Название инновационного продукта/технологии

Цифровая выемочная единица

Ключевые слова

Подземная геотехнология, производственные процессы, цифровые технологии, промышленность 4.0.

Краткое описание инновационного продукта/технологии, с указанием его конкурентных преимуществ и возможностей его использования

Для обеспечения промышленной безопасности и экономической эффективности разработки рудных месторождений на больших глубинах, в сложной горно-геологической обстановке создан проект отработки запасов выемочной единицы (блок, камера) с использованием цифровизации основных производственных процессов. Для этого в настоящее время выполнен анализ теоретических разработок и достигнутого мирового опыта внедрения цифровых технологий в реализацию основных производственных процессов подземной добычи руд. На основе анализа результатов мировых исследований, характеризующих цифровую трансформацию горного производства, будут предложены целесообразные уровни автоматизации (в т.ч. роботизации) горных работ, разработаны новые конструктивные параметры систем разработки и сформулированы рекомендации к корректировке организации труда. На примере разработки месторождений Арктической зоны РФ будут созданы компьютерные модели объектов подземной геотехнологии и посредством технико-экономического анализа обоснованы оптимальные параметры очистных работ базирующихся на применении цифровых технологий, предложены рекомендации по техническому перевооружению рудника и изменению организации труда.

Специфические условия и требования к внедрению инновационного продута/технологии

Объекты внедрения - эксплуатируемые и перспективные к освоению месторождения.

Потенциальные потребители инновационного продукта/технологии

Горнодобывающие предприятия с подземным способом разработки рудных месторождений.

Степень готовности инновационного продукта/технологии, %

20 (проработанная технологическая идея, есть фундаментальный задел)

Правоустанавливающие документы, патенты, свидетельства РИД и иные формы защиты прав интеллектуальной собственности на инновационный продукт/технологию (в случае наличия)

Отсутствуют.

Результаты апробирования инновационного продукта/технологии (в случае наличия) с указанием места и условий

Отдельные элементы цифровизации горного производства (в частности рудничных транспортных систем) реализованы в технологических регламентах на разработку месторождений Кольского полуострова (Ковдорское месторождение комплексных руд, месторождения Хибинского (Кукисвумчорр, Эвеслогчорр, Олений ручей, Партомчорр) и Лавозерского (Аллуайв) массивов. Кроме того, вопросы автоматизации подземных и поверхностных транспортных систем рассмотрены в материалах кандидатской диссертации "Моделирования технологических процессов добычи и переработки полезных ископаемых". Различные аспекты использования цифровых технологий для моделирования объектов геотехнологии, а также автоматизации и роботизации горного оборудования представлены в статьях.

В мае 2019 года на международном форуме-конкурсе "Актуальные проблемы недропользования" в Санкт-петербургском горном университете представлены результаты исследования технологии дистанционного бурения глубоких скважин с использованием электронных паспортов бурения. Совместно с компанией Epiroc (Швеция) выполнено технико-экономическое обоснование эффективности указанной технологии на Кировском руднике КФ АО "Апатит".

Дополнительные и иллюстративные материалы

Опыт работ научного коллектива

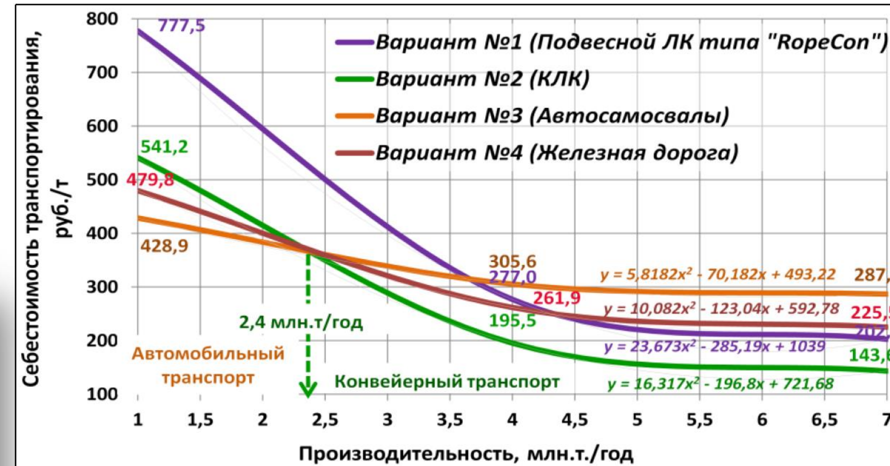
Предложена методология выбора и обоснования технологических решений при освоении стратегических георесурсов, обеспечивающая повышение эффективности разработки месторождений, расположенных вблизи особо охраняемых природных территорий.

В результате апробации методологии на примере Партомчоррского месторождения исследованы параметры и обоснованы критерии выбора транспортных систем при различном объеме грузопотока, обоснованы способ и схема вскрытия, определены параметры малоотходной технологии подземной разработки с рентгенолюминесцентной сепарацией руды и утилизацией породы в выработанном пространстве, а также разработаны мероприятия по охране окружающей среды.

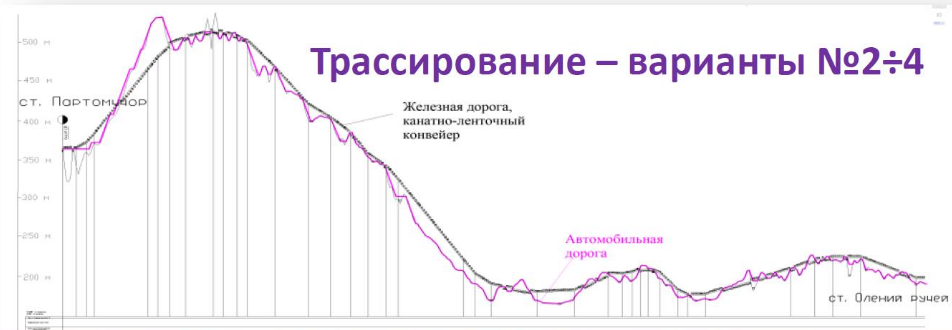
Эколого-экономическая оценка эффективности традиционных и специальных видов межплощадочного транспорта

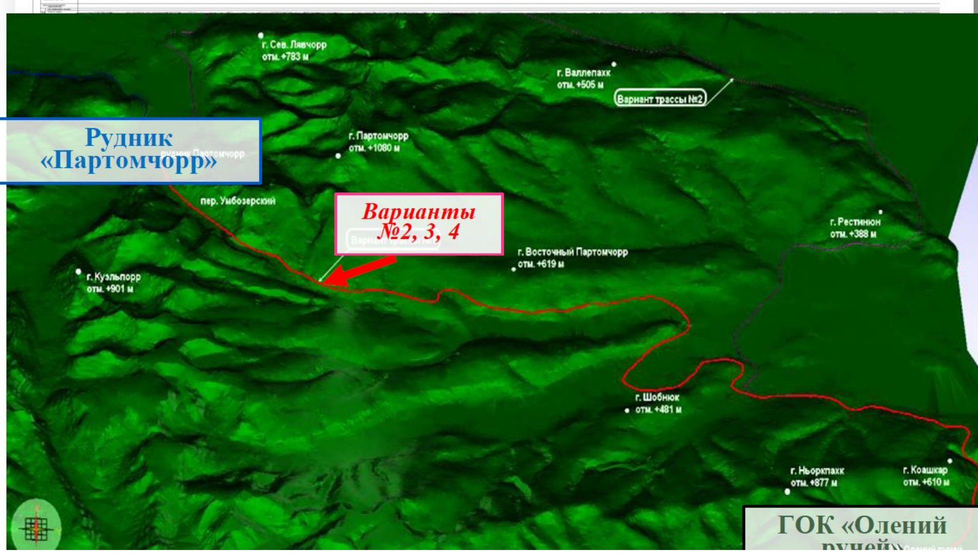
Типы транспорта	В-т	Вид транспорта
Перспективные	№1	*Подвесной ЛК на ходовых опорах «RopeCon»*
	№2	*Канатно-ленточный конвейер*
Традиционные	№3	*Автомобильный тр-т*
	№4	*Железнодорожный тр-т*

