SOLUTION OF ENVIRONMENTAL PROBLEMS IN MINING INDUSTRY AS A PART OF ITS DEVELOPMENT STRATEGY

Nikolai Melnikov, Svetlana Mesyats, Vladimir Skorokhodov, Roman Nikitin

Abstract: Global character of ecological issues induced by natural resources consumption volumes determines a strategy of mining industry development consisting of reducing mining-induced impact on environment at increasing minerals production and processing efficiency. The methodology has been developed of integrated solution of tasks on solid mineral deposits exploitation based on informational technologies of objects modeling, mining-benefication industrial processes and geotechnologies. The methodology ensures increase in efficiency, industrial and ecological safety of production and processing of mineral raw material. Concerning the Kola mining industrial complex were developed innovative production and processing technologies for ore and mining-induced mineral raw material, water-preparation and waste water purification as well as rehabilitation of rock dumps.

Key words: mining industry, environmental strategy of development, modeling, innovative technologies.

INTRODUCTION

Among many problems induced by intensive industrial development the problem of human and environmental interrelation is distinguished by its multi-aspect characteristics. The main environmental impact of mining industry is recovery and removal of huge rock masses which lead to changing natural relief forms, occurring new man-made objects, transforming original mineral substances, and stockpiling newly-formed ones (Fig.1).

Fig.1. Impact zone of a mining enterprise

Geomechanical disturbances related to changes in bedding and country rocks lead to activating landslides, mudflows, as well as seismic and geo-cryogenic processes. Landscape damage results in changing dynamic characteristics of air streams and generating new microclimatic territorial conditions as well as changing hydrographic network conditions. Destruction of soil and vegetation covers results in erosion processes and pollution of considerably larger territories than those of enterprises' mining allotments.

Strategies designed for developing subsoil use should be aimed at keeping and restoration of natural environment, as accumulated waste had disturbed natural balance of biospheric processes and, accordingly, quality of life environment. Analysis of a current environmental setting in the world requires radical revision of methods and approaches for deposits developments. Understanding of global character of ecological issues induced by natural resources consumption volumes determines a strategy of mining industry development consisting of reducing mining-induced impact on environment at increasing minerals production and processing efficiency and providing integrated innovative solution of tasks on useful mineral deposits exploitation.

Informational technologies applied for modeling production objects, mining-benefication industry processes and geoecotechnologies have become a basis for developing the methodology of integrated solution of tasks on solid mineral deposits exploitation which ensures decrease of mining-induced load on environment. In accordance with the methodology a 3D digital model of baddeleite-apatite-magnetite deposit, perspective apatite-shtafelyte and apatite-carbonatite deposits of the Kovdor ore cluster has been created with differentiation by content and reserves of principal components and by-products. It allows assessing $Fe_{tot.}$, P_2O_5, and ZrO_2 content determining industrial potential and perspectives of long-term regional development (Fig.2).

On the basis of the engineering-geological deposit model was developed a technology for constructing open-pit wall with benches having vertical slopes [1, 2] which ensures reserves growth by 40-50% at decrease of an average overburden ratio by 18-20%, allows reducing specific (per ore

ton) areas of overburden dumps, and decreasing environmental impact (Fig.3). The project for a new stage of the Kovdor iron deposit development has been implemented. It increases an open-pit's project depth along a closed contour from 565 m to 875 m, reserves growth by 470.3 mln t ore and reserves provision from 16 to 45 years.

