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SUSTAINABLE DEVELOPMENT OF CRUDE ORE RESOURCES AND BENEFICATION FACILITIES OF JSC «APATIT» BASED ON BEST ENGINEERING SOLUTIONS

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The article discusses the state and prospects of the development of crude ore resources of JSC «Apatit», the project of improvement of the underground mining of apatite-nepheline ores at the Kirovsk mine due to the construction of a new horizon of +10 m is addressed. Specifics of ensuring the safety of mining operations in the conditions of rock-bump hazard on apatite-nepheline deposits are described. The stages of modernization of the benefication complex and automation of production at the enterprise, measures for the complex extraction of valuable components from mineral raw materials are presented.

***Key words*:** «Apatit», mining, dispatching, quarry, deposit, ore, benefication

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Introduction. Joint Stock Company «Apatit», a member of the «PhosAgro» Group, was founded on November 13, 1929 on the basis of the unique Khibiny deposits of apatite-nepheline ores, which are a heavy intrusive body having the shape of a horseshoe. Khibinsky deposit apatite-nepheline is a part of the largest and richest deposits of the world and is the main source of phosphorus-containing raw materials in Russia.

Mining of mineral resources. The Khibiny massif of nepheline syenites and ijolite-urtites, with which the apatite-nepheline ores are connected, is being developed by the Joint Stock Company «Apatit», from the geological point of view it is a complex multiphase alkaline intrusion of the central body, associated with a regional tectonic fault.

The rocks of the developed urtite complex form a heavy conical intrusion of an arcuate shape. The internal structure of this arc is not uniform. The Kukisvumchorr, Yukspor, Apatitovy Tsirk and Rasvumchorr Plateau (the central group of deposits) deposits have relatively simple reservoir forms: clear contact with covering rocks, continuity along the stricke and thickness decreasing with depth. On the East Rasvumchorr there is a brecciation of rocks. The Koashvin and Nyorkpakhk fields are represented by several horizons of apatite-nepheline ores, which are often brecciated.

Apatite deposits of the central group are a continuous bedding plane deposit, complicated by bulges (lenses) and swinebacks (sharp reduction in thickness) between them. One lens combines the Kukisvumchorrskoye and Yukskor deposits, the second lies within the Apatitovy Tsirk and the Rasvumchorr Plateau. Both lenticular bodies are similar in their morphological and structural features. The plane of the ore body has a linear-elongated shape and a symmetrical structure, the length is of about 11 km.

JSC «Apatit» develops six deposits of apatite-nepheline ores: Kukisvumchorr, Yukspor, Apatitovy Tsirk, Rasvumchorr Plateau, Koashva and Nyorkpakhk (Fig.1). As part of the JSC «Apatit» is combined of three production sites: Kirov, Rasvumchorrsky mines – with underground mining and the East mine, which uses open-cast mining to develop three quarries – Central, Koashvin and Norkpakhk.

Today JSC «Apatit» is the largest enterprise in the world (Fertecon data) for the production of high-grade phosphate raw materials – apatite concentrate and the only producer of nepheline concentrate in Russia. Since the beginning of the operation of the JSC «Apatit» mines, there have been more than 1900 million tons of apatite-nepheline ore, including more than 750 million tons mined using underground methods of development. The reserves of the upper horizons, having the most thickness and quality, have been worked out. In the future, reserves will be mined from deeper horizons by underground and open pit mining methods, which will require increased material and labor costs. Therefore, the reconstruction and technical re-equipment of all production sites is a priority task of the company «PhosAgro».

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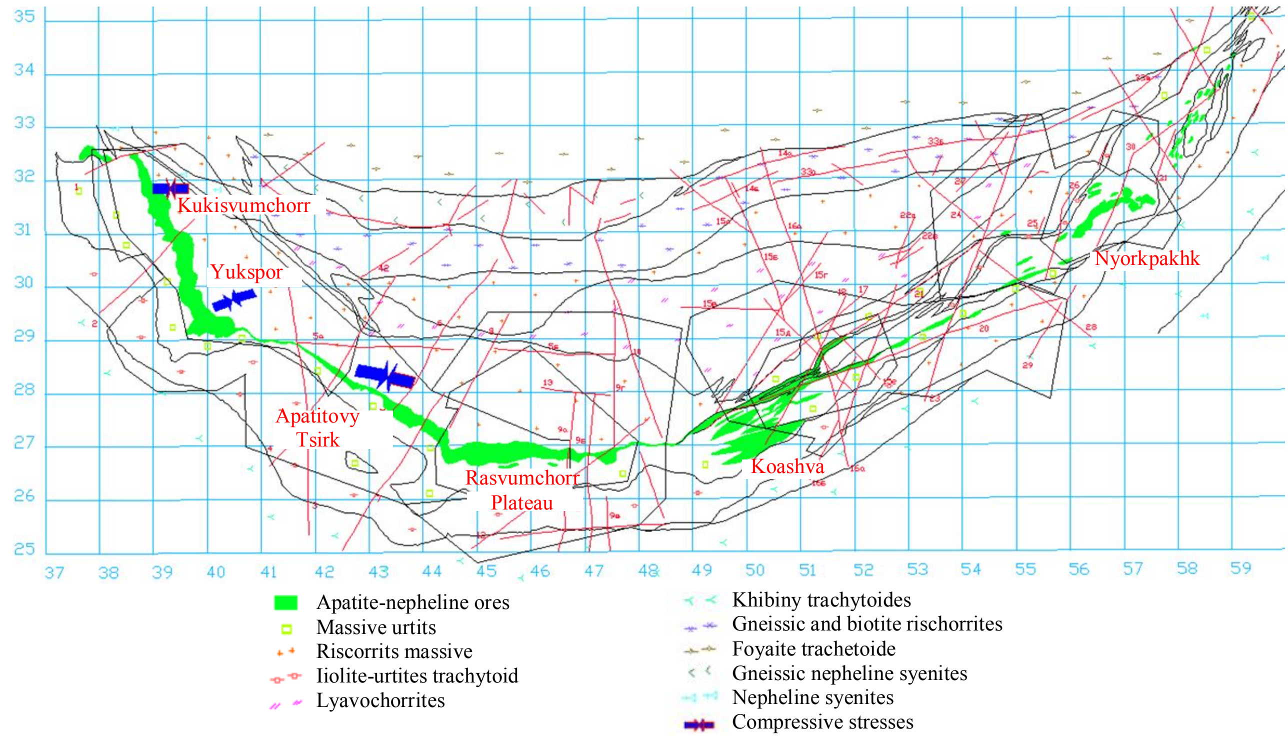

