Geodynamic rock condition, mine workings stabilization during pillar recovery at the level +320 m of the Yukspor deposit of the Khibiny Massif

Svetlana Zhukova[2*], *Pavel* Korchak[2], *Anatoly* Streshnev[2] and *Igor* Salnikov[1]

[1]Kirovsk branch of JSC «Apatit», Department of the Technical Director, Kirovsk, Russia
[2]Kirovsk branch of JSC «Apatit», Department of rockburst forecasting and prevention, Kirovsk, Russia

Abstract. The article represents the results of seismic monitoring during pillar recovery at the level +320m of the Yukspor deposit. The number of seismic events with an energy of more than 106 J is sharply increasing in the affected area of overlying rock base. This reflects fracture intergrowth and gradual rock failure due to stress redistribution. Mining operations cause new fractures and interstices, which in turn lead to residual stress redistribution through the formation of new defects. During the rock failure, stresses in the affected area become stable. If fracturing and timely rockfall of overlying rock base do not occur during excavations, thereafter, sudden caving poses a hazard by an underground air strike and can be a threat to the objects on surface. As for stability of mine workings, provoked gradual rock fall does not pose a threat, since this leads to consequent and constant reduction of the mountain base, and, therefore, support pressure, hanging walls become more stable. Underground seismic monitoring based on continuous seismic registration, local monitoring through various geophysical measurements and mathematical modeling of stress-strain rock condition improve the operational safety under difficult geodynamic conditions.

1 Introduction

Up to date, Kirovsk branch of JSC "Apatit" is one of the world's largest enterprises for the production of apatite concentrate. Ore is extracted from three mines: Kirovsky (the Kukisvumchorr and the Yukspor deposits), Rasvumchorr (the Apatite Circus deposit) - underground mining, and Vostochny (the deposits of Plateau Rasvumchorr, Koashva, Nyorkpakhk) - open-pit mining. The exploitation of apatite-nepheline ores at Kirovsky and Rasvumchorr mines is carried out using an underground method of induced sublevel caving. Over 89 years, approximately 2 billion tonnes of ore had been mined, 4 billion tonnes of mined rock had been transported, ground relief had changed significantly, and the connections of tectonic elements had been broken.

* Corresponding author: Szhukova@phosagro.ru

To increase the production capacity in the 2000s, it was settled to make a second slot at the level + 320m of the Yukspor deposit. In 2013, Mining Institute of Kola Science Center corrected previously developed regulations on pillar recovery for the level + 320m, substantiating optimal position and dimensions of sublevel joint sections. The technology for rockburst conditions, the methods of rock monitoring and mine workings stabilization were proposed. Figure 1 illustrates the layout of joint section of the Yukspor deposit.