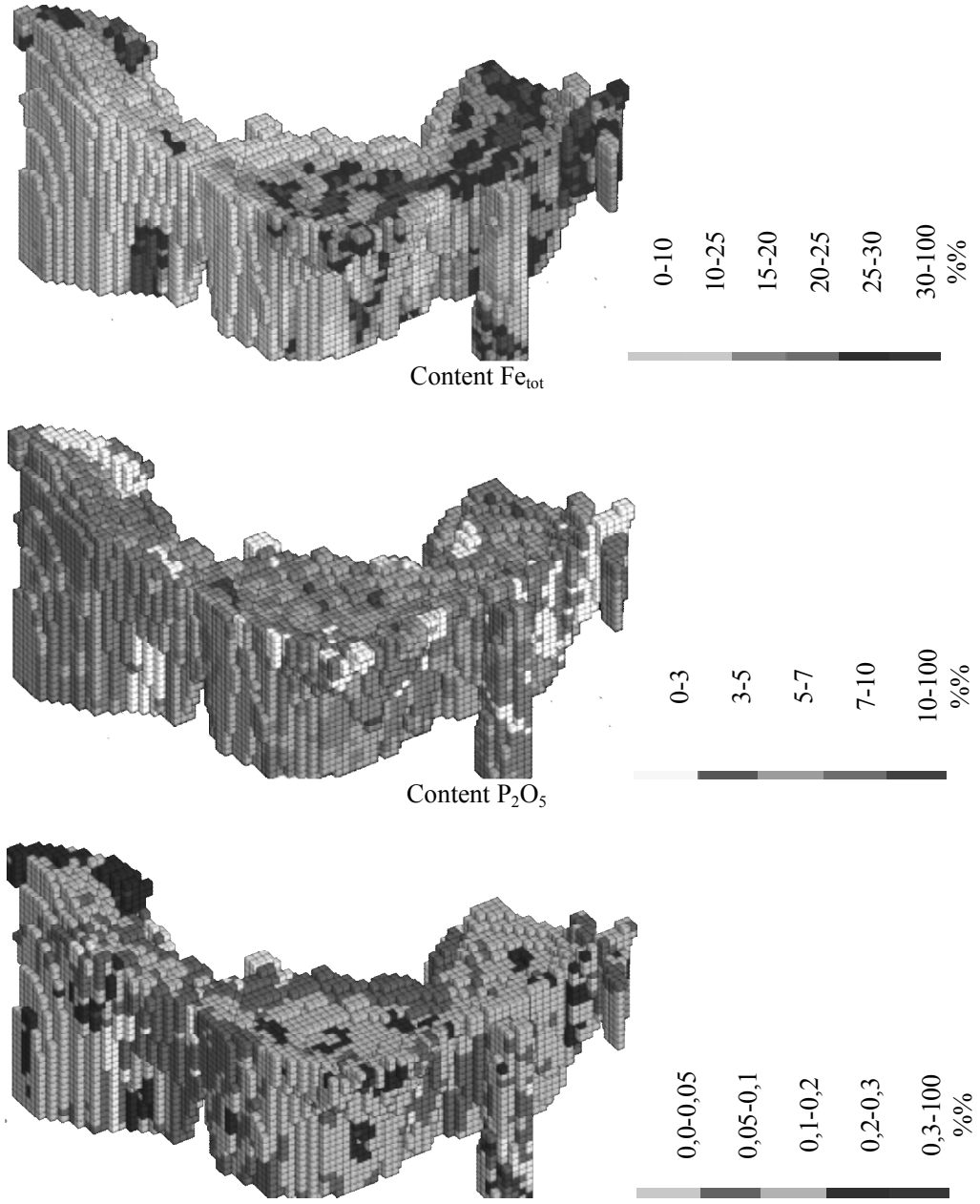


Fig.2. Differentiation by content and reserves of principal components of baddeleite-apatite-magnetite deposit, perspective apatite-shtafelyte and apatite-carbonatite deposits of the Kovdor ore cluster made by 3D digital model

Fig.3. New construction of open-pit wall

Open-pit wall monitoring system has been established in order to increase industrial safety during open mining in new-generation open-pits. It units analogue and digital blocks having functions of seismic stability control, high-accuracy surveys and satellite geodesy, control for geomechanical conditions of near-contour rock masses. The investigations were performed of structural-geological particularities of country rocks, and dynamic impact of balk blasts on beyond-contour rock mass.