Зависимость удельных затрат на транспортирование от годовой производительности

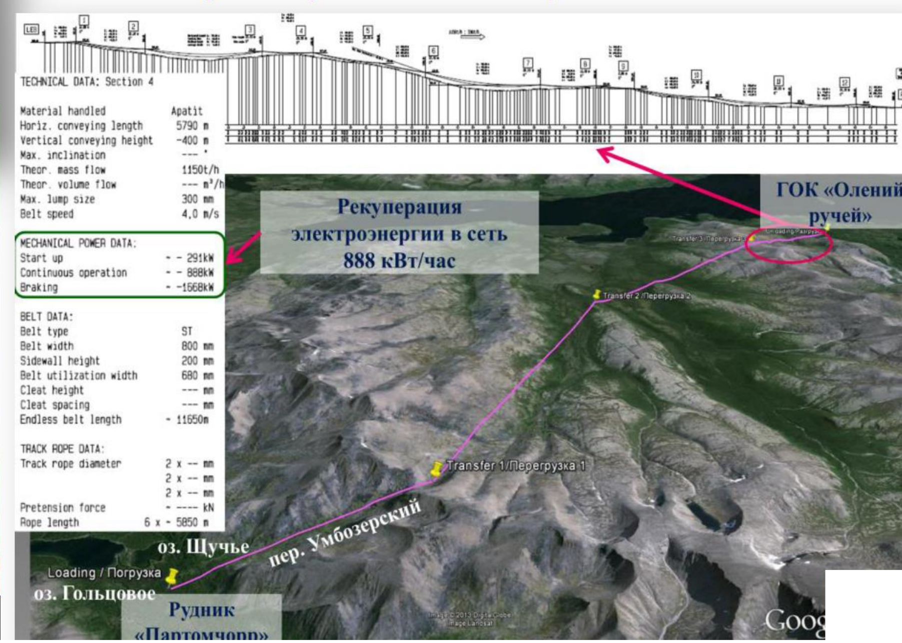


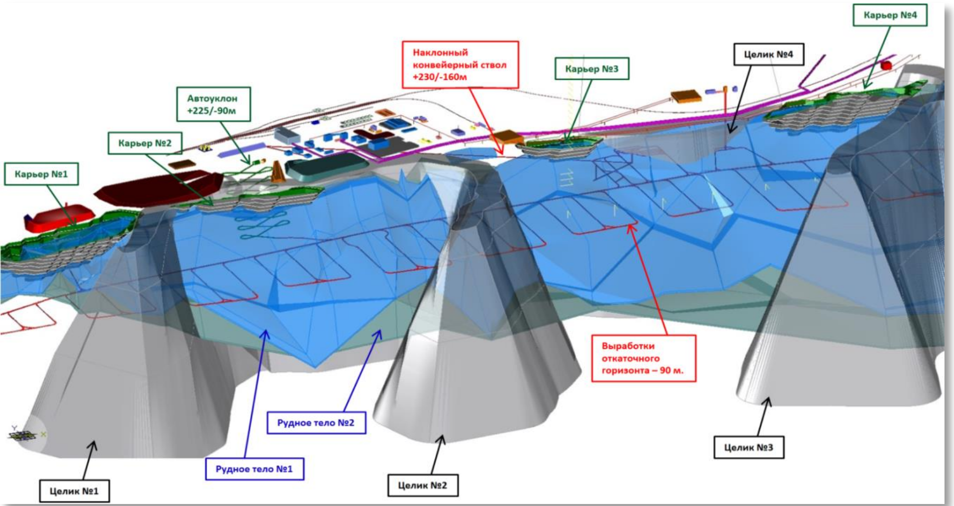
Трассирование – варианты №2÷4



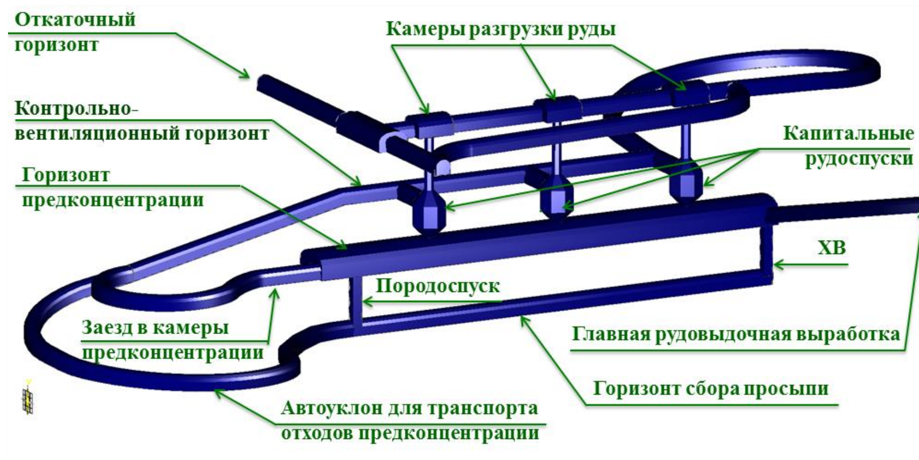


Трассирование – вариант №1





Вскрытие запасов месторождения до гор. -90м при комбинированном способе разработки



Объемная модель комплекса подземной предконцентрации

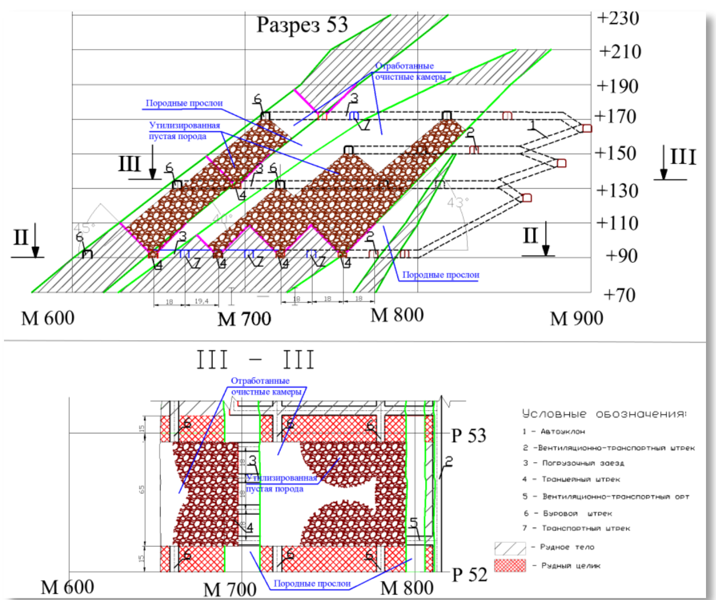
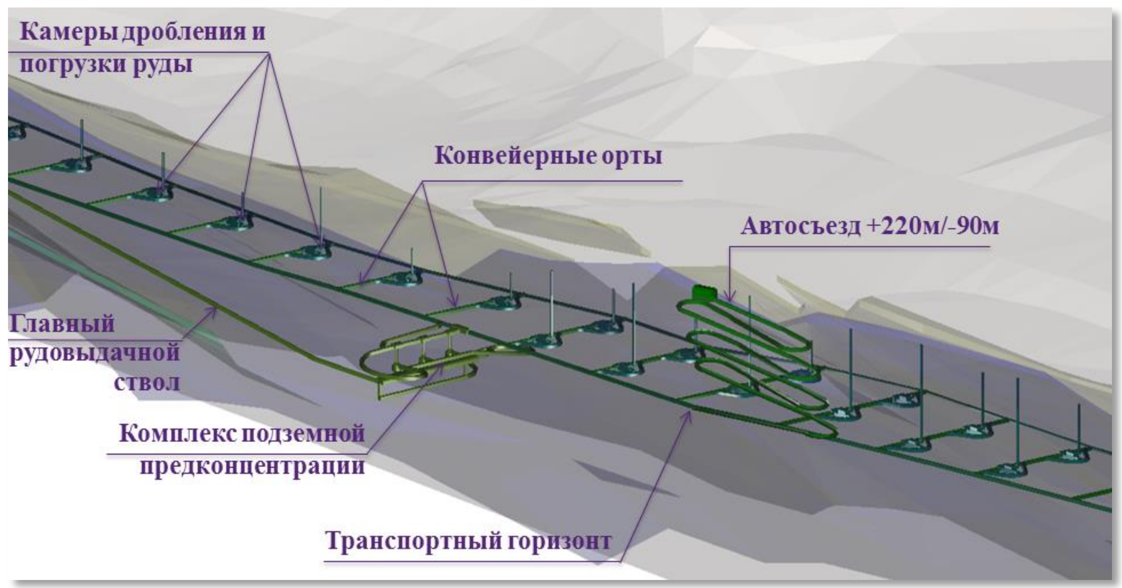


Схема утилизации породы в очистном пространстве для этажно-камерной системы разработки

