UDC 622.271.06.22

S. V. LUKICHEV[1], *Acting Director, Doctor of Engineering Sciences*
E. V. GROMOV[1], *Researcher, Candidate of Engineering Sciences, evgromov@goi.kolasc.net.ru*
E. A. LOBANOV[2], *First Vice Chief Executive Officer—Technical Officer*

[1]*Mining Institute, Kola Science Center, Russian Academy of Sciences, Apatity, Russia*
[2]*North-Western Phosphorus Company, Kirovsk, Russia*

EVALUATION OF PROSPECTS FOR APATITE–NEPHELINE MINING AT PARTOMCHORR*

This article is an attempt of an integrated approach to the manysided problem connected with the assessment of the expediency of subsidiary mineral development within the mining and processing industry of the Kola Peninsula. The chosen object of the research is low-grade apatite-bearing ore deposit Partomchorr mineability of which is complicated by the remote distance to the regional transport infrastructure, by the severe Arctic climate, adjacency to nature-protection areas and by high tectonic stresses that make the deposit rockburst-hazardous.

The scope of the discussion embraces three layouts of a mining and processing plant, with different mining methods and infrastructure arrangement. The integrated analysis of the layouts includes 3D modeling with the appraisal and distribution of useful components, justification of geotechnical solutions, development and evaluation of ore transportation routes to the processing plant, selection of ore concentration technology, assessment of cost of construction and estimation of the environmental impact of mining and processing.

As a result of the research performed, mineral reserves appraisal and distribution of useful components inside the deposit are refined, the main geotechnical solutions are justified, and the promising scenario of ore haulage from the mine to the 30 km away processing plant is proposed. The technical and economic evaluation of the mining and processing plant construction scenarios has shown negative profitability under the current market prices of apatite concentrate (~9,5 thousand Rub), even if the project solutions are going to be optimized. Investment in mining has payback period of 25 years given the concentrate cost is to 18 thousand Rub. The most efficient variant is the hybrid open pit/underground mining with the processing plant to be arranged at the site of the mine infrastructure.

Key words: *subsidiary mineral deposits, technical and economic evaluation, mining transport, underground and hybrid mining methods, open pit mine, underground mine, computer modeling*

DOI: *10.17580/em.2017.01.03*

Introduction

Modern reality mining industry in Russia and in the world features reduction in rich and readily accessible mineral reserves. The task of replenishment of mineral resources requires that low-grade and difficult-to-access minerals are involved in development together with the fields that occur in areas subjected to the environmental limitations [1]. Among such objects is Partomchorr apatite-bearing ore deposit. The current development process is constrained for such reasons as: low content of P_2O_5 (round 7.5%); absence of transport infrastructure; complicated climatic conditions; proximity of the to-be mine to Simbozero Wildlife Area and Khibiny National Park under project; high tectonic stresses that make the deposit rockburst-hazardous [2]. The latest appraisal of the mineability of the deposit made 10 years ago showed its inefficiency [3]. In the course of the years, the market situation changed many times, mining and processing technologies and equipment were upgraded, new modern software programs appeared for geological modeling and reserves assessment [4]. In this connection, it became necessary to re-appraise in-place reserves and revise mineral mining technology. Unstable prices of minerals governed the efficiency assessment of mining in terms of a pricing scenario. The implementation of the tasks is possible using the computer modeling of objects and processes included in the geotechnology [5–7].

To this effect, the computer-aided research was performed in order to find and justify the most rational variant of mineral mining. As a part of the research, 3D models of the deposit were constructed, reserves and distribution of useful minerals were adjusted, geotechnical solutions on mining were justified, various layouts of ore transportation to a processing plant were reviewed and their feasibility studies were completed, ore processing technology was selected, construction cost of the processing plant was evaluated and environmental impact of mining and processing was assessed.