Fig.1. Deposits developed by JSC «Apatit»

To achieve stable operation of JSC «Apatit» for a long time, it is necessary to enhance the development of the crude-ore resources and to maintain the required rates of progress of construction work, primarily in underground mines [1].

The strategy for the development of the crude-ore resources of JSC «Apatit» is focused on increasing the volume of ore developed with underground mining methods, with emphasis on the introduction of cost-effective mining technologies. The main object of underground mining is Kirovsk mine, which is the largest in terms of reserves and the oldest (1929) on the Kola Peninsula (Fig.2).

The goal of the crude-ore resources development project is to increase the productivity of the Kirovsk mine, to increase mining capacities with the construction of the horizon of +10 m, to optimize the transportation scheme of the underground mine in the conditions of the existing distribution routes, replace the open-cut mining methods with underground mining tools.

The implementation of the project for the construction of the horizon +10 m includes the following key stages (Fig.3):

1. Opening of the horizon by three decline developments: truck decline +108/+10 (which includes driving – Kukisvumchorrskoye deposit, truck decline +170/+10 and +106/-24 – Yuksporskoe field.

2. Construction of the continuous handling system of the crushing and delivery complex of the Kukisvumchorrskoye deposit CDC-1 and the Yuksporskoe deposit CDC-2, horizon +10 m, which includes the driving of the crushing chambers CDC-1 and CDC-2, the belt inclines BI-1 and BI-2 and BI-3.

3. Construction of MMFHU NVH-1,2 and VH-1: heat pipelines from CHS; two new MMFHU buildings; installation of fans and air-water heaters.

Fig.2. Kirovsk mine

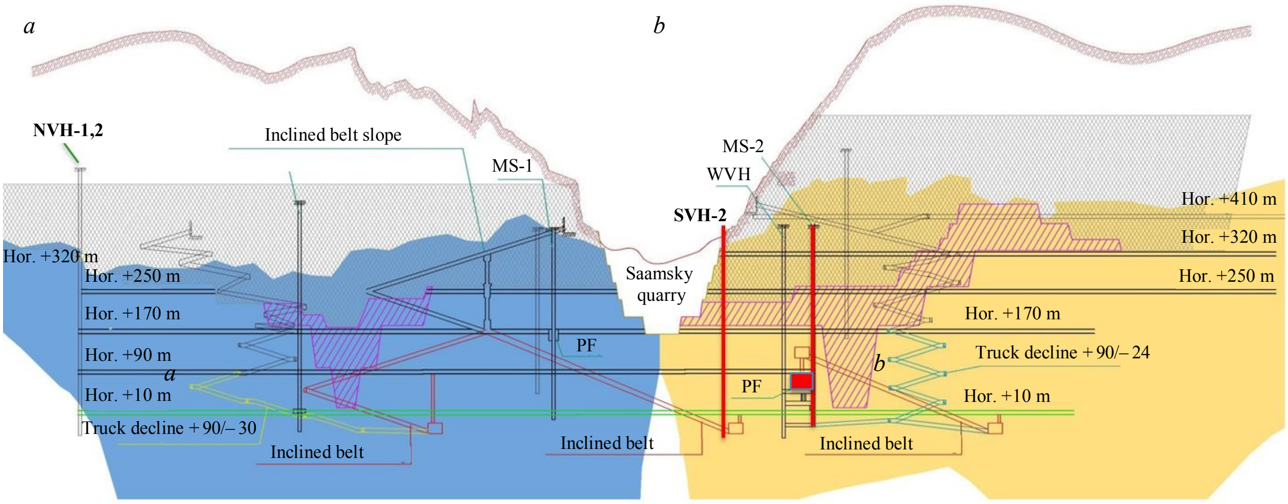

Fig.3. Schematic diagram of the development of Kukisvumchorrskoye (*a*) and Yuksporskoe (*b*) deposits of the Kirov mine

4. Construction of the 10 m production level: mining and capital works (mining of the workings of the production level); installation of utility networks and substations; construction of a haulage track.