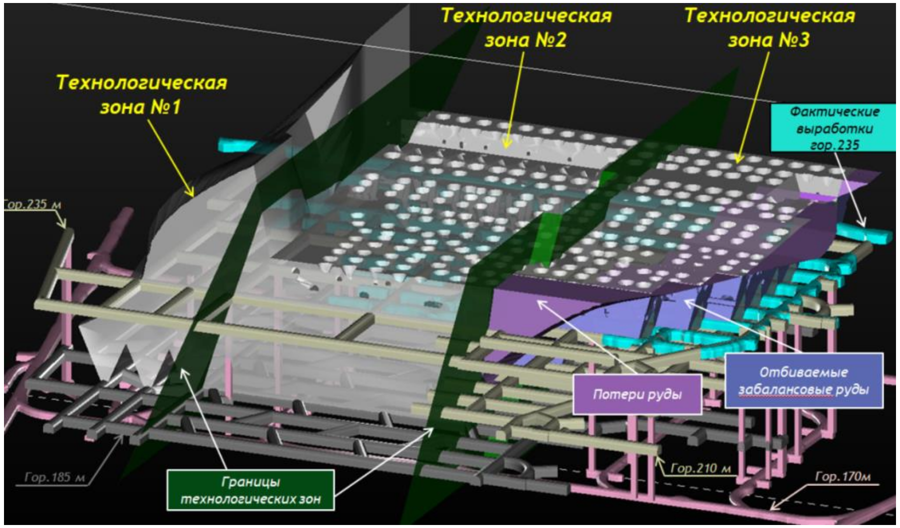


Проектирование схемы вскрытия и подготовки месторождения Партомчорр при применении технологии предконцентрации

На основе моделирования системы подземных горных выработок, последовательности и геомеханических условий их проходки обоснована технология отработки запасов апатит-нефелиновых руд глубоких горизонтов Кукисвумчоррского месторождения вариантами системы разработки с обрушением руды и вмещающих пород:

- **на основе применения комплекса натурных и численных методов обоснованы параметры опережающей разгрузочной зоны для глубоких горизонтов Кукисвумчоррского месторождения при их отработке системами этажного обрушения руды с траншейным днищем и подэтажного обрушения руды;**
- **в ГГИС «MINEFRAME» разработаны и реализованы инструменты моделирования запасов с учетом контуров проектных границ отбойки блока и автоматизированным подсчетом запасов и расчетом показателей извлечения руды;**
- **На примере гор. +170 м обоснована целесообразность модернизации рудовыдачных транспортных схем при отработке мощных месторождений с большим сроком эксплуатации с переходом на малолюдные виды транспорта.**

Моделирование параметров подземной геотехнологии



Моделирование запасов в границах очистных работ с учетом показателей извлечения

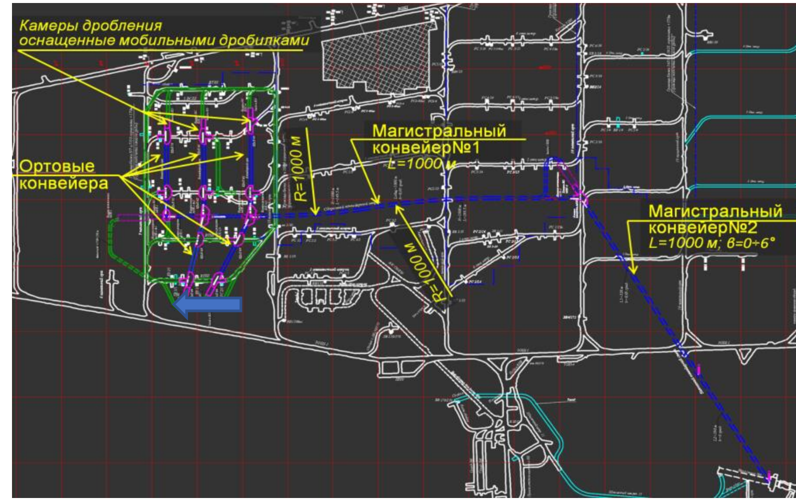
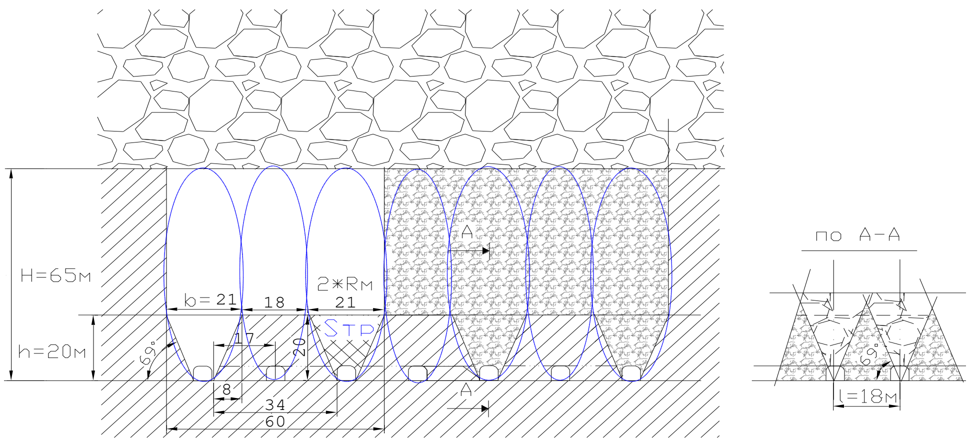
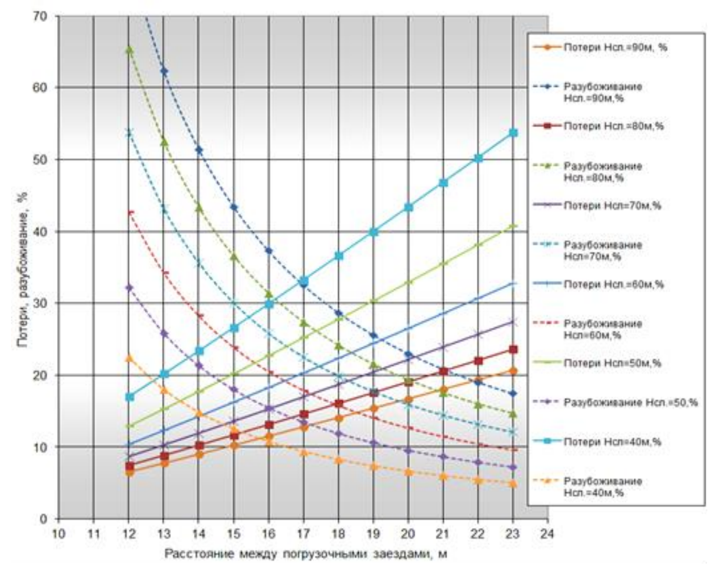


Схема модернизации откаточного гор. +170м в границах бл. 7/10 гор. +170 м с использованием конвейерного транспорта

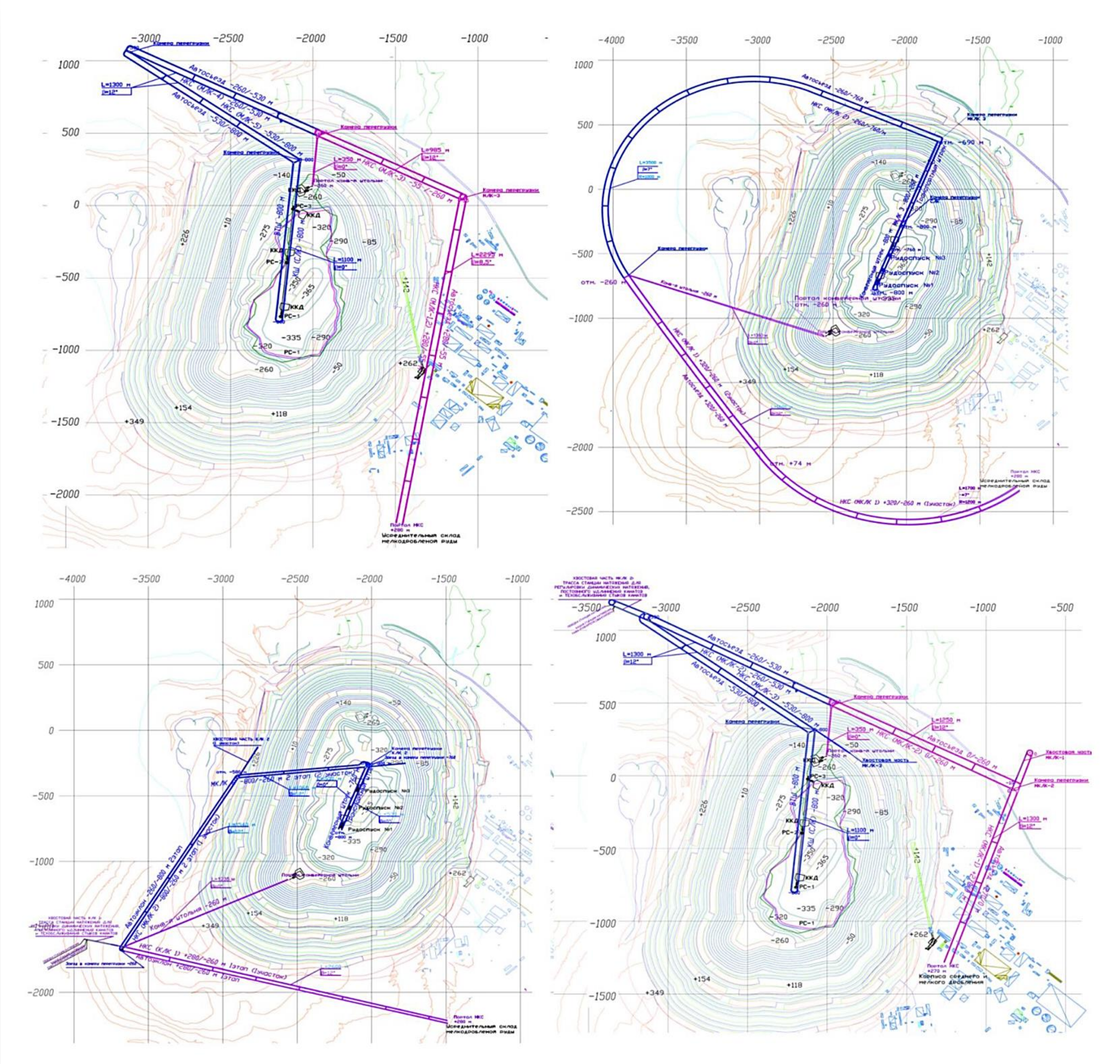


Моделирование эллипсоидов выпуска руды в зависимости от конструкции днища блока



Зависимости коэффициентов потерь и засорения от расстояния между точками погрузки и высоты выпускаемого слоя