Digital geological modeling of the deposit and mining and processing infrastructure layout solutions

Using the geological information system MINEFRAME and borehole sampling data, the framework and block models of the deposit were constructed, and economic and uneconomic reserves were estimated per geological blocks, as well as the distribution of basic and associated minerals was revealed [8, 9]. The results of the reserves appraisal both across the deposit and per ore bodies appeared akin to the earlier estimate (approved by the USSR State Reserves Committee as of July 7, 1978). On the other hand, distribution of useful components per calculation blocks differed by 20–30% sometimes, and the difference exceeded 30% in a few blocks. The reliability of 3D modeling data were proved by the check-up assessment using the method of polygons and backed with the more accurate consideration of interdependence and spatial arrangement of geological exploration holes.

In line with the geological modeling, the scope of the research embraced a few construction layouts at Partomchorr deposit:

*The studies have been supported by the Russian Academy of Sciences, Basic Research Program No. 5: Strategic Mineral Deposits in Russia: Innovation Approaches to Forecasting, Appraisal and Mining.

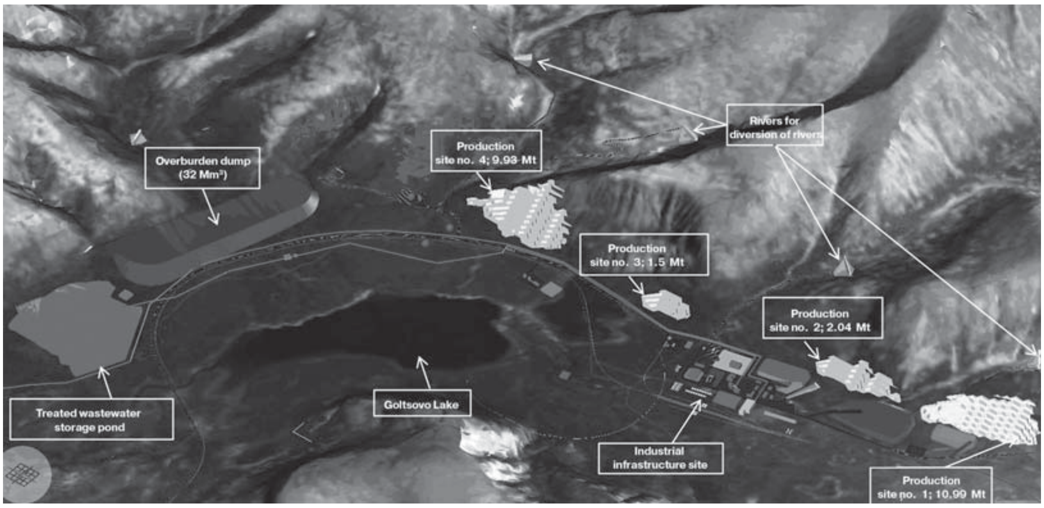

Fig. 1. Layout no. 2 for construction of mining and processing plant

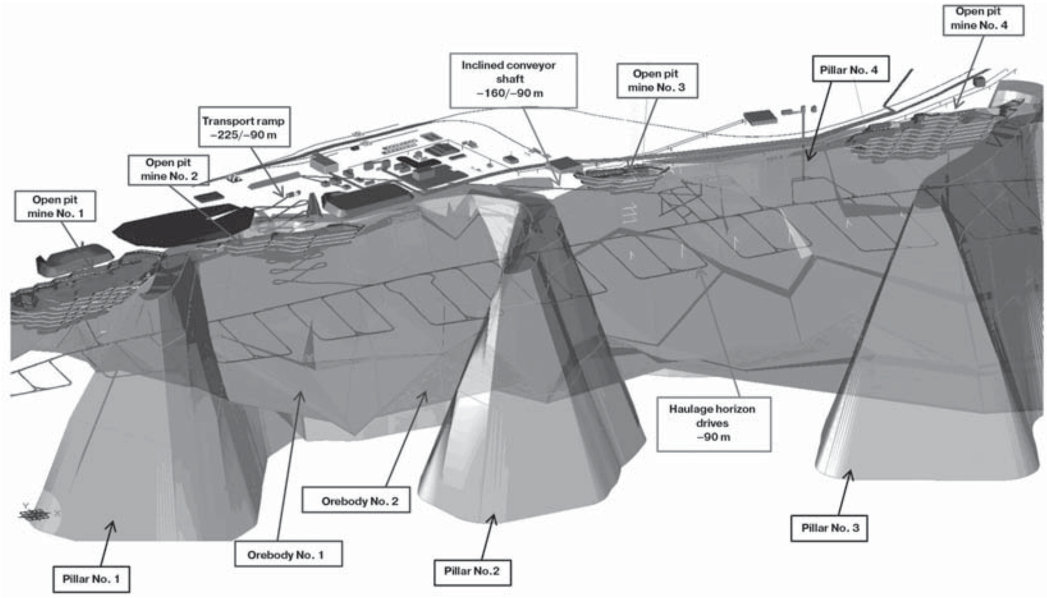

Fig. 2. Mining stage 1, down to level −90 m, in accordance to layout no. 2

1) a full-cycle mining and processing plant with mineral extraction using the underground method and with all processing areas arranged on the surface in the territory of the deposit;

2) the same with the hybrid mining method;

3) an underground mine with the processing plant constructed on the site of Oleni Ruchey mining and processing works.

