. It is characterized by high density of mineral deposits and the importance of its mineral resource base for national economy. The AZRF accommodates about 10% of active world nickel resources, about 19% of platinum group metals, 10% of titanium, and over 3% of zinc, cobalt, gold and silver, as well as the largest amount of rare-earth metals (REM) [1]. There are quite a number of problems related to mining and rational use of the unique arctic mineral resources, their processing and production of special materials for development of the Northern areas in Russia, or production of such materials from arctic minerals in other regions of the country. Actual situation in arctic materials production needs higher level of research and development in the field of arctic material science, modern research and production equipment, competitive capacity of the products, demand in materials produced (partially, and due to lack of consumers’ money) [2–4].
At the same time, development of vast northern territories is impossible without materials that can maintain vehicles performance under extreme temperatures, and ensure appropriate living conditions for people at these areas. The Kola Peninsula minerals processing waste can be a source for such materials production [5].

2. Murmansk region as an important part of the Russian resource base for development of arctic material science

The Kola Peninsula is an important supplier of structural and strategic materials to national and foreign markets. Without stable supply of such materials to the national industry, it is impossible to guarantee the national safety. For example, JSC Kolskaya Mining and Metallurgical Company produces up to 45% of metal nickel, and other metals. However, the main products of the region are ores and mineral concentrates for production of functional materials used in various industries. The Murmansk region economy is mainly focused on production of mineral concentrates as final products. The examples include regional mining and processing operations: JSC Apatit, Kovdorskiy GOK, Olenegorskiy GOK, North-Western Phosphorous Company, Lovozerskiy GOK. The Kola Peninsula is an important Russian base for various mineral resources [6, 7].

The most important federal resources are apatite-nepheline ores (ANO) of Khibiny deposits, loparite ores of Lovozerskie deposits, perovskite-titanium magnetite ores of Afrikandskoe and Vuoriyarvinskoe deposits, ilmenite ores of Gremyakha-Vyrmess deposits, magnetite ores in Kovdorskiy and Olenegorskiy districts, kyanitic ores in Keytvy, deposits of platinum and non-ferrous metals, and a lot of other deposits [6, 7]. The Kola Peninsula host significant portion of Russian apatite, nepheline, kyanite, titanium, rare-earth, vermiculite, phlogopite, and other resources. The resources mined in the region can used for production of up to 30 various concentrates, with can satisfy both the demands of AZRF, and the whole country.

Only at the Khibiny deposits, during 90 years of their operation, 2 billion tons of apatite-nepheline ore were mined. In the Soviet Union, and now in Russia, this was the main mineral resource for production of phosphorous and its compounds. Such ore contains also other valuable rock-forming titanium minerals — sphene, and titanium magnetite, which are not recovered now, and disposed to tailings storage facilities [8].

The first studies on the ANO use were conducted by academician A. E. Fersman in 1932. The studies were focused on recovery of all valuable components from complex ANO and ores from the nearest deposits, and satisfying the national industry demands in deficient products. The list of the main products included phosphate fertilizers, thermophosphates, yellow phosphorus, ferro-phosphorus, phosphoric and sulfuric acids, liquid glass, alumina, cement, concentrate of rare metals, non-ferrous metals, etc. Moreover, the planned production scale of some products shall reach from thousand tons per year up to million tons per year.

3. Scientific basis for the Kola resources processing. Development and improvement of process flowsheets

Many papers and books were written on mineral resources of the Murmansk region, including results of scientific and production companies’ studies, exploration programs. They enable to understand availability of minerals, their reserves, and existing technical solutions on processing [6–9].

Significant portion of the Kola Peninsula is associated with non-traditional resources. There was almost no experience in processing of such resources in the world industry. The Federal Research Center “Kola Scientific Center of the Russian Academy of Sciences” (FRC KSC RAS), in cooperation with Russian industrial and academic institutions, universities and existing operations processing resources mined in the Murmansk region, conducts systematic studies of the regional resource base, ore mining, development of processing methods, processing of concentrates and production of materials. The FRC KSC RAS includes nine scientific institutions in the form of separate subdivisions, including geological, mining, chemical, environmental, economical, and energy institutions. Close cooperation between them enables to maintain high potential of operations, and creates opportunities for deeper processing, and
obtaining of products with better consumer-oriented characteristics. The Rare-Earth Metals Chemistry and Technology Institute of the FRC KSC RAS developed the basic technology package of non-traditional minerals processing [6, 9]. It enables to choose the most sustainable resource-saving technology options providing synthesis of a wide range of products, which is important under unstable conditions at the consumer markets of titanium, rare metals and their compounds.