На примере рудника «Железный» Ковдорского ГОКа рассчитан оптимальный момент перехода от автомобильного транспорта руды к перепуску через подземную транспортную схему. Разработан алгоритм определения границы перехода от одного вида транспорта к другому с помощью средств горно-геологической информационной системы, который позволяет наиболее точно учитывать изменение длины транспортирования с развитием карьерного пространства

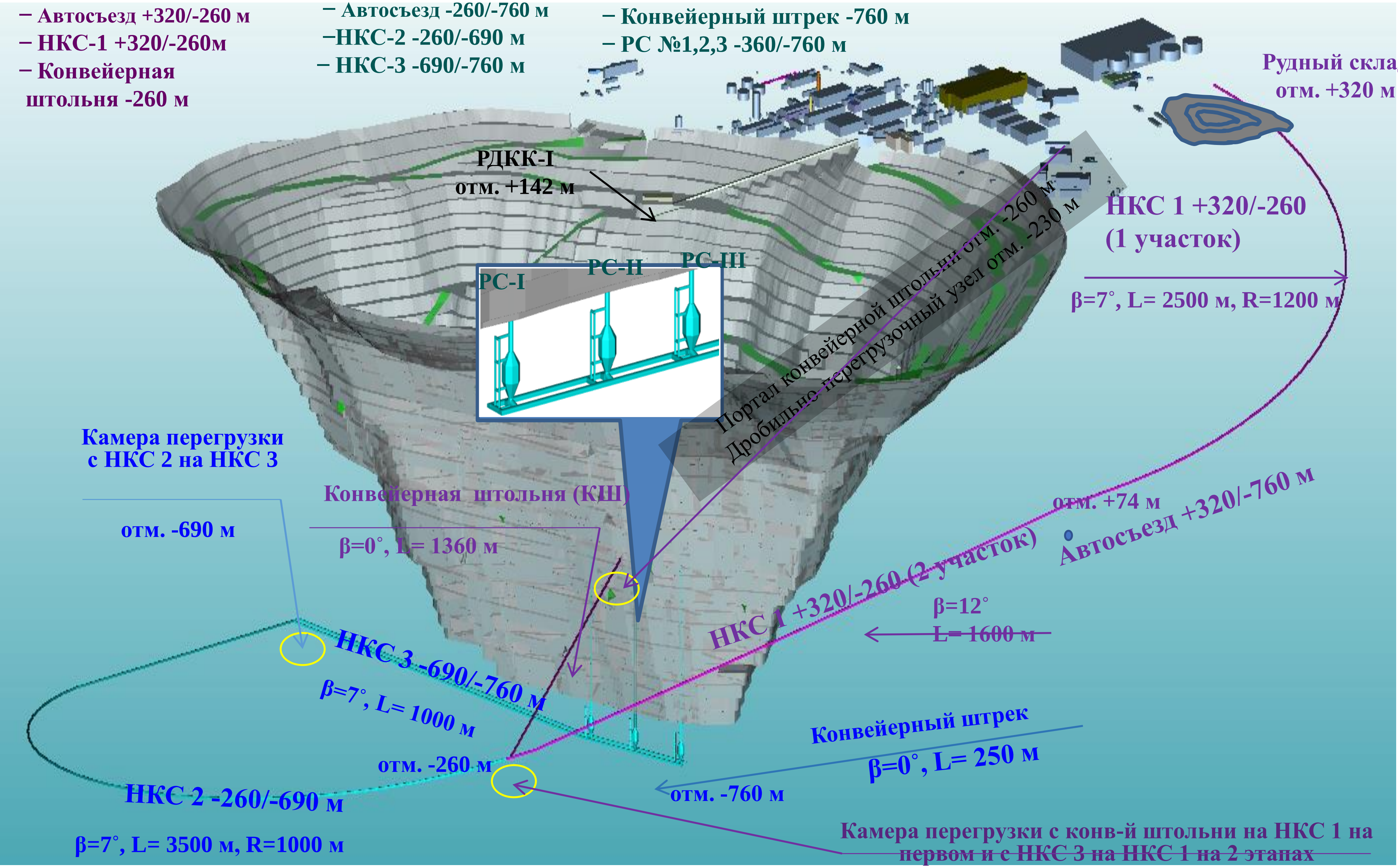


Схемы вскрытия запасов карьера «Железный» подземными транспортными комплексами

Вариант вскрытия автосъездом и наклонным конвейерным стволом, оборудованным канатно-ленточными конвейерами типа Metso