In accordance with the proposed construction layout solutions, digital models of the surface relief and ground and underground infrastructure were built-up, and the boundaries of open pit and underground mining were determined (**Figs. 1** and **2**).

The cardinal difference between layout no. 3 and the two first layouts is the construction of the processing plant at the industrial site of Oleni Ruchey mining and processing works located 30 km off Partomchorr mine. Such arrangement requires an extended transport system under conditions of complex topography of the Khibiny. **Table 1** describes 8 probable scenarios developed for ore haulage with surface and underground routes.

Laying-out with regard to the location of the environmental protection areas allowed modeling transportation routes (**Fig. 3**).

Production forecasts and geotechnology justification

Economic evaluation of Partomchorr mining technology consisted of two parts: selection of efficient mining and transport system for layout no. 3 and cost-effectiveness evaluation of the three layouts [10, 11].

Modeling of construction and operation costs for transportation for the period of mining stage 1 showed that based on the minimum discount rate the most-preferred transportation variant was scenario no. 2 with the cable belt conveyors (**Fig. 4**). The previous research and the experience of cable belt conveyors operation in many foreign and some domestic mines showed that RBC were among the most efficient transport systems with the ore haulage capacity of 400 t/h for a distance

Table 1. Probable external transportation systems

Routes	Scenario no.	Mode of transport
Surface	1	Overhead conveyor RopeCon
	2	Surface cable belt conveyor
	5	Motor transport
	6	Rail transportation, track 1520 mm, Diesel operation
Under-ground	3	Belt conveyor
	4	Slurry pipeline in a trench
	7	Rail transportation, track 1520 mm, Diesel operation
	8	Conveyor-rails-truck haulage package Rail-Veyor, remote control