5. Construction of a high-speed elevator unit SVH-2 at a depth of more than 500 m.

6. Construction of a dewatering system (MMWDS hor. +10m): development of chamber workings (water collectors, sludge pits and CCM chamber); installation of pumping equipment, power supply and pipeline layouts.

An important effect of this scheme is the optimization of the ore handling flow sheet inside the mine, which involves construction of inclined belts N 1, 2, 3 for ore extraction from the horizon +10 m and is associated with the reconstruction of the existing hauling tracks CDC and MS-2, which will enable using the capacity of existing haulage schemes by reducing the average transportation distance by 30-40 %, and also decreasing capital investments in comparison with the ore handling flow sheet «hor. +10 m – surface» with the construction of shafts or inclined belts with new surface haulage systems.

With the construction of the horizon +10 m, it is planned to design and implement a number of innovative engineering systems to provide communication and process control in an automated mode. The key ones are the personnel positioning and communication system, the automated control system for the crushing and delivery complex and the automated transportation management system.

On the new truck declines, production level, inclined belts, personnel positioning and voice communication system will be deployed on the basis of solutions that are currently working in the existing mine workings. The system operates using Wi-Fi technology and provides information collection and transmission, control signal transmission, telephone operation (voice, messaging, alarm), personnel positioning (position record and motion display). The infrastructure underlying the positioning system is universal and will ensure the operation of automation systems for stationary technological complexes and an automated transportation management system. The communication lines of the system will be implemented using an optical communication cable to ensure high throughput and increased reliability. The use of the personnel positioning system and voice communication will improve the safety of work in the underground mine, as well as increase the productivity of personnel through the possibility of in-process control.

During the construction of the continuous handling system of the Kukisvumchorr crushing and delivery system (CDC-1) and Yukspor (CDC-2) of the horizon +10 m, a modern automatic control system (ACS) will be introduced in accordance with the hierarchical three-level model.

During construction of the horizon +10 m, it is planned to implement the automated transportation management system. The main goal of the system is to organize the movement and unloading of railway trains in an automated mode, and the loading of trains in the remote-control mode.

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Fig.4. Locomotive haulage system of hor. +10 m

The system will consist of a set of technical facilities that provide synchronous operation of electric locomotives, switch control systems, unloading systems, as well as the subsystem of video surveillance (Fig.4).

To increase production at the Kirovsk mine, it is necessary to provide the supply of the estimated amount of fresh air to the operating sections of the underground mine, in order to do this, they have to make a radical reconstruction of the two fan-heater units with a total output of fresh air supply of 1280 m^3/s.

It is planned to use a high-speed elevator for transportation of working personnel to the deep horizons of the mine. For the first time in the world, the shaft, used to lift and lower people, will be equipped with a SongSan Special Elevators (South Korea) at a depth of 500 m.

The implementation of the project for the construction and commissioning of a horizon +10 m will increase the productivity of the Kirovsk mine by a factor of 1.5 and ensure the safe and efficient operation of high-performance mining equipment.

The analysis of the world tendencies in the field of explosives has shown that further increase in the level of efficiency and safety of blasting operations in JSC «Apatit» is related to the use of emulsion explosives in underground mining conditions, which are produced at a mining enterprise directly in the process of charging blasting holes and bore holes [5]. Emulsion explosives are characterized by low sensitivity to mechanical influences, high water resistance, full mechanization of the production process and loading of EE into wells, ecological cleanness and the possibility to regulate the energy characteristics of the explosive depending on the physical and mechanical properties of the blasted ore.

The implementation of the targeted program for the introduction of EE for existing underground conditions allowed:

• to fundamentally improve the safety of personnel during preparation and execution of works related to the delivery, reloading, loading (production) of EE and blasting of bore holes and blastholes in underground conditions by: eliminating the influence of negative factors on the worker during pneumatic charging, using safer explosives in comparison to existing ones in relation to requirements for their transportation, storage and application.

• to improve the quality of ore crushing in underground conditions.

• to reduce the cost of mine support by using an effective technology of contour blasting during mining.

• to reduce negative impact on the environment.

• to introduce EE in underground mines and refuse to use TNT-containing explosives without any negative consequences for the enterprise.

• to reduce the likelihood of terrorist acts by decreasing the volume of industrial explosives during storage and transportation processes.

The problem of the high cost price of open ore mining with the development of easy to recover reserves of the upper horizons of deposits in modern conditions is solved by organizing conveyor delivery of overburden instead of expensive transportation by dump trucks. Of all the existing technologies, the introduction of cyclical and continuous method is the most effective tool, this was proved by the experience of foreign mining enterprises.

The operation of such a complex makes it possible to reduce the haul distance for transportation of overburden in the conditions of the Koashvinsky quarry and, as a result, to significantly reduce the number of vehicles, decrease the costs of operation of technological transport (giant tires, diesel fuel, petroleum products), repair costs, reduce the number of personnel (maintenance and operation teams) and the number of serviced technological vehicle roads, and significantly minimize the industrial safety risks.

At the mark of +280 m of the Koashvinsky quarry there will be located a crushing complex and a road to a dumping ramp, the haulers will unload overburden, hard and moraine rocks. After crushing, the mass is transported by a system of conveyors with a total length of about 3600 m to the pile N 4 of the Nyorkpakhsky quarry. There the material is loaded on the conveyor of the spreader, fed to the boom and unloaded by stacking up to a 50-m pile.