1 Этап

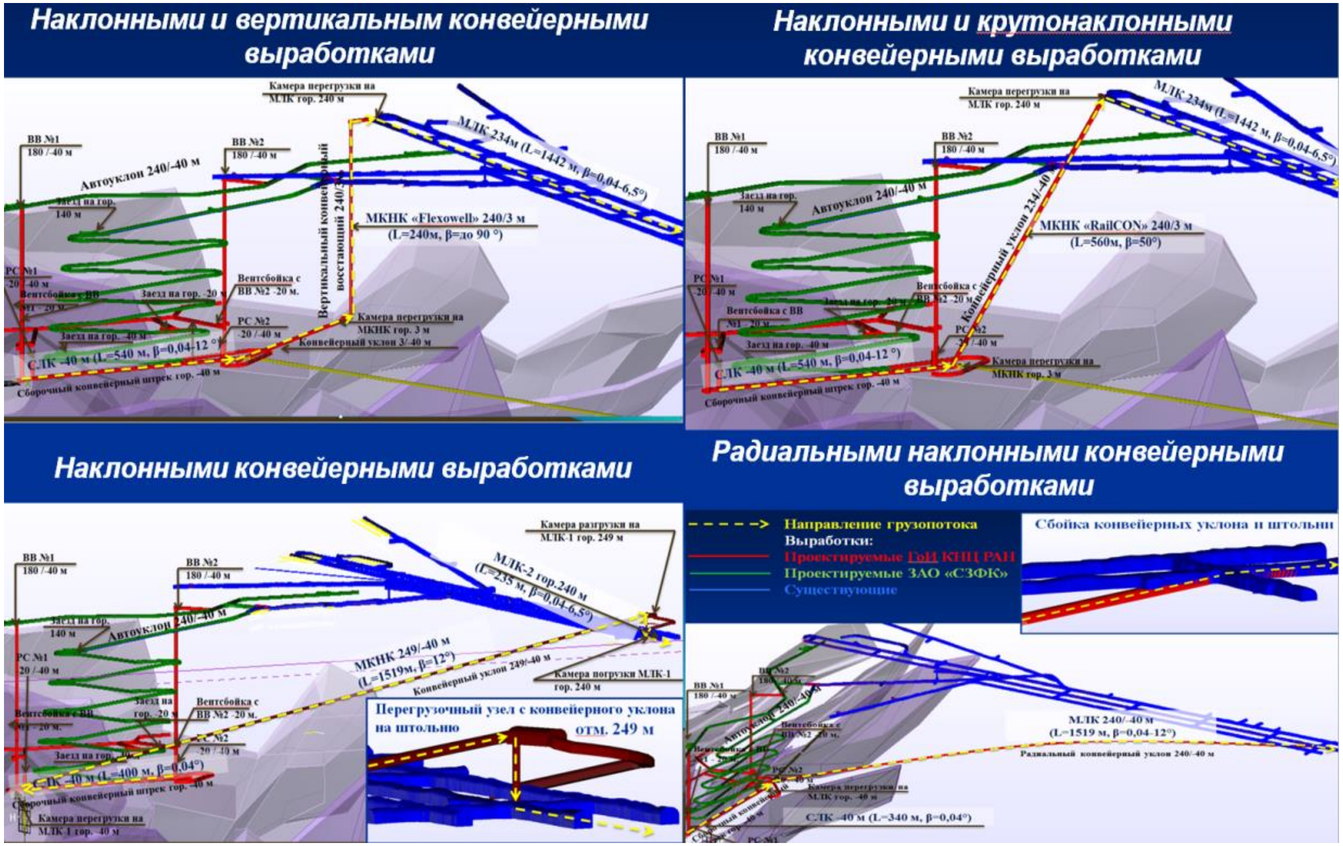
2 Этап



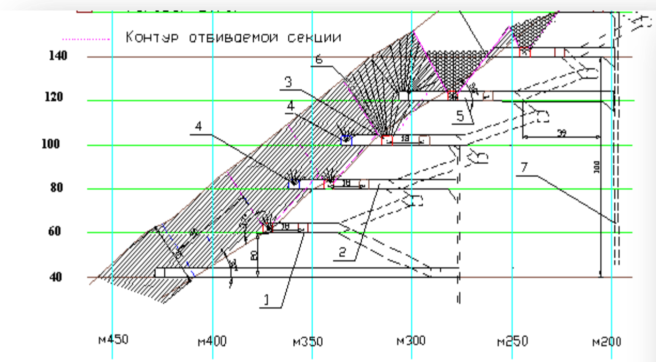
Обоснована геотехнология опытно-промышленной отработки запасов нижнего яруса **месторождения «Олений ручей»** в отметках +180/0м между разрезами 12-17:

- выполнена технико-экономическая **оценка эффективности новых способов вскрытия месторождения** с применением перспективных видов конвейерного транспорта;
- выполнено **обоснование параметров систем подземной разработки** и **предложены схемы утилизации породы** от горнопроходческих работ в подземных условиях;
- **обоснованы параметры перехода к системам разработки с обрушением** руды и вмещающих пород.

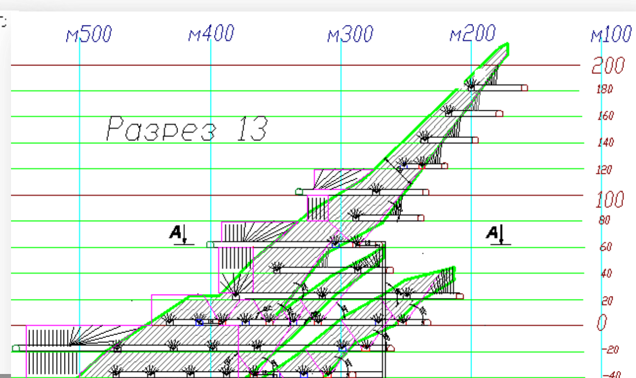
3-D модели вариантов вскрытия месторождения «Олений ручей» с применением различных комбинаций конвейерного транспорта



Варианты систем разработки



С открытым очистным пространством с выпуском руды на траншею, расположенную по простиранию рудного тела

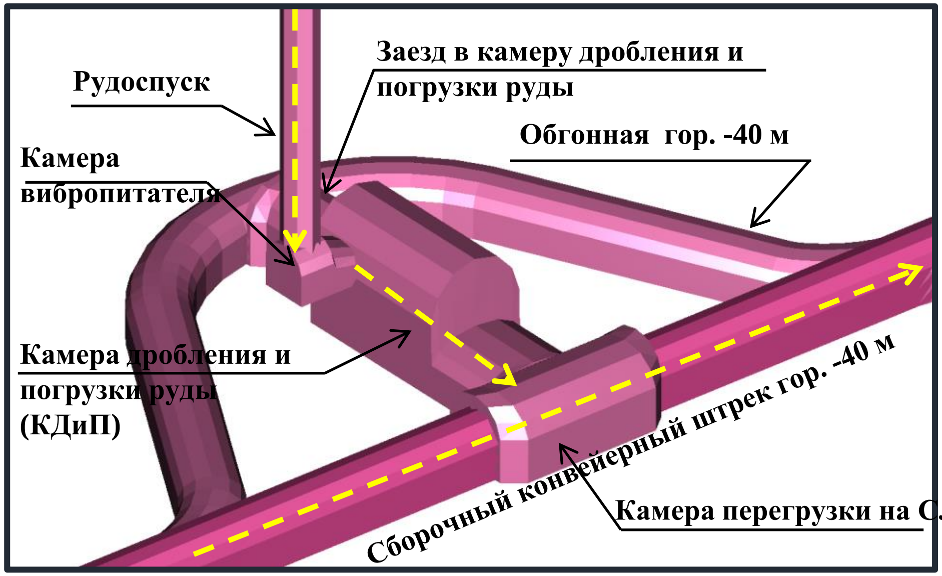


С обрушением и выпуском руды на траншейное днище с отбойкой вертикальных и наклонных породных секций в отработанные пустоты

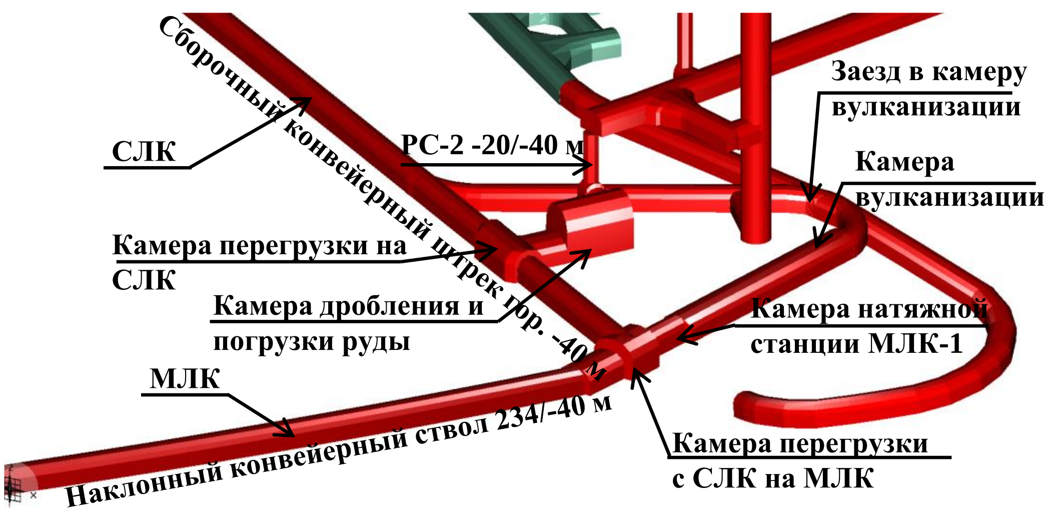
С обрушением и выпуском руды на траншейное днище с отбойкой вкрест простирания рудного тела

Основные конструктивные узлы дробильно-конвейерного комплекса

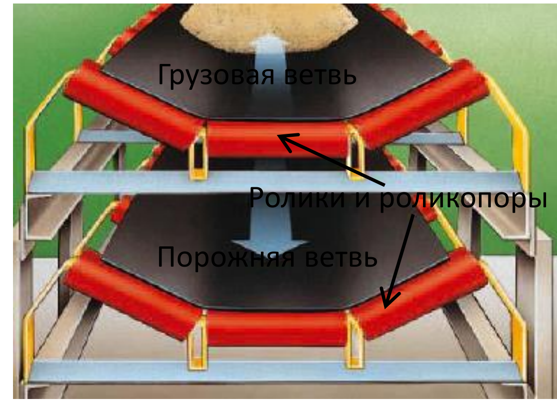
Дробильно-перегрузочный узел гор. -40 м



КДиП и перегрузочный узел сборочного штрекового конвейера на наклонный участок МЛК гор.-40 м

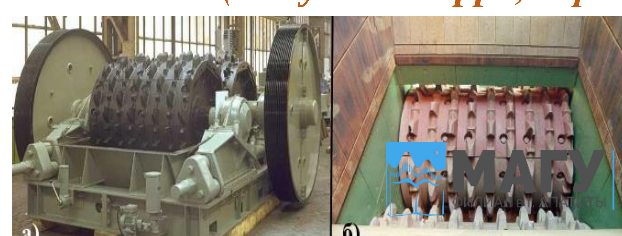


Общий вид магистральной части желобчатого конвейера фирмы («Beumer», Германия)



Общий вид пластинчатого питателя типа RFK 1800 x 13000 - D6I («ThyssenKrupp», Германия)

Двухвалковая дробилка первичного дробления DRC («ThyssenKrupp», Германия)



Возможные уровни автоматизации

Уровень 1

Система дистанционного управления в пределах прямой видимости

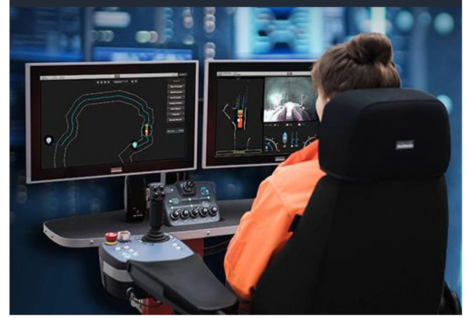
- ***Повышение безопасности персонала***
- ***Умеренная стоимость***
- ***Высокий риск повреждения***