In recent years, the FRC KSC RAS has developed technologies for synthesis of some rare titanosilicates minerals analogues as promising polyfunctional materials, for example, molecular sieve, titanosilicate “nanopuzzles”, cation exchangers, photocatalyst, etc.. Their composition, morphology, and properties are characterized. The synthetic analogs of the ivanyukite-group titanosilicates (SIV) are obtained [10]. A principal scheme of titanite concentrate processing for SIV synthesis are given in Figure 1.

**Figure 1.** A principal scheme of titanite concentrate processing for SIV synthesis.

The framework composes corner-sharing SiO$_4$ tetrahedra and TiO$_6$ octahedra linked through bridging oxygen atoms and provide pore system with channels containing H$_2$O molecules and exchangeable Na$^+$ cations. It has been found that SIV has high selectivity towards Cs$^+$ and Sr$^{2+}$. The direct calcination of the $^{137}$Cs,$^{90}$Sr-loaded SIV leads to the formation of the Synroc-type titanate ceramics. The synthetic ivanukite with wide-pore microporous framework is considered to be perspective cation-exchanger for the treatment of non-ferrous metals industry wastewater from heavy metals, and processing of liquid radioactive waste accumulated in the Arctic zone of Russian Federation.

The scientific basis for processing of complex resources of the Kola Peninsula has been studied in sufficient detail by now. The developed technologies demonstrate the ability to recover almost all valuable components from mineral concentrates; however, in practice, the efficiency of using mineral resources is not high enough, which is explained by low market demand, as well as low economic indicators of some potential products recovery.

Rare-earth metals registered as national resources in the Khibiny ores are among the “lost” components of apatite concentrate processing. Over 100 thousand tons as recalculated to REM oxides are lost annually during production of apatite concentrate. 10% of this amount are presented by the most
deficient REM of medium-weight group. At the same time, the technology of collective REM concentrate recovery from apatite and phosphogypsum was tested at pilot scale in the operations of JSC PhosAgro, Cherepovets, JSC Acron, Velikiy Novgorod, GK Yuniskhim, LLC, Voskresensk, and the technology of individual REM recovery was tested at large laboratory scale in NPK Rusredmet, LLC [11, 12]. The prospects of such technologies implementation are determined by actual demands of the national industry. Establishment of enterprises based on the principle of public-private partnership could accelerate implementation of these technologies in case of any government orders for produced rare-earth metals, including those for state reserves of strategic materials.

Promising products for development of the Arctic regions are components of electrode coatings and welding fluxes based on mineral concentrates from ores of the Kola Peninsula deposits — sphenic, nepheline, titanomagnetite, quartzite, dolomite, olivinite, and other concentrates [13]. Such materials, which ensure higher welding and processing properties, in particular, higher cold resistance of welded steels, have undergone extensive tests at JSC Sevmash, and a number of welding operations under the patronage of CRISM “Prometey”. Lower demand of the welding industry in mineral concentrates (from hundreds of tons to thousands of tons per year) is an obstacle to production of non-core low-tonnage materials at large mining and processing operations. At the same time, the use of imported welding materials is growing, and their share currently exceeds 50%. Without the state support (government order, preferences for companies producing import-substituting products, including for the Arctic region), we cannot change this situation.

The ideas stated by academician A. E. Fersman in 1932, related to sustainable use of mineral resources in the Murmansk region, were noticeably ahead of their time, and needed improvement. By present, the concept of the Kola Chemical and Technological Cluster Project (KCTC) has been developed in detail at FRC KSC RAS. The cluster is focused on production of high-tech materials for the national industry. Basically, such materials are low-tonnage. In the 1980s, in Apatity, a large plant for production of lithium niobate was built for the civil sector of the economy and the military-industrial complex of the Russian Federation. A small enterprise for production of high-capacity tantalum condensate powders was established. JSC Apatit, with participation of KSC RAS, started to produce coagulants-floculants, explosives from products of nepheline processing, components of special-purpose welding materials, and other products. The importance of these works for the country was recognized with the RF Government Award in 1997, and the RF National Award in 2000.

4. Conclusion
Depletion of reserves of many operating deposits in Russia and other countries increases attractiveness of a new resource base of the Arctic zone, including mineral resources of the Kola Peninsula, and necessity for its use in the near future.