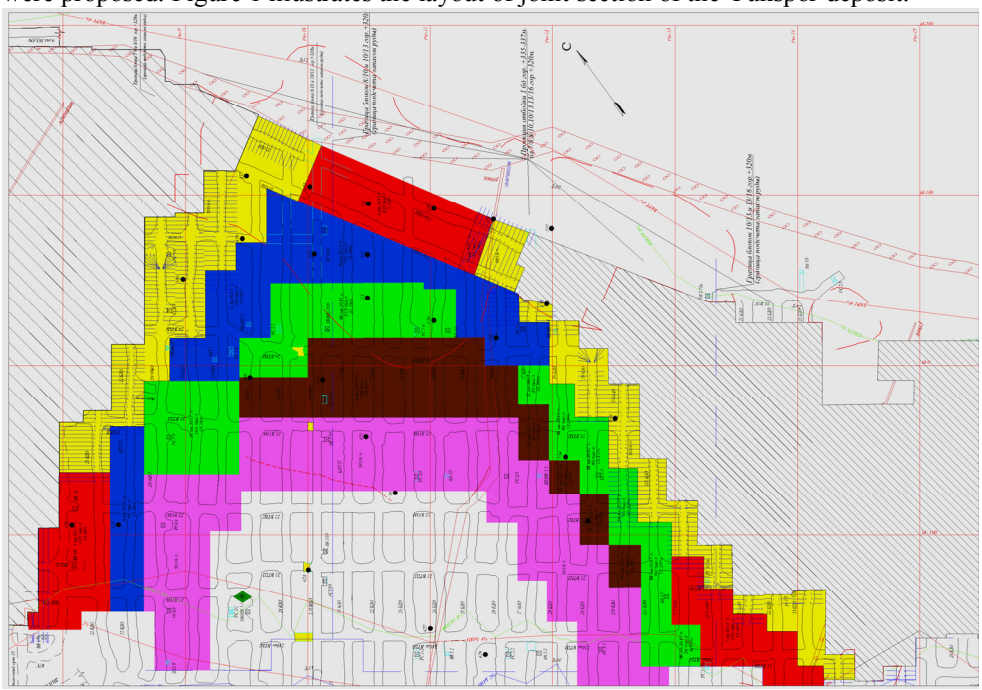

Fig. 1. Joint section of the Yukspor Deposit, bl. 10/13, sublevel + 358m, level + 320m.

The loss of stability of mine tunnels and pillars is mainly caused by the following reasons:

- pillar mining in the affected area and rock pressure increase cause dynamic rockfall, strainburst on the outline of the excavations and pillar bursting;
- seismic induced dynamic events of different origin;
- in highly fractured rocks, as well as in oxidized areas, rockfall occurs under natural and man-made broken conditions. If there are no timely arrangements for safe mining, the formation of gradually increasing kettlebacks begins;
- geological inclusions in the rock mass (dikes, veins, etc.) cause the rockfall along the outline.

The development of three sublevels of the level + 320m of the Yukspor deposit showed that all of the above factors are relevant for the conditions of the mines of Kirovsk branch of JSC "Apatit" and significantly affect the safety of mining operations.

To prevent negative effects of rock pressure, the Department of rockburst forecasting and prevention was established in Kirovsk branch of JSC "Apatit". The following forecasting tools for geomechanical events are used:

- Seismic monitoring - continuous registration, interactive editing of seismic data, analysis of local rock-bump hazard based on continuous seismic monitoring.
- Local monitoring - visual inspection, disking method, control of borehole walls' destruction, various geophysical measurements.

- Mathematical modeling of stress-strain rock condition - detailed numerical local models of stress-strain rock condition of the researched areas based on mining, geological and geomechanical data analysis.

The results of rock condition monitoring are provided below.

2 Seismic monitoring

Underground seismic monitoring is carried out by geophysical monitoring group (GMG) of the Department of rockburst forecasting and prevention using automated systems to monitor (hereinafter AMS) the rock condition detecting geodynamic events with an energy from 1.0 E+02 J, and an accuracy of a few meters (in the area of particular accuracy). AMS is a software and hardware complex for local forecasting of rock-bump hazard based on continuous seismic monitoring of underground mines of Kirovsk branch of JSC "Apatit". Local forecasting of rock-bump hazard based on continuous registration of seismic activity increases mining safety under difficult geodynamic conditions. Telemetric subsystem of seismic data collection (Kirovsk and Rasvumchorr) includes: a network of seismic stations hosted in the mine tunnels underground, cable communication lines and a telemetry controller [1].

2.1 Seismic analysis

When registering a seismic event in the Khibiny Massif, it was determined seismic setting of controlled production area is not steady. In effect, there is a whole spectrum of geodynamic events observed in Kirovsk branch of JSC "Apatit": tectonic rockbumps, rockburst, strainburst, seismic induced rockfall and rock bulking.

According to the results of microseismic monitoring at Kirovsky mine (Km) from 1997 to 2017, AMS had recorded 92 seismic events with an energy of 1.0 E+07J. For the period of January 1, 2007-Janury 31, 2017, AMS had registered 489 seismic events at the Yukspor deposit with an energy of 1.0 E+06J, most of them were recorded in the area of pillar mining and overlying rock base. That is related to stress redistribution and rupture intergrowth into the overlying rocks. It is known that not only geological and tectonic structure, stream conditions, methods of excavation affect the seismic response, but the progress rate and the amount of simultaneously blasted explosive materials as well.

