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Learnings from early production at the Kemi sublevel cave

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Abstract

The sublevel caving (SLC) mine at Outokumpu's Kemi Mine, in Finland, is in a ramp-up phase. The mine is located in the vicinity of an active underground benching mining area, both operate simultaneously in different parts of the orebody.

Initial SLC design parameters were based on global benchmarking of similar mines, in-house subject-matter expertise and over 20 years of experience from underground mining of the deposit using stoping methods. Key parameters evaluated were the sublevel spacing, crosscut orientation and spacing, opening slot height, drill and blast parameters, and draw rates. Detailed life of mine (LOM) cave flow modelling and geotechnical impact assessments were conducted to support the evaluation of the parameters.

This paper describes the evolution of mine design parameters from mining study phase, through trial mining, and into the current ramp-up phase. It also describes the experience gained during the early years of SLC mining and the main factors impacting successful production ramp-up are discussed.

Keywords: *underground mining, sublevel caving, production ramp-up, mine design*

1 Introduction

Review of sublevel caving mining method started with pre-studies in 2015, followed by extensive trials in 2020–2021 and production commencement in 2022. The production footprint was continuously expanded from the initial trial area as mining transitioned to a ramp-up phase.

The Kemi Mine is located in Finland, 650 km from the capital Helsinki, as shown in Figure 1.

Figure 1 Location of Kemi Mine

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The mine currently operates with 2 different mining methods and multiple mining areas, as shown in Figure 2. An overview of the mining geometry and geological setting, including a typical geological section are shown in Figure 3. A typical geological geometry is shown in Figure 4.

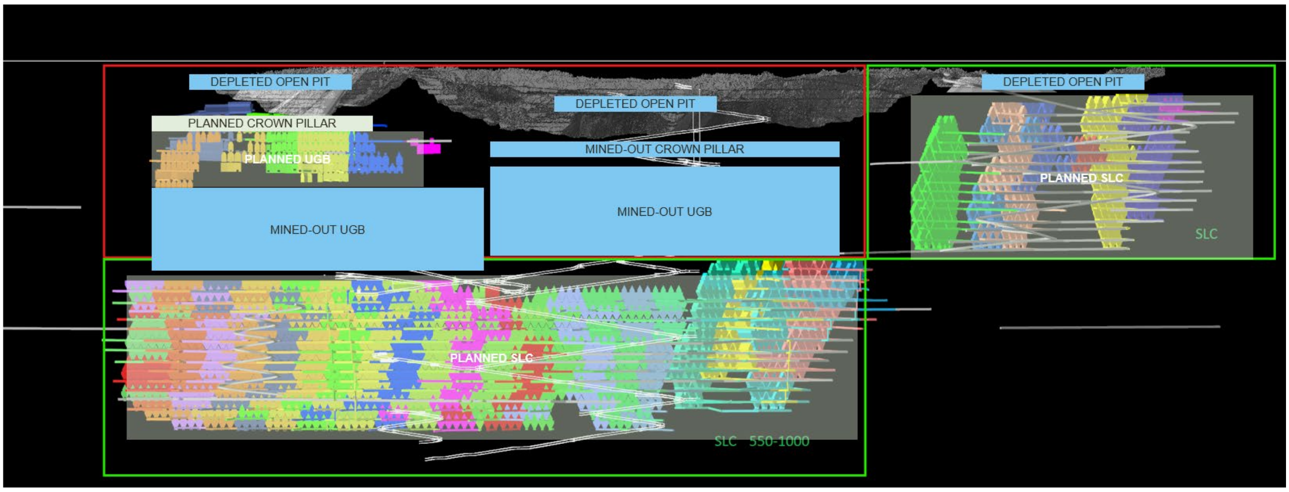

Figure 2 **Underground benching mining areas (mined-out and planned) shown with a red rectangle; planned sublevel caving is shown in the green rectangles. Depleted open pits in are in dark grey. Below open pits is crown pillar mining area shown (mined-out and planned)**