With the introduction of the CCM in the conditions of the Koashvinsky quarry with the capacity of 30 million tons per year of rock mass it is expected to put down the haul distance from 2 to 4 km, decrease the number of technological vehicles to 25, and reduce the number of personnel.

Features of ensuring the safety of mining operations in the rock-bump hazard conditions at apatite-nepheline deposits. The development of deposits leads to the restructuring of the stressed-deformed state of the rock mass, primarily due to the increase of tension in tectonically stressed zones and to the reduction of rock stability in tectonically unloaded zones. Therefore, the mining operations significantly increase the geodynamic activity by an order and more. The most dangerous fact is that the main deformations are manifested in the mine workings, they lead to failure of mine support and mining equipment and occurence of injury-risk situations.

Geodynamic hazards are one of the main factors lowering the productivity of mines due to the danger of development of new horizons in several places, the cross-movement of heading operations, the complexity of roof support installation and operation in tectonically tense and weakened zones, restrictions on the size of the pillars, etc.

During open-pit mining, the sources of most danger are the tectonically weakened zones associated with rockfalls, deformations of the benches and walls, crack formation and propagation, landslides and caving.

A special problem is the complex tectonic structure and the stressed-deformed state of the rock mass in combined open-underground mining and excavation of pit reserves.

Special measures must be taken to ensure the safety of mining operations in such conditions, including anti-rock-burst measures, reduction of slope angles, etc. These measures reduce the economic efficiency of mining, and at the same time do not ensure complete safety of mining operations.

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During the years of the Khibiny deposits development on underground mines, and in recent years and on open pits, there were registered 16 man-made earthquakes, 20 rock-tectonic bursts and 45 rock burst and micro-bursts (as of September 2017). Almost all underground horizons and workings displayed processes of peeling, bursting, and dynamic roof-rock slip formation.

To reduce negative consequences of rock pressure in JSC «Apatit», they have established a group for forecasting and preventing rock-bursts, which has been successfully working already for 30 years [3].

The most widely used are three levels of the system used for monitoring and forecasting of geo-mechanical situations.

• Regional (general) geodynamic monitoring – seismic monitoring with the help of an automated system for monitoring the seismicity of the massif (ASMSM), surveying monitoring of the displacement (settling) of the surface, deformations of the slopes.

• Local geodynamic monitoring – visual inspection, the method of core disking, measuring the stress-strain state of the rock massif, monitoring the destruction of shaft walls, various geophysical measurements, visual inspection of the state of the slopes and benches.

• Expert system SIGMA-GT (developed by the Mining Institute of the Kola Science Center of the Russian Academy of Sciences) to assess the geo-mechanical situation in the mining area on the basis of finite element mathematical modeling (FEM).

The monitoring systems allow:

• to identify and localize the most hazardous areas and choose the most appropriate and effective measures to prevent hazards;

• to reveal early signs of the beginning processes of potential future huge dynamic phenomena, for example, landslides, caving, rock-tectonic bursts, and to prevent these phenomena or to plan mining operations in such a way as to minimize their impact;

• to determine as accurately as possible the time, place and scale of the impending dynamic events and in advance to withdraw people and equipment from the zones of already coming dynamic phenomena;

• to identify the least hazardous areas, ensure their development by the most effective methods, for example, with a lower slope stability factor than in the averaged calculations, with simpler roof support, with larger chambers, etc.

Since 2015, together with the Scientific Center of Geomechanics and Issues of Mining Industry of the St. Petersburg Mining University, there have been implemented the Complex Program of Instrumental and Methodological Work for Ensuring Safe Development of Apatite-Nepheline Ores of JSC «Apatit». The main goal of the program is to increase the safety and efficiency of extraction of apatite-nepheline ores by improving the quality of the assessment and forecasting of geodynamic risks through the integrated use of modern geodynamic monitoring tools, and selection on this basis of adequate means of reducing the hazard and using highly efficient mining technologies.

The implementation of this complex program can be broken down into several major stages (Fig.5):

• Geodynamic zoning, creation of an experimental site for testing the elements of a complex monitoring system for state of rock massif, installation of elements of an integrated monitoring system, development of local and seismic monitoring systems.

• Establishment, testing and correction of elements of the complex monitoring system, design of experimental integrated monitoring systems in open and underground mining, creation of geodynamic models for underground mines and quarries, development of local and seismic monitoring systems.

• Creation, adjustment and testing of an experimental integrated monitoring system for open and underground mining, development of hazard criteria according to complex monitoring data.

• Creation and commissioning of the hardware and software complex for safe mining of the JSC «Apatit» sites, development and adjustment of the hazard criteria.