Уровень 2

Система телематического управления в подземных условиях

- ***Значительное повышение безопасности персонала***
- ***Умеренная стоимость***
- ***Повышение коэффициента использования***
- ***Высокий риск повреждения***

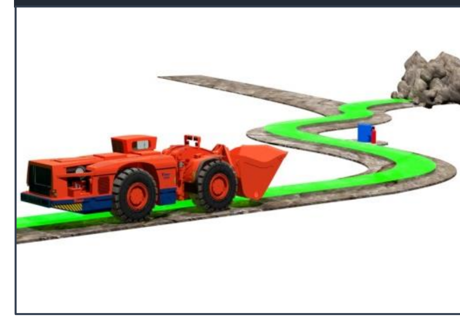
Уровень 3



Система полуавтоматического управления с поверхности

- ***Значительное повышение безопасности персонала***
- ***Значительное повышение коэффициента использования***
- ***Низкий риск повреждения и рост срока службы***
- ***Высокая стоимость***

Уровень 4



Система автоматического управления

- ***Значительное повышение безопасности персонала***
- ***Значительное повышение коэффициента использования***
- ***Низкий риск повреждения и рост срока службы***
- ***Управление несколькими ед. техники***
- ***Высокая стоимость***

Промышленные испытания автоматизации работы ПДМ и автосамосвалов

KIDD MINE – Канада
AUTOMINE® LOADING – LITE

Произв-ть ПДМ

Проценты

Увеличение КИО позволило:

- 121% увеличить производительность ПДМ на добычных горизонтах
- 52% увеличить дневную производительность на откаточных горизонтах

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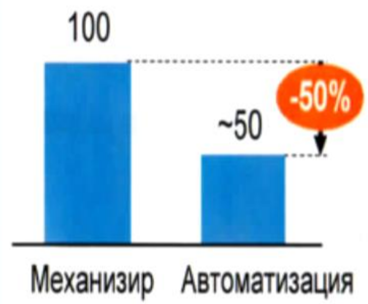
FINSCH MINE – ЮАР
AUTOMINE® HAULING – FLEET

Стоимость за тонну

Проценты



Увеличение скорости откатки и КИО привело к:

- 7 самосвалов вместо 10

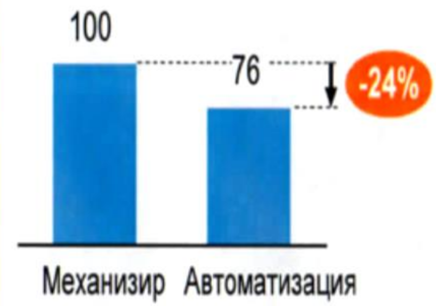
Снижение эксплутационных расходов:

- 2 оператора в смену вместо 10
- 60% ниже стоимость ТО
- 35% выше экономический срок службы машины

NORTHPARKES – Австралия
AUTOMINE® LOADING – FLEET

Стоимость за тонну

Проценты



Увеличение КИО привело к:

- 23% увеличению производительности ПДМ

Снижению операционных задач:

- 3 оператора за смену вместо 7

Стабильное и непрерывное производство

SANDVIK

Performance evaluation of tele-remote underground drilling for sublevel caving

ABSTRACT: The article presents the analysis of the world experience of longhole drilling automation during underground mining. The results of the Russian pilot project of tele-remote drilling with the use of electronic passports at one of the Kola Peninsula mines are presented. The article describes technology implementation stages, its features, and changes in the mine in-frastructure, labor organization and main technical characteristics of the system. A technical and economic comparison of the cost of stope excavation was made as a result of tele-remote drill-ing pilot tests during a sublevel caving mining. It is shown that tele-remote drilling with the use of electronic passports allows reducing the deviation of the borehole trajectory by 60÷80%; de-creasing the boulder output by more than 2 times and the explosive consumption by more than 9.5%; and increasing the equipment utilization factor and drilling performance by 15÷31%. In total, this allowed reducing the stope excavation costs by 7.9%.

1 INTRODUCTION

Modern trends in the development of the mining industry are characterized by gradual transfer to underground mining, deepening of operations and reducing of useful component content in ores (Melnikov, 2013). This, as a rule, leads to the complication of mining and geological and geomechanical conditions, increase of emergency situations, growth of production costs and de-crease of the value of extracted raw materials, as well as to other negative consequences. Against the background of rapidly developing digital transformation of industry in developed countries, a radical solution to the problems of safety and reduction of mining prime costs is the transition to automated (or autonomous) tele-remote control technologies (Schwab, 2016). In this regard, the task of assessing the efficiency of automation of the main technological process-es at Russian mines is relevant. The development of hard rock massifs includes one of the most dangerous and expensive processes that have a significant impact on the qualitative and quanti-tative properties of ore raw materials - drilling and blasting operations, which are considered in this study (Jianguo, 2018).

2 WORLD EXPERIENCE IN DRILLING AUTOMATION AT UNDERGROUND MINES

The most comprehensive implementation of production processes automation was obtained at the Kiruna and Malmberget underground mines, operated by LKAB (Sweden). Kiruna mine produced about 29 Mt of run-of-mine and Malmberget mine about 14 Mt. Thus, the Kiruna mine develops an iron ore deposit at an angle of 60°, with a capacity of about 80 m. The has been mining iron ore with the sublevel caving mining method (SLC). The dimensions for a typ-ical layout for the Kiruna mine is about 25 m between crosscuts (production workings) and about 29 m for the sublevel height (floor to floor). The dimensions of the crosscuts are about 7 m wide and 5 m high, production blocks about 400 m long. In order to optimize longhole drilling, LKAB has created the Wassara AB special division, which has developed unique hydraulic submersible hammer drills. Testing of the Wassara hammer in 1990-1995 made it possible to long hole up to 56 m long with a deviation of less than 1.5% from the design contour (compared to 5-20% with other drilling methods). Introduction of a new drilling technology allowed increasing the volume of ore per drilled meter increased by 500%. The volume of the stripped section increased by more than 800% (from 1.2 to 10 thousand tons), the increased the sublevel height from 12 to 28 m, decreased number of sub levels by 70% (Fig. 1 on the left).

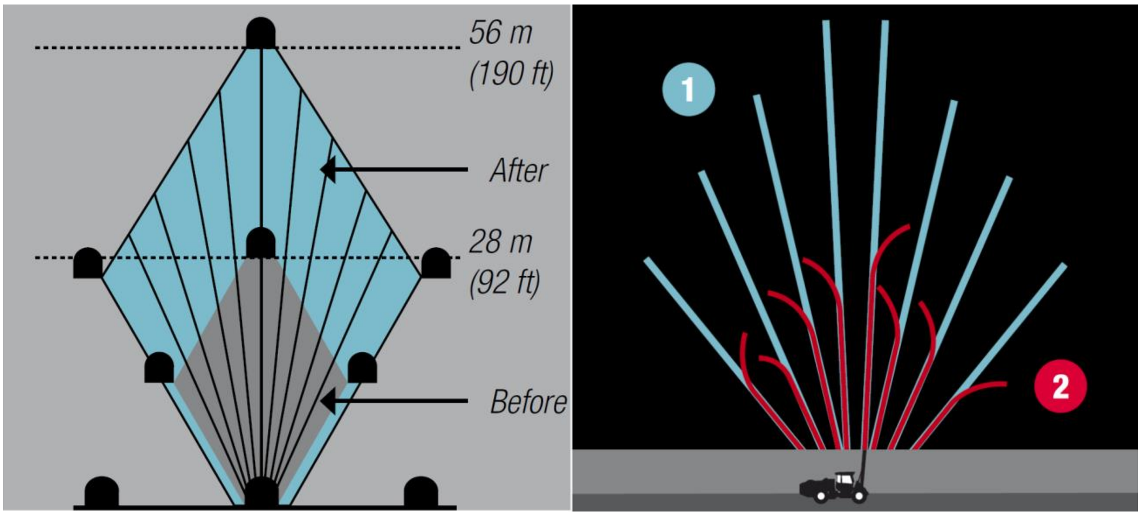


Figure 1: Comparison of sections drilled with traditional pneumatic and hydraulic Wassara AB hammers (left). Trajectories of boreholes with electronic passports (1) and with manual control (2) (right).

Today, Wassara AB hammers are used on the new Epiroc S7 drilling rigs, which are controlled remotely from the mine surface (1 operator controls 3-6 rigs). The drilling rig operate on the basis of electronic passports (EP) for drilling, which are developed in special software and transmitted to the drilling rig via Wi-Fi network. Thanks to the introduction of the new technology, the well deflection was reduced to less than 1%. The achieved drilling speed was 0.5÷1 m per minute with a borehole diameter of 115 mm (Morton, 2018).