The developed fundamentals of chemical technology for the Kola Peninsula complex resources, and efficient processing flowsheets with production of materials for modern advanced industries enable to satisfy the demand in structural and strategic materials (non-ferrous, rare-earth, noble, ferrous metals, their compounds, materials for electronic equipment, catalysis, sorption, medicine and other purposes) not only in the Arctic zone, but also in the whole country. Production of materials for construction industry on the basis of overburden, ores, mineral concentrates, beneficiation and chemical processing waste can and should lead to an increase in the efficiency of resources use, a noticeable decrease in the amount of industrial waste, and improvement in the environmental situation.

Establishment of a pilot industrial base for adaptation of processing flowsheets, production of high-tech product batches, and collection of data for design and construction of industrial operations becomes an important priority objective in satisfying demand for new materials. The success of this objective is determined by concentrated efforts of scientists and regional industrial operations focused on implementation the KCTC project, which increases completeness and economic indicators of resources use. At the initial stage of the KCTC project, a pilot production of new titanium-containing sorbents will be established to solve environmental problems — treat non-ferrous metallurgy from heavy metals, and process liquid radioactive waste accumulated in the Arctic zone of Russia. The KCTC establishment
will significantly accelerate implementation of innovations, improve the economic security of the country, and ensure the production of modern competitive products. In particular, it is planned to create a production of sealants for the aerospace industry, tantalum and niobium condensate powders, materials for acoustic-optoelectronics at national scale. It is important to note that further development of the mining industry and solution of socio-economic problems of the region can be carried out without any noticeable increase in the environmental impact and environmental degradation.

Acknowledgement
The reported study was financially supported by RFBR according to the research project 18-29-121039 and was partly supported by the theme of state assignment of AAAA-A17-117020110035-5

References
[1] N P Laverov, V I Vasilyev and A A Makosko 2015 Scientific and technical problems of the Arctic development. Scientific session of the General Meeting of the Russian Academy of Sciences, December 16, 2014. (Moscow: Nauka) 490 p. [In Russian]
[2] Buznik V M and Kablov E N 2017 Current Situation and Prospects of Arctic Materials Science. Bulletin of the Russian Academy of Sciences, 87 9 827 [In Russian]
[3] Buznik V M, Burkovskaya N P, Zibareva I P, Cherepanin R N 2017 On the issue of a roadmap development for the Russian Arctic materials science. Materialovedenie [Materials Science], 4 8 [In Russian]
[4] Buznik V M, Burkovskaya N P, Zibareva I P, Cherepanin R N 2017 On the issue of a roadmap development for the Russian Arctic materials science. Materialovedenie [Materials Science], 5 22 [In Russian]
[5] Construction and technical materials produced from mineral resources of the Kola Peninsula 2003. Makarov V N, Krasheninnikov O N, Gurevich B I et al. Part 1, 2 (Apatity: KSC RAS publishing house) 430 p. [In Russian]
[6] Kalinnikov V T and Nikolaev A I 2011 Prospects for the development of chemical industry raw materials based on the Kola peninsula Tsetnye metally 11 17 [In Russian]
[7] Fedorov S G, Nikolaev A I, Brylykov Yu E et al. 2004 Chemical processing of mineral concentrates of the Kola Peninsula (Apatity: K&M publishing house) 198 pp. In Russian.
[8] Nikolaev A I, and Krivovichev S V 2019 Prospects for the Development of the Kola Chemical Technological Cluster in Transition from a Resource-Based Economy to an Innovative Economy, Theoretical Foundations of Chemical Engineering 53 5 980
[9] Nikolaev A I and Krivovichev S V 2017 Natural minerals and their synthetic analogues as prototypes of functional materials (based on the experience of the Kola Nanomaterials Research Centre) Bulletin Tomsk State University. Chemistry 8 7 [In Russian]
[10] Lokshin E P and Tareeva O A Technologies development for the extraction of rare earth elements while sulfuric acid processing of the Khibiny apatite concentrate for mineral fertilizers production 2015 (Apatity: KSC RAS publishing house) 268 p. [In Russian]
[11] Polyakov E G, Nechaev A V and Smirnov A V 2018 Metallurgy of rare metals (Moscow: Metallurgizdat) 732 p.
[12] Nikolaev A I, Brusnitsin Yu D, Vasilieva N Ya et al. 2000 Production of Welding Materials from Minerals of North-West Russia Mineral Processing and Extractive Metallurgy Review 22 1-3 p 273.