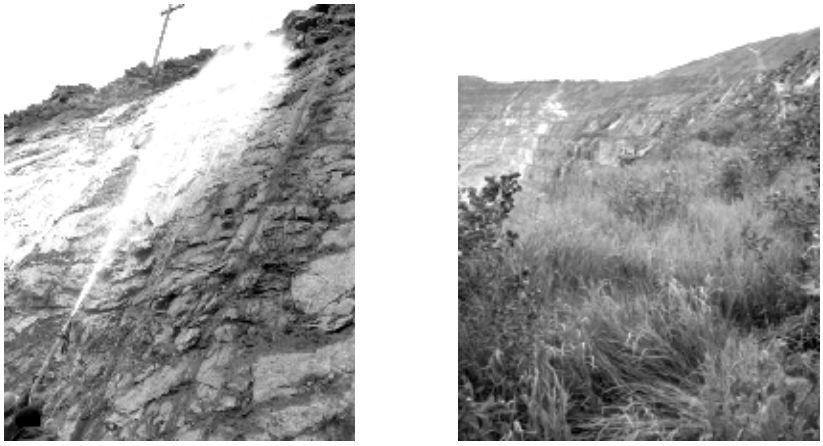
Automated integrated monitoring system for in-pit atmosphere has been designed and implemented at the "Kovdorskiy GOK" JSC [3]. It includes monitoring of meteorological conditions resulting in contaminants accumulation in working zones; monitoring of in-pit atmosphere composition allowing correlating pollution levels with any meteorological situation, and snow-survey characterizing distribution of pollution along the open-pit depth. The system's on-line functioning and formation of a unique informational resource for database supporting are provided by generating a software complex and GSM communication channel which allow remotely controlling its functioning and transfer atmosphere data to conditions the enterprise's server. The automated system includes monitoring network of meteorological and gas-analytical stations in the open-pit and a computer module responsible for monitoring data collection and treatment and communication equipment. The forecast is built on following parameters: generally available synoptic information; actual monitoring data on in-pit atmosphere; modeling results of wind streams movement and circular zones generation; and mathematical models of pollution distribution in in-pit atmosphere. Creation of the informational resource gives an opportunity to analyze open-pit atmosphere conditions in order to obtain reliable forecast ensuring relevant managerial decisions-making while mining planning.

Perspective of considerable deepening of open-pits and formation of large areas with vertical or steep-inclined slopes on limited contour elevates actuality in increasing stability of benches in ultimate position. This, together with technological factors, is determined by rock weathering intensity. As is known, weathering changes chemical composition and properties of rocks on slopes' surface, and disturbs near-contour rock mass structure due to frost-shattered fracturing which leads to rocks falling. In order to increase industrial and ecological safety of open mining operations there were developed methods of supporting benches elements in ultimate position. These consist in covering bench slope with polymer compositions in order to reduce weathering intensity and create a sod layer on safety berms with the aim to increase their buffer properties (Fig.4) [4, 5].

Studies have shown high resistance of the polymer cover to radiation, photochemical and temperature impacts and aggressive environments, and considerable decrease of rocks' chemical weathering due to surface preservation from direct impact of atmospheric precipitation and gases. Creation of the sod layer on safety berms increases their buffer properties, contributes to replenishment of oxygen in open-pit atmosphere, develops in-pit air circulation and decreases harmful mixtures concentration in open-pit atmosphere.

An innovative technology has been designed for deposits underground mining under ecological restrictions with preliminary concentration of broken ore and waste rock disposal in mined space. It is based on computer modeling of mining-geological objects by Mine Frame software designed by specialists of the Mining Institute KSC RAS [6].