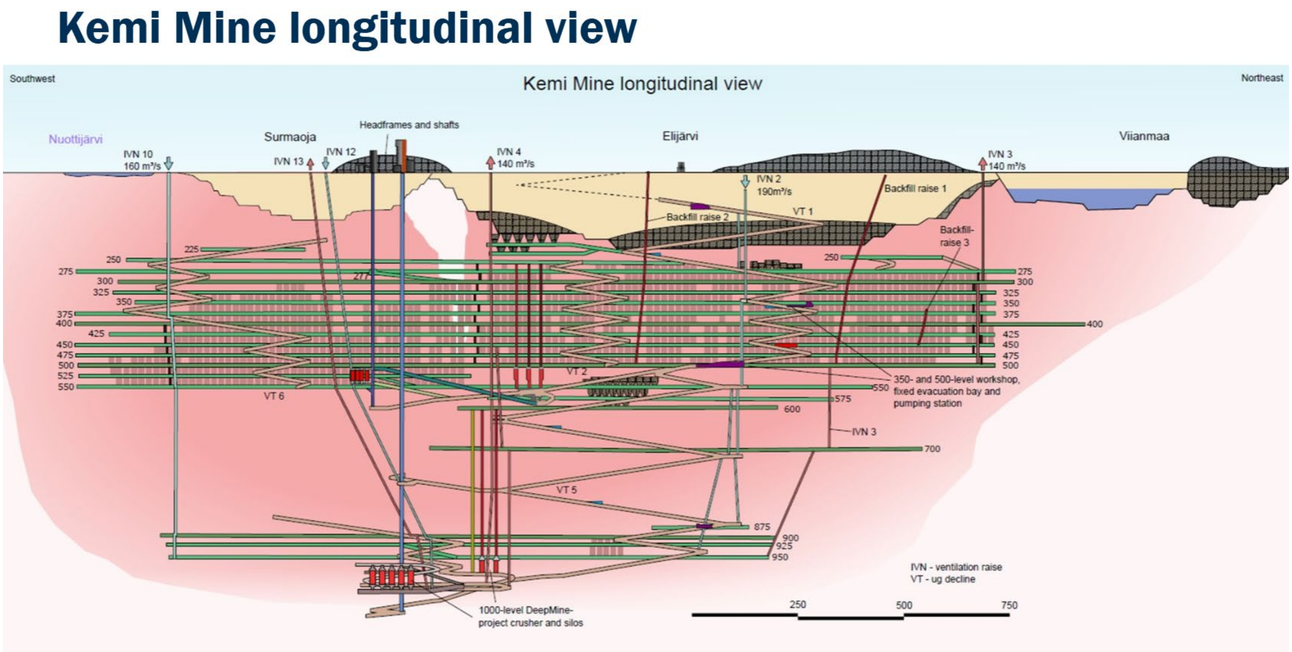

Figure 3 **Cross-section of Kemi underground as-is tunnels looking north–northwest. Depleted stopes in light grey, main footwall drives in green and sublevel caving initiation area in dark grey**