Measures aimed at preventing geodynamic risks and developed on the basis of the results, should be taken into account:

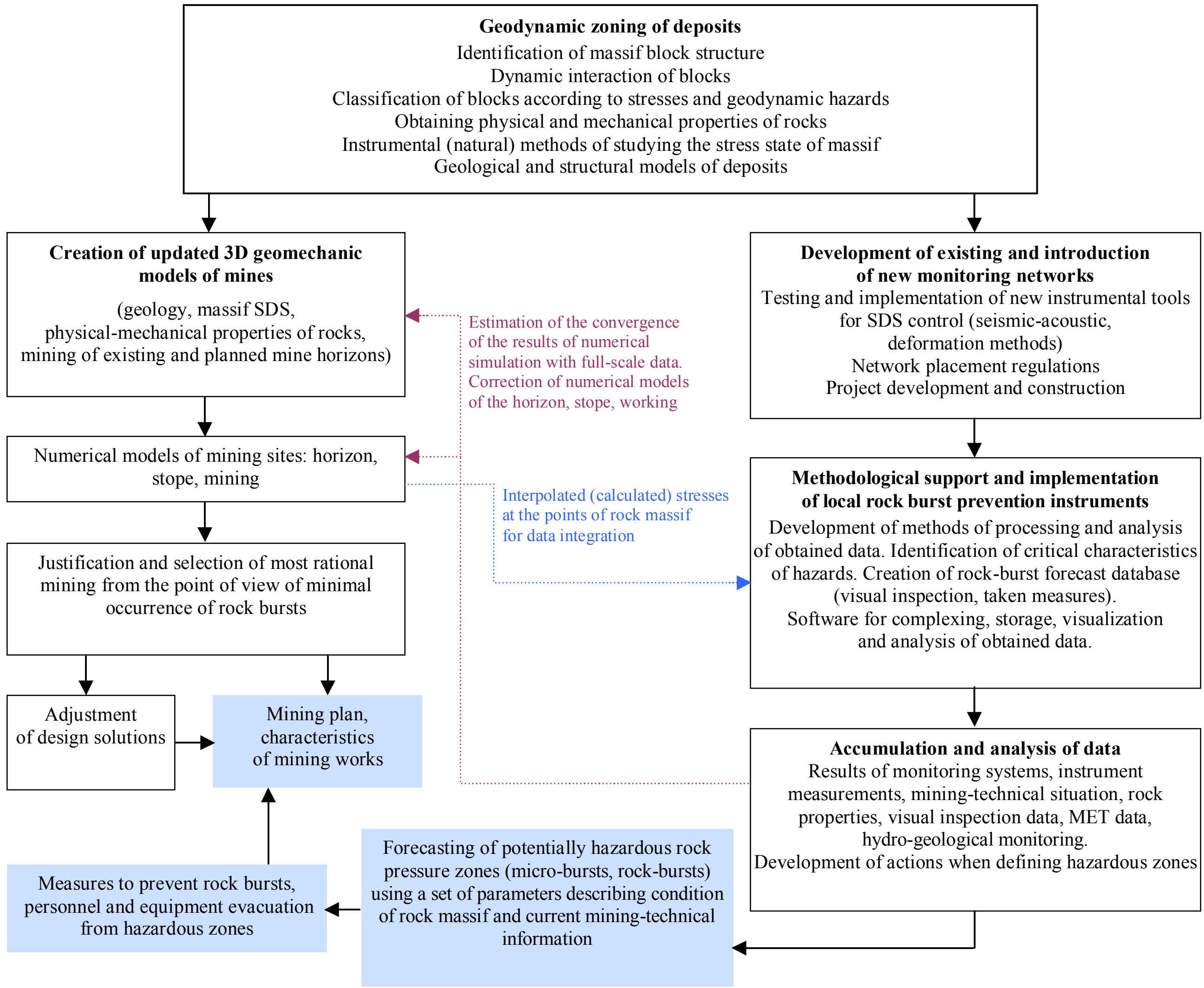

Fig.5. Flow diagram of geodynamic safety

• at the stage of designing new horizons and stopes (opening, preparation and mining order, workings advancement and mining systems), to ensure systematic extraction of reserves without the formation of pillars and hazardous rock-burst areas of the massif;

• when planning mining operations for each month and year and implementation of measures aimed at preventing rock bursts in accordance with the project documentation and the results of the current forecast;

• when conducting mining operations, to clarify the stress-strain (rock-bursts hazardous) state of the rock massif in the mine workings by local methods, perform rock-burst prevention and adjustment measures.

Such logic of mining operations will allow to exclude ineffective solutions at each stage, the consequences of which at the next stages of development of mining operations are difficult, and often impossible to eliminate. Negative manifestations of rock pressure are usually expressed in high costs for maintaining workings, restoration of workings by destroyed rock-bursts, or development of new ones in place of destroyed ones, and in the course of stoping it influences the loss of prepared for mining ore reserves.

Complex ore processing and extraction of valuable components. Currently, the processing of extracted apatite-nepheline ores is carried out at two concentrating plants: ANOF-2 (commissioned in 1963) and ANOF-3 (1988). In the period from 1932 to 1992, ANOF-1 was in operation.

Decrease in the share of apatite in processed ores with its replacement by secondary minerals and general deterioration of the mineralogical composition of the beneficated ores predetermines the implementation of effective technological upgrades to maintain the high quality of apatite concentrate and the full extraction of the valuable components.