The deposit's zoning cy useful components content in ore ensures ore quality managing when forming freight flows entering for preliminary concentration.



a b

Fig.4. Supporting of bench elements in ultimate position by applying the polymer cover (a), by creating the sod layer on safety berms (b)

Its priority trend are: reuse of underground mined space and mining-induced raw materials; underground preliminary concentration of broken ore; disposal of concentration equipment with minimum environmental damage (including underground conditions); integrated extraction of useful components; use of closed water-recycling system; diesel to electric transport transition; monitoring of conditions and rehabilitation of damaged natural objects. Implementation of underground preliminary concentration of broken ore and disposal of non-conditioned ore in mined space into a technological production flowsheet is of special actuality when developing ore deposits with low content of useful components. Concerning the Partomchorr deposit with underground mine capacity up to 6 mln t per year, the technology designed allows eliminating waste rock delivery to surface, improving geomechanical conditions in the rock mass, reducing volumes of waste rock and non-conditioned ore intended for concentration by 27%; increasing ore quality in 1.4 times (1% separation threshold); decreasing costs for ore transporting and concentrating as well as for tailings construction by 20%; and decreasing mining-induced impact on environment.

On the basis of mining-geological objects modeling a methodical approach has been developed for determining freight flows parameters at underground mining. It consists of generating blocked models of ore bodies on borehole sampling data and in accordance with constructive particularities of excavation units. Information concerning useful component distribution in every block allows reducing costs for underground preliminary ore concentration, rich ore being delivered directly to a processing plant.

Feasibility study of external ore transportation to a concentration plant of the mining-processing complex Oleniy Ruchey is based on ecological aspects concluding in using conveyer transport on protected territories. This approach considerably reduces volume of earth works; provides short terms of route construction; eliminates freight dusting on a main route's part and necessity in constructing trans-shipping stations; decreases noise level during operations (less 55 Db at homing stations); and reduces environmental damages in a case of emergencies.

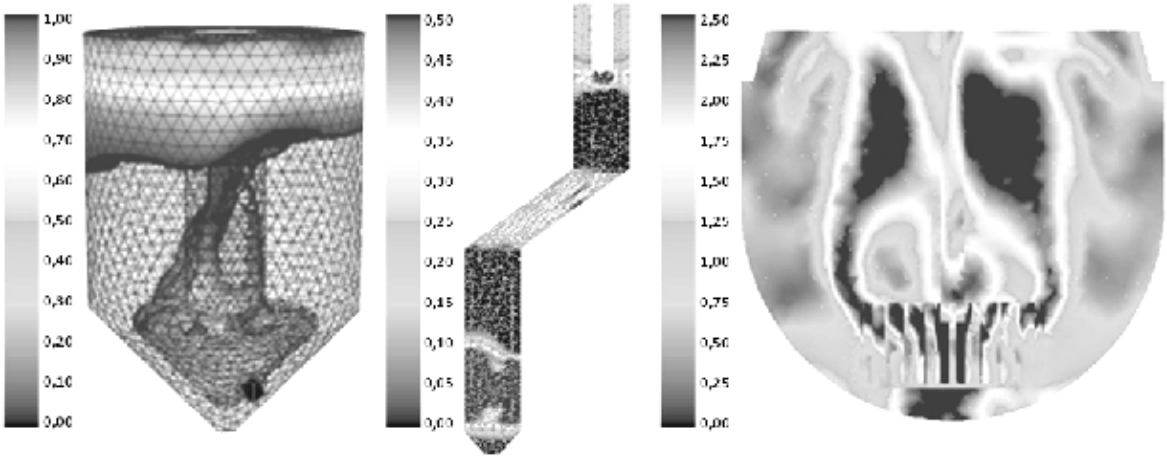
In order to increase integrity and full recovery of useful components providing decrease in industrial waste there have been developed innovative technologies of integrated processing of apatite-nepheline and apatite-carbonate-silicate ore and mining-induced mineral raw material on the basis of applying new reagents- collectors and reagent regimes. Reagents-collectors from bifunctional compounds have been verified for floating apatite-containing ore. Presence in a collector's molecule of two originally different functional groups with ionogenic and non-ionogenic characteristics defines its effective interaction with a mineral's chemically heterogenic surface. Flotation methods using hard-to-solve low-oxyethylated isononylphenoles have been scientifically developed and verified. These are based on increase in their solubility due to solubilizing ionogenic surface-active substances (SAS) in micellar dispersions and changing in