From 2018 to 2023, the Kiruna mine is planning to conduct new large-scale pilot tests (PST) of the SCM with increased sublevel height and automation of drilling, load-haul-damp (LHD) equipments and trucks (battery/electricity-driven). The new technology is tested in a orebody orebody is known by the name Konsuln. This orebody has a dip of about 75° to the east, which is steeper than the main orebody. Its thickness varies from 20 to 50 m. In the test mode in the period from 2018 to 2023 it is planned to extract about 9 million tons of ore. In order to reduce the costs of mining workings and ore transportation, three sublevel deposits with increased height (up to 50 m) will be excavate. The first level will have a 40 m sublevel height and the second and third levels will be 50 m high. In addition, a new transportation scheme called "fork layout" will be used at the site, which will reduce the length of workings and move the transport drift from the inside the footwall. Figure 2 shows a plan view of the proposed layout of the test area for Level 536. Two crosscut spacings will be tested in this area (25 and 22 m). The maximum length of drilled boreholes is set to 60 m (Quinteiro, 2018). The purpose of testing the new Wassara AB hammers in combination with Epiroc drilling rigs equipped with Rig Control System and Rig Remote Access drilling control systems is to reduce the deviation of the boreholes from the design parameters by no more than 1%.

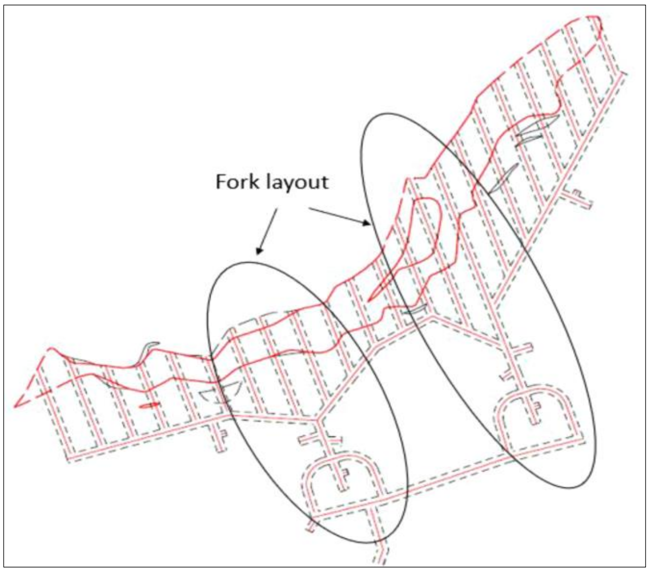


Figure 2. Plan view of the proposed layout of Level 536 for transverse sublevel caving with fork layout and 50 m sublevel height

The Malmberget mine is located about 5 km from the town of Galliwara in the far north of Sweden. The mine consists of about 20 ore bodies, of which 12 are currently being mined (Fig. 3 (a) (Gustafson, 2016). The mining area stretches 5 km in the E–W direction and 2.5 km in the N–S direction. In Malmberget mine, fully-automated Atlas Copco Simba W6C drill rigs are used for all production. These rigs are not equipped with standard top hammer rock drills, but with Wassara W100 hydraulic hammers drill significantly faster, have less hole deviation, and generate less dust in the surroundings. However in 2013, 4% of all holes needed re-drilling because of blockages, with another 3% defined as "Wet holes" also requiring special treatment. The drilling is performed/controlled remotely from a control room at level 1000 m. Three operators operate two drill rigs each all year round 24 hours a day. Fully automated fan drilling consisting of ascending blastholes in the SLC is provided by the ABC Total mode, which allows drilling even during the night when there is no personnel at the mine (Ghosh, 2017).

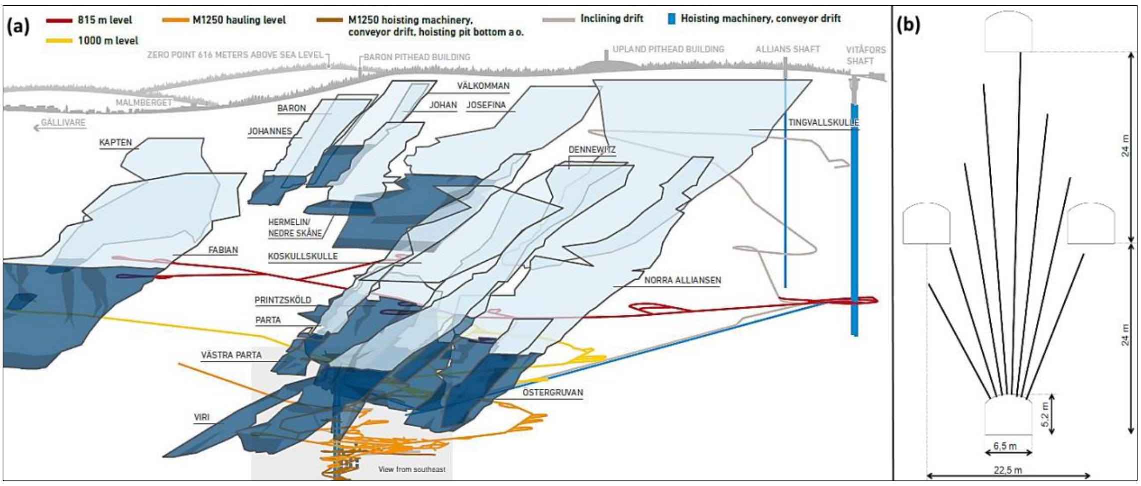


Figure 3. (a) Malmberget mining operation and its orebodies, (b) cross-section of production drift layout at one of the ore bodies

Before drilling starts on each production fan, the drill rig has to be carefully positioned, which is manually done by the operator. The standard length of production workings (crosscuts) is 85 m and is drilled with 25 fans. Each fan consists of 8÷10 boreholes drilled at a distance of 3-3.5 m from each other (Fig. 4 (b). The diameter of the boreholes is 115 mm and the drill steel length is 2.3 m. The used drilling technology "Wassara AB" allows to drill wells with maximum high up to 55 m (usually the borehole high is not more than 50 m), with a deviation of the trajectory from the project ~ 1.5%. The fans are drilled at an angle of 80÷85°, and the last (twin fans) at angles of 85÷90°, which allows to increase the extraction of ore. The achieved drilling speed is ~0.8 m/min. The blasthole are charged with an emulsion explosive substance. Blasting operations at the mine are performed every night from midnight to 2 a.m. Usually three fans are blasted out in one blast, each of which produces about 6,600 tons of ore (Gustafson, 2016).

The Syama gold mine (Mali) has been operated in the open pit by BHP Billiton since the 1980s. In 2015, when the mine was taken over by Resolute Mining, it underwent major changes. In particular, when designing the transition to the underground mining method, for the first time in world practice, the mine was planned with the full automation of the main technological processes (up to 2032). The Syama mine, locate 300 km southeast of Mali's capital Bamako and have dimensions of about 1 km long, 200 m thick, with a gold content of 3.5 grams per tonne and reserves of ~ 2.9 million ounces. In 2018 Resolute Mining signed a strategic agreement with Sandvik on mine automation. As part of the agreement, AutoMine® and OptiMine® systems, as well as a full fleet of Sandvik TH6663 trucks and Sandvik LH514E electric LHD will be supplied for process analysis, optimization and automation. Work on the deep drilling programme at the mine began in late 2015. The efficiency of which is conditioned by the absence of the need to stop operations during a changeover, the possibility of working in a gassy environment, etc. The operating time of the equipment during the day increased from 15~16 to 22 hours. The advantages of automating a mine are clear, as the technology increases efficiency and improves safety. The cost profile of the mine has been reduced by as much as 15% thanks to the implementation of automation. This reduces the cost of production from $881 per ounce down to $746 per ounce. Despite the upfront additional cost of the autonomous equipment being as much as $10m-$15m. Resolute will ultimately cut mining costs by 30% (Jamasmie, 2018).

In addition to the drilling of treatment wells, there is successful experience in the automation of underground drilling for rock (core) sampling. For example, Boart Longyear's LM™75 drill rig was tested at the Olympic Dam mine in Australia for six months (May-October 2013) using diamond-coated wear-resistant drill bits and equipped with Drill Control Interface (DCi) drilling control system (Fig. 4). Olympic Dam is located 560 km north of Adelaide, South Australia. In addition to containing iron oxide, copper, and gold (i.e., IOCG), the Olympic Dam deposit hosts uranium, silver, and rare-earth elements(REEs) (Tappert, 2011). The underground mine produces 10 million tons of ore per year using the sublevel open stope mining method. Diamond drilling is used to extract rock samples (core) for analysis of the Olympic Dam ore body geometry and to collect geochemical information which will be used to create block models for planning and extraction of future resources. The drill rig control interface is fully electronic and allows a single operator to control both the process and the boom arm simultaneously, providing real-time feedback. The operator can initially set preliminary drilling parameters, after which the system operates autonomously. This allows for continuous operation during the operator changeover period.