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a b

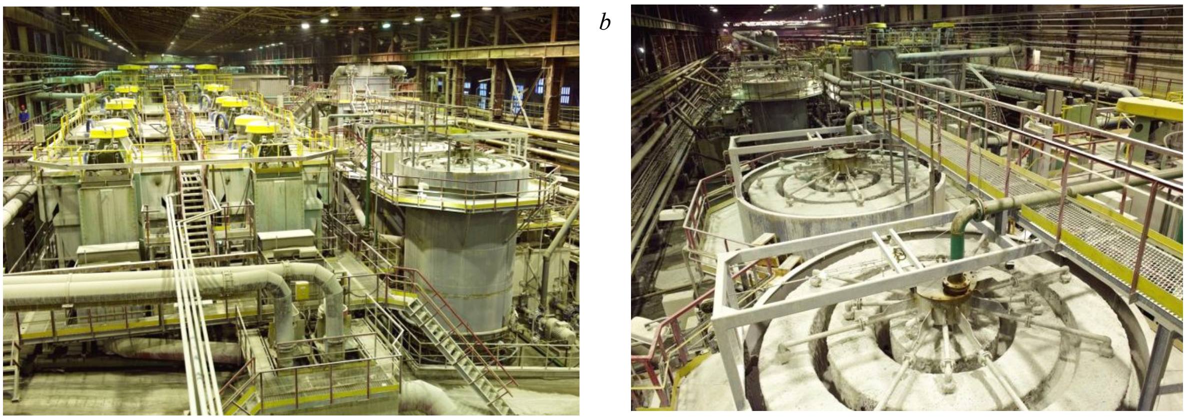

Fig.6. Flotation equipment of JSC «Apatit»: OK-38 (*a*), SPT (*b*)

JSC «Apatit» is constantly working on the technical modernization of equipment with the removal of physically and morally worn out equipment that does not meet modern requirements for safe operation and economic efficiency of production.

The main direction of work in the last 10-15 years in the field of the instrumental design of the flotation process was the replacement of small volume flotation machines at ANOF-2, which were of mechanical type FMR-6.3 in the operations of main and control flotation for machines of the pneumatic- mechanical type OK-38, and in the cleaning operations for the column pneumatic machines, which allowed to reduce the number of operations from three to one. This technological equipment allows to work stably with high performance when grinding ore with a minimum content of slurry fractions. At ANOF-3 they use only pneumatic-mechanical flotation machines OK-38, which for 25 years of operation proved their effectiveness and reliability (Fig.6).

The complicating factor of benefication of apatite-nepheline ores is the process of flotation in conditions of closed water circulation. Permanent salt accumulation predetermines the search for highly selective to apatite collection reagents, which are insensitive to hardness salts and efficiently operating at reduced pulp temperatures. As a result of many years of research from 2013, a new reagent is introduced into the composition of the collection mixture.

In conditions of variability of the material composition of the processed ores, along with the use of the most effective hardware design of technological processes, the role of the availability of modern analytical control for the operational management of the flotation of apatite-nepheline ores is growing significantly.

More than 20 years of successful work at ANOF-3 allowed to develop general technical requirements for constructing an advanced automated system of analytical control of ASAC in operating concentrating plants (Fig.7). At present, ASAC technical re-equipment at ANOF-3 and ANOF-2 has been completely done; HERZOG (Germany) sample preparation equipment has been modernized; sections are equipped with ABB robot (Sweden); high-performance X-ray spectrometers ARL9900 LP (Switzerland).

Integration of ANOF-2 and ANOF-3 plants into the automated process control system data on the analytical control allows the technologist to obtain quality characteristics (mass fractions of P_2O_5 and Al_2O_3, mineralogical express analysis) of crushed ore, flotation concentrate and technological tailings and to perform instant control of the production.

The key step in improving the technology of benefication of apatite-nepheline ores in recent years has increased the efficiency of grinding operations.

A specific feature of apatite-nepheline ores is a sharp difference in the hardness of the main ore-forming minerals. If the microhardness of apatite is 523 kg/mm^2, nepheline, titanomagnetite and other minerals – 750 kg/mm^2 and more. This feature leads to an increased selective crushing of apatite in comparison with nepheline and accompanying minerals during ore preparation.