application conditions. Low-ethylate neonoles, for example H_{9-2}, are dissolved in micellar dispersions of an ionogenic SAS due to solubilization with formation of micelles with mixture composition. So, when a mineral's surface is hydrophobizated under flotation conditions combined adsorption layers are generated with increased oleophilic properties. The method developed of joint use of H_{9-2} and H_{9-10} neonoles when preparing solutions of solubilizator has been implemented into the production which has allowed optimizing ratio of a mixture components, reducing energy and labor consumption due to temperature decrease and shortening in time of solutions preparation and increase in flotation stability. At that, recovery of apatite increases by 1.5-2% at simultaneous decrease of reagent consumption by 25%, which defines increase of industrial ecological safety [7].

In order to extend size range of extracted useful components and involve stockpiled concentration waste into processing there have been developed topology-creating principles for technological flowsheets and technologies of ore and mining-induced zirconium-phosphor-containing raw materials.

Databases of fundamental achievements in natural sciences and physical, chemical and physical-chemical properties of minerals have become a basis for designing CFD (Computational Fluid Dynamics)-models [8]. The models simulate separation processes of mineral components in working volumes of advancing and constructed concentration devices. Fractional separation characteristics obtained after computational tests analyzing have become foundation for imitation models of technological chains of mineral raw material processing. These are based on using mathematical modeling methods for constructing optimal topologies of technological flowsheets for complex ore processing. A unique methodical approach to technological processing flowsheet design gives opportunity to simulate work of a designed device within a technological chain and realizes feedback with its designing which at the end contributes into creation of effective technologies.

Computer modeling and computation hydrodynamics tool application have designed functioning models of flotation, magnetic-gravity and gravity equipment (Fig.5). Computation experiments have become a basis for designing new constructions of magnetic-gravity [9] and gravity separators [10] and devices for distributing activated water dispersions of air in flotation [11].



a b c

Fig. 5. Graphical image of CFD-models working results in different concentration devices:
a) concentration areas of fractions with different magnetic susceptibility in magnetic-gravity separator;
b) heterogenic medium velocity field in hydraulic separator;
c) heterogenic medium velocity field in flotation chamber

Application of the magnetic separator with advanced magnetic system during processing ferrous quartzite (the Zaimandrovskaya deposits group) ensures increase of Fetot content in magnetite concentrate up to 70% at decrease of energy consumption up to 40%. Separation of fine mineral particles with segregation between inclined separator plates during processing the same raw material

allows increasing Fetot recovery by 4% at refinement of rough hematite concentrate.

Application of a device with radial distribution of activated water dispersions of air at reverse nepheline flotation from current apatite waste allows increasing Al_2O_3 recovery by more than 1% into nepheline concentrate with Al_2O_3 content and managing to decrease collector consumption up to 40%.

Decrease of industrial waste is reached not only due to increasing full recovery of useful components but also as a result of involving stockpiled ore concentration waste (Fig.6).

The "Kovdorskiy GOK" JSC is the first Kola mining industrial enterprise processing waste from the magnetic-concentration plant after the technology developed jointly by specialists from the Mining Institute KSC RAS and enterprise specialists. For the exploitation period of the mining-induced deposit there had been processed more than 60 mln t of initial raw material, and produced additionally 7.09 mln t of apatite concentrate and 32.800 t of baddeleite concentrate.

Optimization of technological processing flowsheets has allowed developing:

- Technologies for complex concentrating mineral raw material from the mining-induced deposit ("Kovdorskiy GOK" JSC) providing production of conditioned concentrates such as apatite concentrate (570,000 t/y at P_2O_5recovery up to 60%), baddeleite concentrate (3.000 t/y); iron, apatite and rough baddeleite concentrates as recovery 23%Fe_{tot}, 42.3% P_2O_5 and 25% ZrO_2;
- The resource-saving gravity-magnetic technology for mining-induced raw material processing ("Olkon" JSC) which ensures production of conditioned iron concentrate at recovery Fe_{tot} above 50%;
- Combined flotation-magnetic technology for integrated concentration of mining-induced raw material ("Apatit" JSC) which provides production of conditioned apatite concentrate (78% P_2O_5 recovery) and nepheline concentrate (argil recovery up to 70%).