Figure 4. Semi-autonomous drilling by drill rig with Drill Control Interface

The DCi control system allows operators to use programming, so that a more experienced operator can configure drilling parameters for inexperienced drillers and when the drilling cycle is completed or the programmed parameters are exceeded, the drill rig will automatically shut down. This simplifies the selection and training of personnel and extends the service life of the equipment, avoiding unnecessary breakdowns. DCi has a lighter and more portable control unit than hydraulic control systems. A weight difference of 50 kg and a small number of components make it easier and faster to move the control unit. To disconnect the drill rig from the DCi, there is no need to disconnect the hydraulic hoses, but only to disconnect the three connectors.

DCi provides a real-time report of the most important data on the operation and performance of the drill rig, which is recorded, stored and easily loaded for quick analysis. This current information allows the driller to regulate the operation of the drill rig and allows, for example, to increase productivity during operation. A diagnostic system can be launched at any time to determine the CU's performance, assess the operator's correct operation and detect equipment failure early. During the PST new drill rig with the DCi to drill a total of 5,726.3 meters using diamond core bit. This was an increase of 907.7 meters drilled over the previous six month average, which resulted in a unit cost improvement of $2.90 per meter average and monthly productivity increase of 13.5 percent (Longyear, 2017).

The Ridgeway copper and gold mine (Australia), located near the famous Cadia Hill open pit, has been operating only since 2002. Ore is mined using an SLC with a sublevel height of 25 m. In an effort to improve rig productivity, mine management has explored ways to achieve higher daily drilling rates with the same staff and equipment. For several years now, this has been achieved through automated fan drilling with Epiroc's Advanced Boom Control (ABC) system. Ridgeway has two Simba L6 C units, one of which is equipped with an ABC system. The increase of productivity on drilling makes more than 10 %. The main obstacle on the way to full automation of drilling was the necessity of manual bit change during drilling or during transition between boreholes. Today, the drilling process is fully automated: the feed and replacement of rods and bits is done automatically according to the programmed drilling schedule and drilling sequence (Hall, 2007).

RioTinto's Diavik mine, located in the sub-Arctic tundra far from populated areas (about 300 km to Yellowknife, Canada), uses the Epiroc Simba M7 open stope mining method (OSM) to drill blasting wells, and Simba M6 to drill blasting holes. The machines use dry drilling (without water) with remote telematic control when working in hazardous areas or near the open pit (Jakubec, 2018). Three cameras are installed on the drill rig: one fixed on the top of the cabin and two removable cameras with the possibility of rotation and approach. Each camera has its own monitor, which allows for the most thorough control over drilling (Lewis, 2018).

In Russia, a new model of Epiroc drilling rigs - Sandvik DL421 - has been launched at the Udachny and Aikhal underground mines of Alrosa Group. The model is designed for drilling vertical and inclined fans, as well as parallel and single wells with diameters from 64 to 115 mm up to 54 meters high. In order to improve safety, accuracy and productivity of drilling operations, EP for drilling are being introduced, which are being developed in the geoinformation system and transferred to the drill rig via USB flash drive.

3 PERFORMANCE EVALUATION OF TELE-REMOTE CONTROL DRILLING

In recent years, PhosAgro's mining and processing companies have been undergoing an active digital transformation. Recently, for example, we have been implementing a unique project to remotely drill wastewater treatment wells using ES drilling at Kirovsky (since 2018) and Rasvumchorsky (since 2019) mines of Kirovsk branch of Apatit. Both mines, which develop apatite-nepheline ores in the Khibiny Massif, use an SLC method. The ore is broken into rhombus-shaped sections with a maximum borehole high of about 37 meters. For drilling boreholes Simba E7C CU are used. In the geoinformation system, EP drilling are developed before hand, which are loaded into the drill rig software via an external storage device or a mine wireless network (Wi-Fi). Prior to drilling, the mine surveyor marks two points on the sides of the workout, the coordinates of which allow the machine to position itself in space. The operator, being in the cabin of the drill rig in the underground conditions, delivers and installs equipment in the bottom hole, after which the machine starts drilling in automatic mode. Currently, 3 operators are used to control 6 units of equipment, one of which controls the drill rig from the mine surface (Fig. 5), and two other operators, being in underground conditions, navigate of equipment and its and rearrange it from fan to fan. In the near future the company plans to complete 4 more drilling rigs, which will allow to reach the park of 10 units working in tele-remote mode. Thus, five people will take part in the management of the work of 10 units of equipment. In the future, the new Simba machines will be able to move the drilling rigs between the fans without the presence of an operator directly on the machine.

Figure 5. Semi-autonomous drilling to Kirovsky mine of Kirovsk branch of Apatit company.

The introduction of tele-remote semi-automatic drilling technology has already enabled PhosAgro to increase its equipment utilization ratio by ~22÷24% and its daily output by 15÷31% (Fig. 6) (Khrishcheniuk, 2018). Drilling accuracy increased by 60÷80% (with the borehole high 36 m the deviation from the design contour decreased from 2.5 m to 0.6-0.7 m). Due to the increase of accuracy the output of rock mass boulder decreased by more than 2 times (from 12.5% to 6%), and explosive consumption by 9.5%.

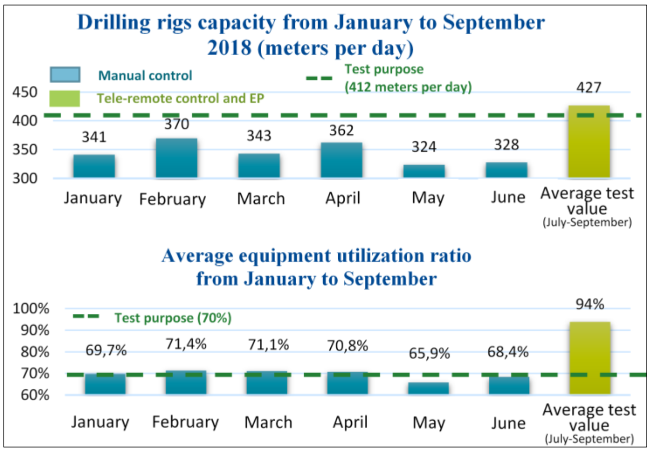


Figure 6. Results of tele-remote drilling pilot tests

For a more detailed assessment of the tele-remote drilling efficiency with the use of electronic passports, a comparative calculation of the unit costs of ore reserves breaking down of one section (fan) was made for manual and tele-remote drilling control. Calculation is carried out both directly on the basis of the drilling process and related processes: blasting operations, ore mucking by LHD, boulder ore mucking and secondary blasting. For this purpose, expenses were determined for the following items: salary, factory supplies, energy and equipment depreciation. The results of the comparison are presented in Table 1.

Table 1. Comparison of unit costs of stope excavation for various borehole drilling technologies.

№	Expenditure item	Units	Drilling control technology		Difference
			Manual	Tele-remote	
1	Salary	USD/tonne	0.32	0.25	22.17%
2	Factory supplies		1.32	1.26	4.30%
3	Energy		0.05	0.04	15.64%
4	Equipment depreciation		0.4	0.37	7.33%
5	Total costs		2.09	1.92	7.92%

Calculations show that tele-remote drilling with the use of electronic passports reduces the cost of stope excavation by almost 8%. Given the total design capacity of the Kirovsky and Rasvumchorsky mines (~32.5 million tons per year), this will allow PhosAgro to save approximately RUB ~$5.5 million per year.

4 CONCLUSIONS

The analysis of drilling automation experience at ten domestic and foreign mines has shown that modern information technologies make it possible to achieve a significant increase in drilling accuracy, make it possible to bring the operators of drilling rigs to the surface of the mine, providing them with more comfortable and safe working conditions, as well as make it possible to drill without interruption for the change and ventilation of the mine. This helps to increase the productivity of equipment and reduce the cost of underground mining.

Pilot tests of semi-automatic drilling conducted at PhosAgro's mines in cooperation with Epiroc showed that the equipment's technical utilization ratio increased by ~22÷24% and the daily productivity of the drilling rig by 15÷31%, drilling accuracy by 60÷80%, the output of boulder decreased by more than 2 times, and the consumption of explosives decreased by 9.5%. Comparison of ore reserves recovery costs of one section (fan) at manual and tele-remote drilling of boreholes with the use of electronic passports for Kirovsky mine conditions showed that tele-drilling allows to reduce the cost of stope excavation by almost 8%. The greatest effect was achieved due to the reduction of expenses on such items as salary (22.2%) and energy (15.6%), which was due to a decrease in the number of service personnel, increased productivity of equipment and reduced cost of transportation of boulder items. According to preliminary estimates, the introduction of tele-remote drilling technology at the Kirovsky and Rasvumchorsky mines of Kirovsk branch of Apatit JSC will allow PhosAgro to reduce its stope excavation costs by ~$5.5 million per year.

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