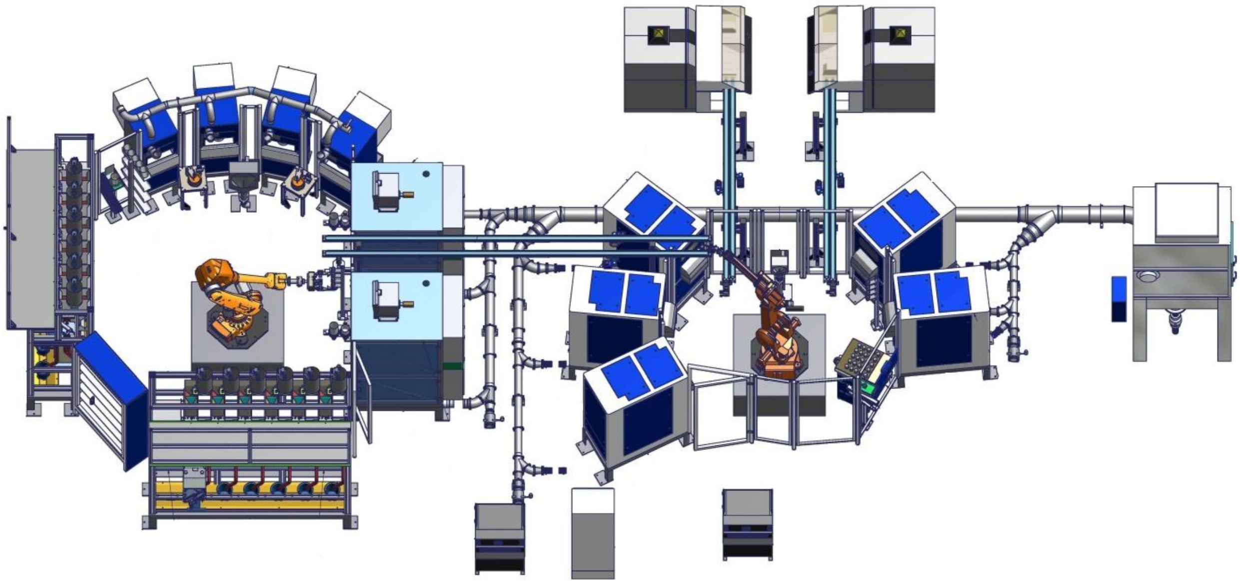

Fig.7. The layout of the main equipment of the modernized ASAC system

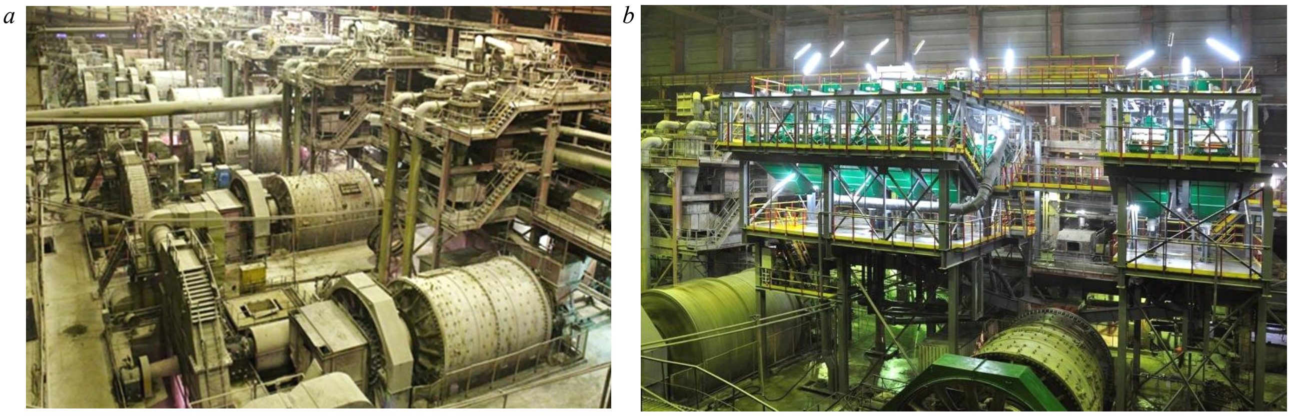

Fig.8. Crushing of apatite-nepheline ore with the use of wet (a) and fine screening (b)

The low efficiency of classification in hydrocyclones has negative technological and economic consequences. The re-grinding of apatite worsens the flotation and dehydration indicators in the production of apatite concentrate, complicates its transportation, loading and processing at chemical enterprises. High circulation load on the mills leads to a decrease in their productivity, an increase in the specific electricity consumption, as well as wearing out of steel balls and lining, high consumption of process water and other indirect materials.

At the ANOF-3 plant, a program for the technical re-equipment of the separation system in the ore grinding cycle with the installation of screens Derrick (USA) and LandSky (China) in a closed cycle with a ball mill BMC 5.5 × 6.5 (Fig.8) [4].

According to the results of industrial operation, there was registered not only the increase in the grinding capacity up to 30 % (from 310-320 to 380-400 t/h) due to a reduction in the return of the grinded product back to the mill, but also an increase in the feed size of flotation with sufficient recovery of apatite. According to the mineralogical analysis, the number of released apatite grains with other minerals in large classes of the sub-screen product of screens is significantly less than in similar hydrocyclone discharge classes. It means, in the first place, more favorable distribution of P_2O_5 by the size classes for the flotation separation of the screened product, with a higher degree of apatite exposure in its large grades. As a result, the class content of +0.16 mm in apatite concentrate increased to ~ 30-35 % (TU 2111-040-00203938-98 as modified N 5).

As a result of the adjustment of apatite-nepheline ore crushing process to the maximum possible size with preservation of the ore grain release, optimization of the loading of ball mills and im-

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provement of the entire technological process of production of apatite concentrate are ensured. The main advantage of the technology of production of large grinded material is the reduction of slurry fractions in apatite concentrate, which allows to reduce its losses during dewatering, loading, transportation and unloading operations.

Increasing the efficiency of the classification of crushed apatite-nepheline ore significantly improved the technical and economic indicators of ore benefication. The main effect-forming factors of the modernization of the plants are:

• reduction of apatite-nepheline ore re-grinding and, correspondingly, specific consumption of electric energy by 20 %, grinding balls by 20 %, lining of mills and other consumables, increase of mills productivity by 25-30 %;

• optimization of the composition of the collection mixture and the consumption of expensive components in connection with the decrease in the specific surface area of the particles of crushed apatite-nepheline ore;

• increase in the yield of apatite concentrate by reducing losses with thickener sludges and filtrates.

In addition, the thickening process was changed using highly effective flocculants to reduce losses of apatite concentrate during removal of thickeners.