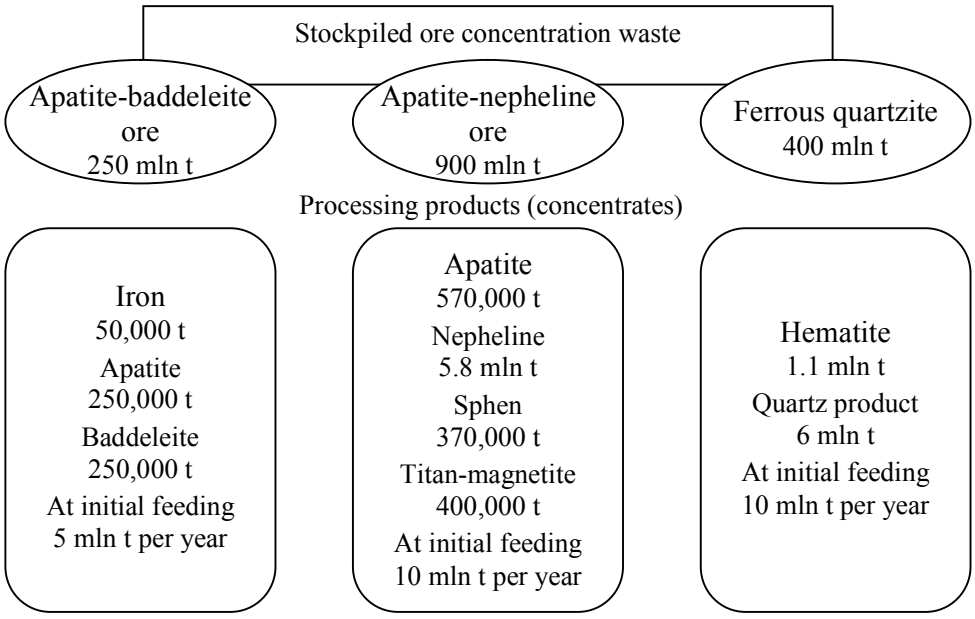


Fig. 6. Mining-induced deposits of Kola mining industrial

One of main tasks on decreasing mining-induced load on environment set before mining industry is reducing waste water volumes after its using with technological aims, and waste water purification during its secondary utilization and discharge into natural water bodies. Requirements to modern waste water purification methods consist in achieving high purification degree at decreasing volumes intended for recycling.

There has been designed an up-to-date technology of waste water purification from multi-component contaminations after coagulation, sorption and flotation in activated water dispersion of air at accumulating contaminants in multi-phased system in one volume [12]. The technology allows

delivering 80% of purified water into circulating water supply of an enterprise. This reduces fresh water consumption and waste water volumes discharged into natural water bodies. The technology ensures a required purification degree regardless of contaminations at the input and doesn't require suspended particles to be preliminary precipitated. Industrial testing evidences high competitive availability of the technology compare to known waste water purification methods. Implementation of the technology for purifying waste water allows reducing waste water discharge by 5.7 mln m^3/y at following parameters (Table 1).

According the project, the water from boreholes for lowering the water table in the open-pit's mining allotment is planned to be used after its purification instead of water from a natural basin. So, the technology will allow using all the water which is currently pumped from the open-pit and discharged into the lake for technological aims.

Competitive advantages of the proposed waste water purification technology are absence of necessity in preliminary precipitation of suspended particles; decrease of purification cost due to using several water purification processes in one volume; use of low-pressure air during flotation in activated water dispersion of air. Nowadays engineering documentation for devices having different dimension-type has been developed with productivity from 5 to 350 m^3 waste water per hour.