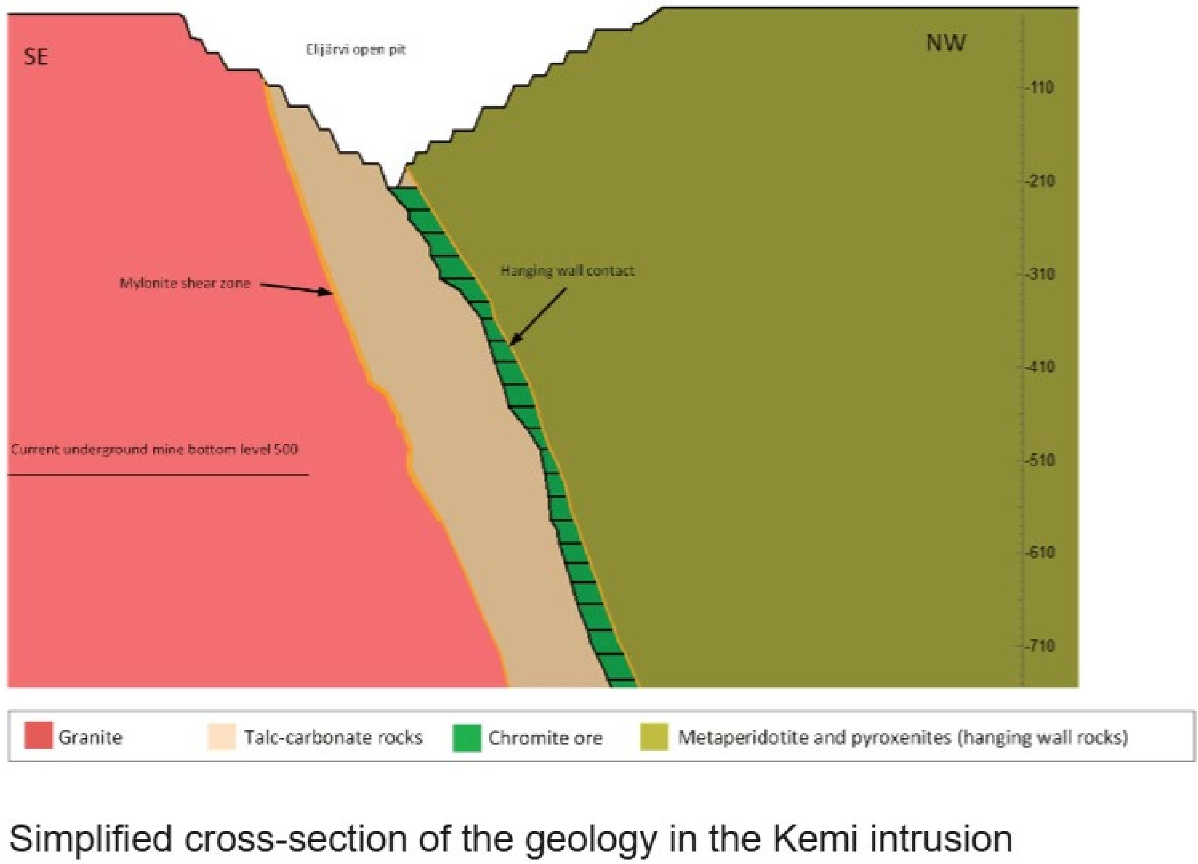

Figure 4 Kemi underground mine geological layers

Underground mining at the Kemi Mine has evolved from a 1.5 Mtpa sublevel-benching operation to a 3 Mtpa sublevel caving (SLC) mine over a of the past 15 years. The major driver for the increase in capacity was from the increased demand from Outokumpu's ferrochrome smelter in Tornio, Finland. The reasoning and background for the change in mining method transition are described in previous published papers from Caving 2022 (Karlsson et al. 2022) and MassMin 2024 (Ihanus et al. 2024) conference proceedings.

The open pit mines are fully depleted and are now utilised for waste rock storage ahead of crown pillar mining. The purpose of waste backfill is to prevent cold air entering unmanaged to the underground workings and providing additional support for open pit walls.

1.1 Initial design parameters

1.1.1 Level layout

The SLC is planned to cover a mining depth between 500 and 1,000 m (500 and 1000 m metre under surface, correspondingly), overview shown in Figure 5.