The complex of measures to improve the technological processes carried out over the last 10 years at the concentration plants of JSC «Apatit» allowed to create and implement a new strategy for the development of benefication facilities, the basis of which was the development of a more modern and technologically efficient ANOF-3 plant to a capacity of 9.0 million tons of apatite concentrate per year and the creation of production of nepheline concentrate with the capacity of 1.3 million tons per year. The ANOF-2 plant is used for processing low-grade and unpayable ores that, after reviewing the conditions for open mining operations (the reserves of the Rasvumchorr and Nyorkpakhk deposits on boundary value of 2 % P_2O_5 instead of 4 %), became economically efficient to recycle. Investments in the development of benefication facilities in the period of 2012-2018 amount to about 13 billion rubles.

The most acute problem of the rational use of mineral raw materials is the problem of nepheline, the second most valuable mineral of the Khibiny ores. Because of the limited demand, nepheline concentrate is produced in much smaller volumes than current technology allows at the existing level of ore processing.

The volume of production of nepheline concentrate directly depends on the demand of the only enterprise in Russia – the processor of nepheline concentrate – CJSC «BazelCementPikalevo». Products of complex processing of nepheline concentrate are alumina, aluminum hydroxide, soda, potash, cement. Despite the complex processing of nepheline concentrate, high energy inputs for the production of marketable products and relatively low productivity are the main disadvantages of the development of mixing technology based on wet mixing of nepheline concentrate and limestone. It is necessary to switch to modern intensive methods of dry batch preparation by analogy with the dry method of cement production.

In order to increase the efficiency of refining nepheline concentrate, «PhosAgro», within the framework of the program for modernization of the Pikalevsky industrial complex, developed under the guidance of the Ministry of Industry and Trade, conducted pilot-industrial tests of the new energy-saving technology of dry limestone-nepheline sintering with FLSmidth (Denmark) and the St. Petersburg Mining University. The test results confirmed energy savings of 25 % and an increase in sintering equipment productivity by 25 %, which significantly improves the economic performance of nepheline concentrate processing.

In recent years, the Kola Science Center of the Russian Academy of Sciences has been actively developing the chemical processing of titanium-containing minerals (primarily sphene) into efficient TiSi sorbents possessing unique sorption properties for purification of liquid radioactive waste and contaminants. The results of tests of laboratory samples show the promise of using these sorbents for purification from radionuclides. In the near future, pilot-industrial tests will be carried out on the development of the sorbent and its testing for sewage treatment at industrial facilities of the Kola Peninsula [2, 9].

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The company «PhosAgro» has its own technologies for the production of all mineral concentrates of complex processing of apatite-nepheline ores – syenite, titanomagnetite, sphenic, aegirine and the ability to meet the demand of Russian consumers. The main application areas of the concentrates mentioned above are metallurgy, oil production (drilling muds), construction materials (special concrete grades, geopolymers), glass industry (ceramics and dark glass production).

The company «PhosAgro» implemented in the period 2013-2015 a full range of works on the development of technology and the realization of the project for extracting rare-earth elements at enterprises processing apatite concentrate in mineral fertilizers independently (JSC «PhosAgro-Cherepovets») and involving the developments of the St. Petersburg Mining University in the framework of the Federal Target Program «Research and Development for Priority directions of development of the scientific and technological complex of Russia for 2007-2013».

JSC «PhosAgro-Cherepovets» together with the engineering chemical-technological center «RusRedMet» (St. Petersburg) developed the process of extracting rare-earth elements from wet-process phosphoric acid. The design documentation was completed by the Russian design institute and passed the necessary examination. In the period 2011-2015 a full range of research and design works, manufacturing, including original and non-standard equipment, construction and installation works, commissioning and adjustment of the process at industrial scale. The technology is protected by patent No. 2528692, «The method of extracting rare-earth elements from wet-process phosphoric acid during processing of Khibiny apatite concentrates» [5], all the basic technological equipment and technical documentation were manufactured and developed by Russian organizations. The practice of production of wet-process phosphoric acid, the developed technology for obtaining pure collective concentrates of light and medium-heavy groups was realized for the first time.

The required technical documentation (TU 1767-001-10563112-2013) has been developed for the produced concentrates, they have been studied by Russian and foreign specialized institutes. A modern material and methodological base for instrumental analysis of the technological process, working media and finished concentrates has been created. The consistently high quality of the concentrates produced, the lack of radioactivity and the technological possibility of their separation into individual REE of high purity by traditional methods are confirmed [7, 8].

In 2014-2015 years two batches of REE carbonates of the medium-heavy group of 240 kg were delivered to the Russian consumer as part of the implementation of the program for the development of the REE industry, which was an integral part of the state program «Development of Industry and Enhancing Its Competitiveness for the Period to 2020».

During the operation of the pilot plant, collective light and medium-weight group carbonates were produced in the amount of 14 and 1.2 tons, respectively. The largest Russian technology companies (Rostekh, RosAtom, TVEL) were informed of the beginning of industrial production of REE concentrates, their quality and volumes.

At present, JSC «PhosAgro-Cherepovets» continues to work together with ICTC «RusRedMet» to separate complex REE concentrates into individual REE oxides, samples of individual oxides of lanthanum and cerium have been obtained.

Thus, JSC «Apatit» has a long-term program for the development of the crude ore resources, benefication facilities with the integrated use of apatite-nepheline ores, applies modern scientific methods and engineering solutions to ensure rational use of subsoil materials and provision of safe mining conditions, it actively introduces the developments of leading Russian scientific organizations.

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