Table 1. Waste water purification parameters

Indicators	Suspended substances	Dry weight	NH_4	NO_3^-	NO_2^-	Cl^-	Н/пр.	SO_4^{2-}	P_2O_5	$Fe_{общ.}$	Mn^{2+}	Cu^{2+}
Before purification	100.5	585.3	7.3	30.92	2.11	26.3	1.2	172.4	1.33	0.37	0.2	0.06
After purification	0.1	44.0	0.09	0	0	30.1	6e-4	5.35	0.1	0.013	0.03	0.002
Purification degree, %	99.9	92.5	98.8	100	100	88.2	99.5	96.9	92.3	96.5	85.0	96.0

As a rule, impact zones of mining enterprises are zones of crisis environmental state as a result of almost full destruction of soil-plant cover which is a natural special resource and has the utmost customer value. Global character of the Earth's soil layer destruction and understanding of the fact that it is not only a basis for nature management but also a managing biospheric system, determine a task of damaged lands rehabilitation as one of the principal tasks for modern nature management which consists, first of all, in restoring ecosystemic functions of territories.

On the basis of analyzing factors limiting processes of damaged lands overgrowth a methodical approach has been established [13] to solve a problem of rock dumps rehabilitation. It consists in creating a plant cover without applying a fertile layer through optimizing seeded phytocenosis bioproductivity due to suppressing erosion processes, improving water-and-physical properties, and increasing biochemical activity of root layers.

A technology has been developed for mining-induced landscapes rehabilitation in the line with the evolutionary soil-formation concept according to which soil is a product of interrelation of matrix rock, biota, climate, relief and time.

Generation of seeded phytocenosis intensifies initial rehabilitation stages of biogeochemical circle which is the main mechanism for natural landscapes self-regulation; formation of biogenic-humus-accumulative layer on mineral substrates with following transfer to phytocenosis having a structure of a surrounding landscape which ensures remediation of ecological capacity of a landscape, and at the end – rehabilitation of ecological territorial functions. Formation of biologically active medium through creating seeded phytocenosis without applying a fertile layer solves rock dumps rehabilitation problem (Fig.7).

a b

Fig.7. Stockpiled ore concentration waste before (a) and after (b) formation of a plant cover without applying a fertile layer. Generation of seeded phytocenosis ensures: elimination of wind and water erosion, retention of substantial composition of mineral raw materials from mining-induced deposits

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РЕШАВАНЕ НА ПРОБЛЕМИТЕ НА ОКОЛНАТА СРЕДА КАТО ЧАСТ ОТ СТРАТЕГИЯТА ЗА РАЗВИТИЕ НА МИННАТА ИНДУСТРИЯ

Н. Мелников, С Месиац, В. Скороходов, Р. Никитин

Резюме. Глобалният характер на екологичните проблеми предизвикани от обема на консумираните природни ресурси определят стратегията за разитие на минната индустрия, редуцирането на отпадъчните минни продукти замърсяващи околната среда и увеличаването на ефективността на процесите за получаване на минерали. Методологията за това включва решаване на задачи за съхраняване на твърди минерали, основани на моделиране и на информационни технологии, на създаване на изгодни индустриални процеси и на геотехнологииге. Методологията осигурява увеличаване на ефективността, индустриалната и екологична сигурност на продукцията на първични минерални материали. Представени са примери от Колския минен концерн, включващи продукцията на необработени минерални материали, пречистването на производствените води и възстановяването на скалните отпадъци.

Ключови думи: минна индустрия, екологична стратегия за развитие, моделиране, иновативни технологии.

N.N.Melnikov
Academician RAS, Professor
Director MI KSC RAS
melnikov@goi.kolasc.net.ru

S.P.Mesyats
Head of laboratory of geoecotechnologies
mesyats@goi.kolasc.net.ru

V.F.Skorokhodov, Dr. Sci. (Eng.)
Head of laboratory of new technological processes and devices
skorohodov@goi.kolasc.net.ru

R.M.Nikitin, Researcher
remnik@yandex.ru