Figure 2 shows the time series of distribution of registered natural events with an energy of 1.0 E+06 J and ore distribution at the Yukspor deposit. With the increasing ore extraction volume, seismic activity at the deposit raises as well.

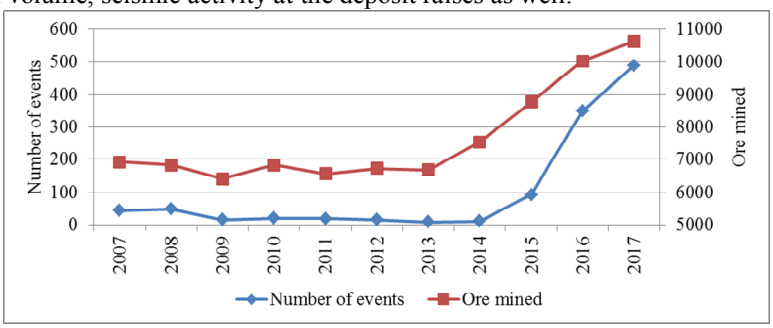

Fig. 2. Time series of distribution of registered natural events with an energy of 1.0 E+06 J and ore distribution at the Yukspor deposit.

Since the beginning of pillar recovery at the level +320m of the Yukspor deposit (Fig.3), the number of seismic events with an energy of 1.0 E+06J in the overlying rock

base had sharply increased. This reflects fracture intergrowth and gradual caving of overlying rocks.

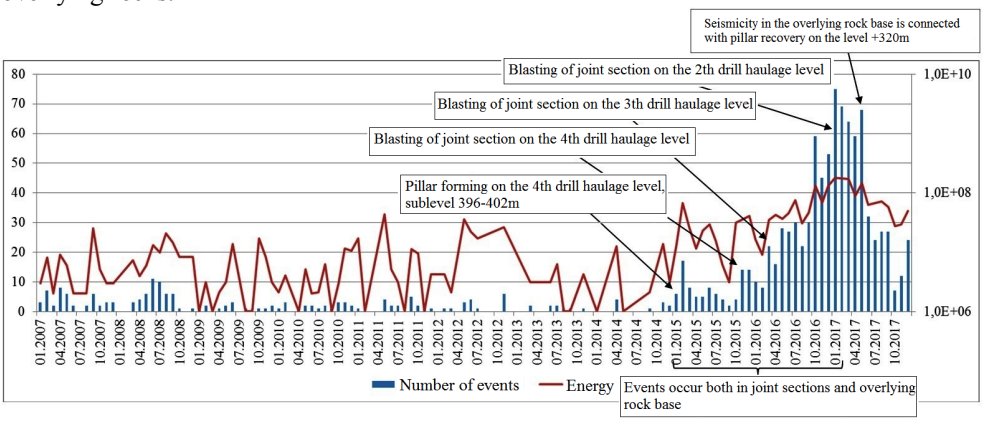

Fig. 3. Energy change and temporal distribution of seismic events within the affected area of the overlying rock base at the Yukspor deposit.

As a result of mining operations, the undermining of hanging wall occurs, which causes extension zones in one part of the rock and increasing compressing strain in another. In case of rockfall, stress stabilization in the affected area occurs [2, 3, 4]. If fracturing and timely recovery of the overlying rocks do not occur during the excavations, then sudden rockfall can be dangerous because of the air strike underground and be a threat to the objects on the surface. As for stabilization of mine tunnels, caving is not a threat, and after caving, due to the reduction of the mounting base, and therefore the decrease of bearing pressure, the stability of hanging walls increases.

As statistical data analysis shows, these processes are accompanied with an increase in the number of seismic events and energy. When registering series of seismic events or events with energy greater than 1.0 E+06 J, according to the approved methods, a zone of local rock-bump hazard is declared, people and equipment are removed from the outlined area.