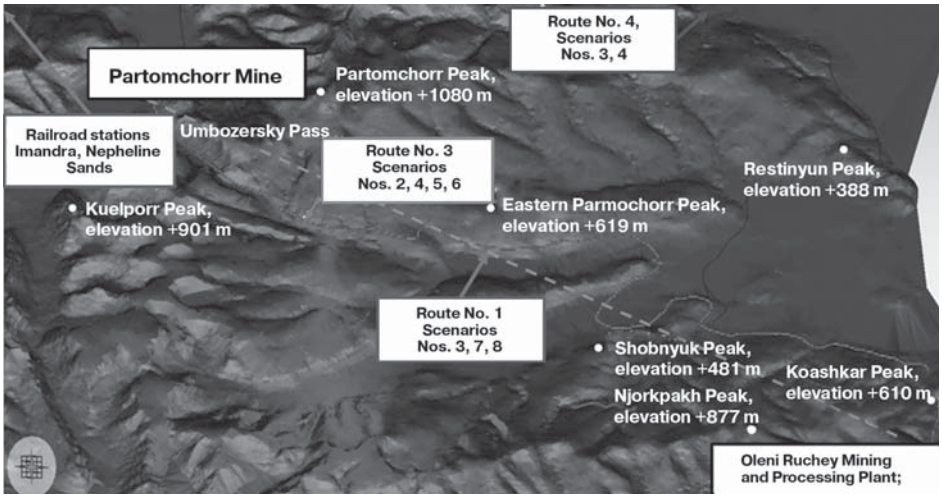

Fig. 3. Modeling transportation routes in MINEFRAME GIS

from 4 to 50 km, including the complicated topography and climate of the North. One of the examples is the Line Creek cable belt conveyor located inside the Elk Valley wildlife area, Canada, and having the length more than 10 km [12–14].

Then, the investment efficiency was evaluated for the mine layouts under analysis. The project capacity of the mine was assessed considering the requirement for the temporal pillars to be preserved under the surface water bodies, and made 7. 5 Mt of ore annually. Geological reserves totaled more than 840 Mt out which mining stage 1 embraced 330 Mt of ore. The calculated data are reported in **Table 2**.

The calculated data showed negative NPV for all scenarios and the absence of the discount payback at mining stage 1. For this reason, the minimum cost of apatite concentrate so that profitability was positive was evaluated. It was found that the return of investment began from the apatite concentrate cost starting from 18 thou Rub/t: in 28 and 24 years for layouts no. 1 and 2, respectively, while layout 3 yet had no period of payback.

For the most-preferred mining and processing layout no. 2, the environmental impact of the production was evaluated and the nature-conservative measures were developed. The previous studies of the hybrid mining approach [3] suggested dividing the industrial infrastructure site into: a main site (including the processing plant arranged at a distance of 7 km from the mine), an open pit mine area (two extraction sections) and an underground mine. The longer haulage

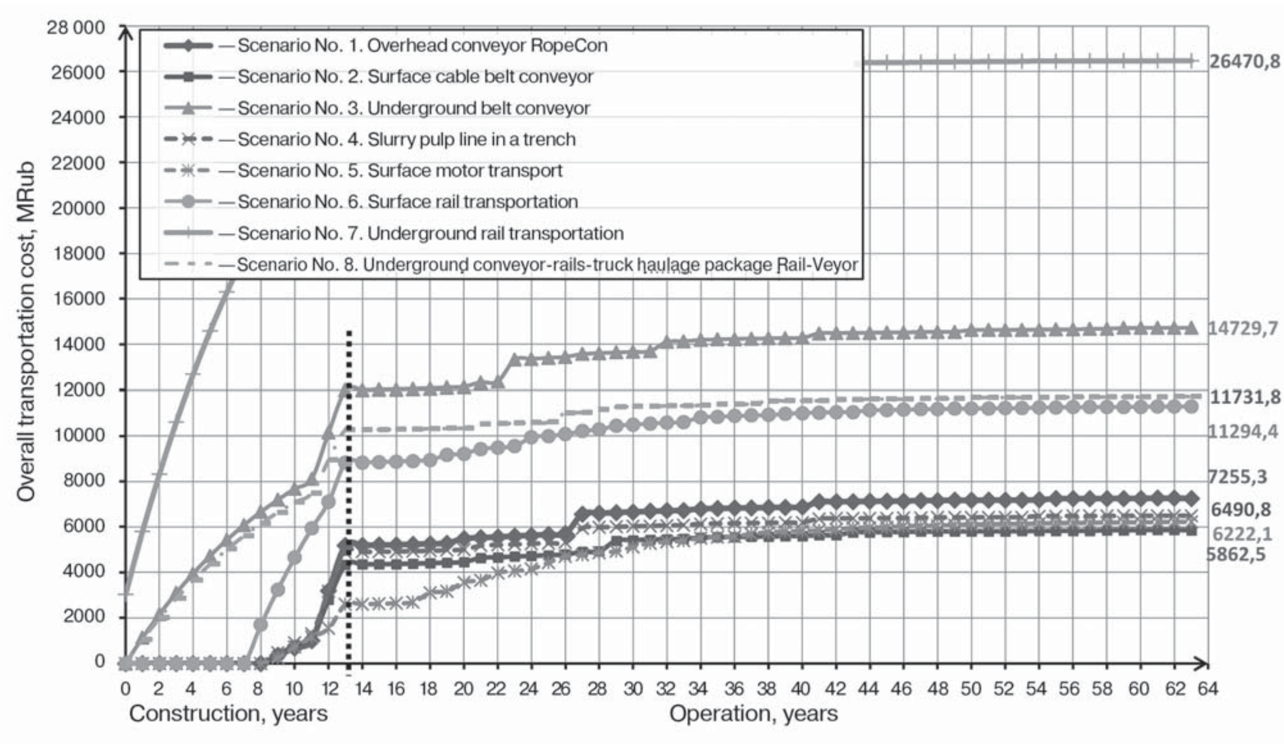

Fig. 4. Modeling construction and operation costs of external transportation on an accrual basis (discount rate of 10%)

distance became one of the sources of the unprofitable operation in accordance with that layout as well as entailed amortization of vast lands and enhanced the environmental impact in the region of Simbozero Wildlife Area. The presented research provided for separation of open pit mining into 4 small-area extraction sections, which, together with the closer space arrangement of the other infrastructural objects of the mining and processing plant, allowed their accommodation on the same site. All that enabled enhancing commercial viability of the mining and processing plant construction in accordance with the specified layout and abated environmental pressure in the unique natural and climate zone of the Arctic.

Table 2. Production forecasts

Index	Mining and processing plant layout		
	No. 1	No. 2	No. 3
Average content of P_2O_5 of geological reserves, %	7.49	7.49	7.49
Loss/dilution (open pit mining), %		5.61 / 7.55	
Loss/dilution (underground mining), %	20.3 / 17.8	20.3 / 17.8	20.3 / 17.8
Mining period (mine operation), years	50	51	50
Sustained operation period, years:			
— open pit mine		7	
— underground mine	38	35	38
Mining and processing plant construction period up to project capacity, years	16	21	16
Including up to first ore breakage	4	6	4
Apatite concentrate production (dry weight):			
— per years up to the project capacity	1080	1080	1080
— overall for the calculation period	45 987.8	45 987.8	45 987.8
Capital investment to gain the project capacity, MRub	41,920,5	41,676,1	52,656,0
Operational costs for the calculation period, MRub	399,522,4	395,764,9	429,356,4
Total cost of 1 t of concentrate (by reaching the project capacity), Rub/t	8,338,4	8,438,6	8,916,2
(NPV at the discount rate of 10%)	–22,600,7	–20,259,3	–31,923,1
Payback period PP, years	42	45	none
Discount payback period	none	none	none

Conclusion

In terms of Partomchorr deposit, the article describes an approach to evaluation of prospects for mining subsidiary mineral reserves based on the integration of the computer modeling and automated feasibility study. The authors think this approach allows all-inclusive consideration of the problem and its manysidedness, and enables avoiding a common ready-made opinion on parameters of mining, which prevents from the comprehensive analysis of the international achievements and from their adaptation to the conditions of a specific object.

As a result of the research performed, reserves of useful mineral components and their distribution inside ore bodies have been refined, basic decisions on mineral mining have been justified and the promising scheme for ore transportation from the mine to the processing plant located 30 km away have been proposed. The technical and economic assessment of the mining and processing plant layouts shows negative profitability at the current market price of apatite concentrate (~9,5 thou Rub) even in case of optimization of project solutions. The authors show that investment in mining is paying back in 24–28 years given the concentrate price is up to 18 thou Rub. The most efficient variant is the hybrid open pit/underground mining with the arrangement of the processing plant in the area of the mine infrastructure site.

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