3 Rock stability and status categories of mine workings during pillar recovery

Kirovsk branch of JSC «Apatit» assessed a stable rock condition and the condition of individual mine tunnels basing on physical properties of the rocks composing the deposit and the magnitude of affective stresses. In accordance with strength assessment and rock fracturing and external features of rock-bump hazard on the outline, status category is determined. There are five status categories A - mine working remains stable, B – rock fracturing, C – rock bulking, slight seismic induced rockfall, D - seismic induced rockfall, E – strainburst and intense seismic induced rockfall, microbumps and rockbursts are possible [5].

At the preparation stage and subsidiary pillars development at the sublevels +320m, rock pressure was observed in the cross drifts and mine tunnels. In the areas of intersections, the rockfalls with geological structural heterogeneities up to 15 meters were noticed.

In case of convergence of mining operations, breaking of joint sections on the overlying sublevels and mine workings made in a hanging wall of the ore deposit fall into the affected area of pillar mining. Compressive stress increases, and, therefore, rock pressure intensifies.

February 5, 2017 and March 27, 2017 at the sublevel +334m, geodynamic events occured. The Commission on rockbursts classified them as microbumps having appeared as a result of a number of negative factors, both natural and self-induced, exacerbating the rock condition in general:

- geological features of rock structure (vertical fractures filled with secondary minerals);
- overlying rock failure border and breaking border of the sublevel +334m are located in the affected area;
- seismic induced fracture intergrowth in the overlying rocks, as the rockfall mounting base is located on the border of stable and non-stable rock exposures.

To forecast further pillar condition at the level +334m, mathematical simulation of stress-strain state in software system SigmaGT was carried out. Classification of rock-bump hazard was made for all mine workings of the pillar. When defining the category as "Dangerous", repeated measures on rock load relief are applied and the rock support system is improved (Fig.4).

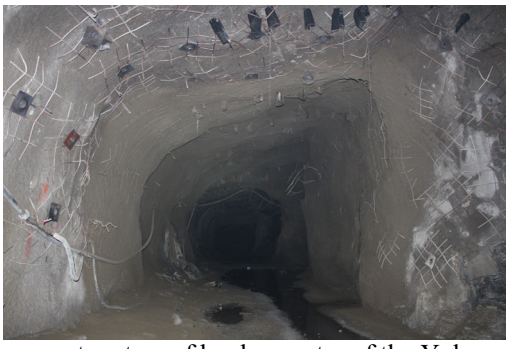

Fig. 4. Improved rock support system of haulage entry of the Yukspor deposit.

Since the beginning of mining of joint section at the sublevel +402m in 2015, Kirovsk branch of JSC "Apatit" has significantly revised the approaches to the the types of rock supports. New types of rock supports are implemented - reinforced sprayed concrete, self-attaching anchor bolts, resin-grouted roof bolts and others [6]. Regulations on mining operations on apatite-nepheline deposits were updated: "Guidelines for safety operations on dangerous and burst-prone deposits", "Guidelines for support erection and control of excavations at the mines of JSC "Apatit".

As practice shows, new approaches to the types of supports, definition of their parameters and stabilization of excavations, provides mining safety under the conditions of high compressive stress and seismic impact from blasting.

Conclusions

Automated control systems to detect geodynamic danger zones in on-line mode, effective interaction of production and science, scientific-research and experimental-industrial operations on the development and the introduction of new (and improvement of the existing) means, ways and methods to reduce the risk of adverse situations related to the transition of mining tunnels into unstable condition, allow effectively designing, passing and operating under difficult geodynamic conditions of the Khibiny deposits [7-9].

We note that in order to reliably solve the problem of preventing dangerous manifestations of rock pressure in underground mines, multilevel systems of complex geodynamic monitoring should be created, which may include a number of measurement methods and technical means that ensure effective registration and in-depth analysis of a

wide range of spatially and temporally changing geophysical parameters wave fields (geoacoustic, microseismic, deformation, etc.).

Joint interpretation of geoacoustic and microseismic monitoring data, correlated with geological and mining technical models, provides high reliability of forecast estimates [10, 11].

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