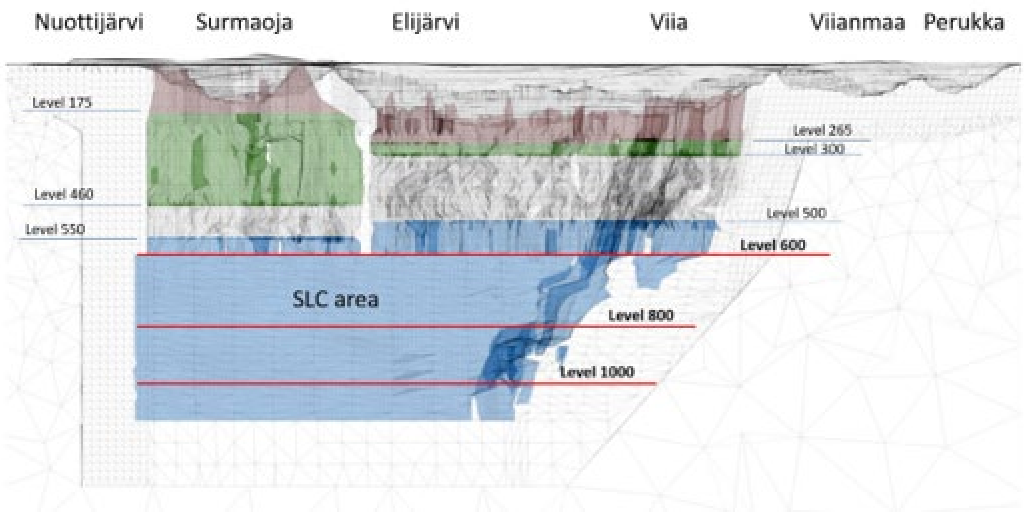

Figure 5 Kemi Mine sublevel caving (SLC) mining area

Majority of SLC mining is planned to be in transverse configuration due to the geometry of the orebody. The reasoning behind the selection is that the transverse approach relies heavily on experience from upper levels for tunnel stability. The required number of drawpoints to maintain production output also supports a transverse approach. There is potential to apply longitudinal configuration at the narrowing flanks of the deposit. The plan view of a typical SLC level in the life of mine plan is shown in Figure 6. The position of the footwall drive is dictated by geotechnical considerations, i.e. located in granite. The overall layout of SLC is much like sublevel opening stoping (SLOS) in the upper levels due to previous experience and successful production thereof. All footwall drives and fixed infrastructure is developed in granite. Access drives in soft talc-carbonate are subject for deformation during production.

Figure 6 Plan view of a typical sublevel caving level in the life of mine plan (as-is tunnels in colour, planned drives with dotted lines)

1.1.2 Drill and blast

Benchmarking of drill and blast (D&B) parameters used at other SLC operations was completed early in the design phase. For familiarity with underground benching mining, a drill pattern was selected to match the sublevel height of 25 m. For the undercut level (or first SLC level below the old workings), a conservative blind 15 m vertical height was selected. Various design options including different side angles, drillhole charge densities and burden were evaluated in the study. Figure 7 presents an overview of the options evaluated.

65 Degree Wall Holes		A - 65	B - 65	C - 65	D - 65	E - 65	F - 65
Sub Level Spacing	m	25	25	25	25	25	25
Stope Width	m	15	16	17	17	18	18
Drive Height	m	5.5	5.5	5.5	6	5.5	6
Drive Width	m	6	7	7	8	7	8
Stope Height	m	34.7	34.7	35.7	34.7	36.8	35.7
Draw Ratio		1.5	1.3	1.4	1.1	1.6	1.25
Surface Area	m^2	342	362	386.5	377	411.5	402

70 Degree Wall Holes		A - 70	B - 70	C - 70	D - 70
Sub Level Spacing	m	25	25	25	25
Stope Width	m	15	16	17	17
Drive Height	m	6	6	5.5	6
Drive Width	m	8	8	7	8
Stope Height	m	34.6	36.0	38.7	37.4
Draw Ratio		0.9	1	1.4	1.1
Surface Area	m^2	327	352	386.5	377

Figure 7 Alternatives evaluated for initial sublevel caving drill and blast patterns

1.2 Evolution of design parameters

The various following parameters were evaluated and trialled during the early years of SLC production.

1.2.1 Undercut mining height increase

Gradual decrease of the effective horizontal pillar between the undercut level and previous workings was succeeded by longer drill lengths and charge columns. The undercut height increased from 15 to 25 m, using flat-top shape of drill pattern. This enables higher ore recovery on undercut level.

1.2.2 Slot opening

Opening of transverse production drives evolved from using a large-diameter borehole to longhole drill and blast with multiple easer holes. This enables faster drilling using standard longhole drilling equipment as well as a higher success rate of blasting the slot to full height. Typical slot heights are ranging from 15 to 35 m.

1.2.3 Crosscut spacing

Increasing the centre-to-centre distance of production drives from today's 18 to 20–22 m is anticipated to return better geotechnical stability as pillars between drives are larger; however, this has yet to be confirmed. Draw width in limited scale SLC trial area was averaging 1.5 times drive width.

1.2.4 Ring advance

A trial to extend the ring advance from 2.5 to 2.8 m was conducted and deemed successful based on blast vibration measurements and mucking result observation trials

2 History of sublevel caving production

2.1 Early works

Initial studies and early design for the SLC mining method at the Kemi Mine were conducted during 2015 and 2016. These generated a work plan for further evaluation and modelling work, which were completed between 2016 and 2019. Parallel to these studies, early development works were started to access the SLC undercut level and central initiation point. Total development for the trial area was 1,721 m and produced 525 kt of ore .

2.2 Phased approach

SLC production was divided in 3 stages: trial, ramp-up and steady state. Trial mining was undertaken over 3 levels and 2 to 4 adjacent production drives. This volume of material was required to monitor the ore flow between drives and levels as part of the initial mining trial (Figure 8 and 9). Production from the trial area lasted approximately 18 months (June 2021–Dec 2022), during which a number of smart marker tests were conducted and ore flow was verified through instrumentation. The final decision to continue SLC mining was made following the success of the initial trial.

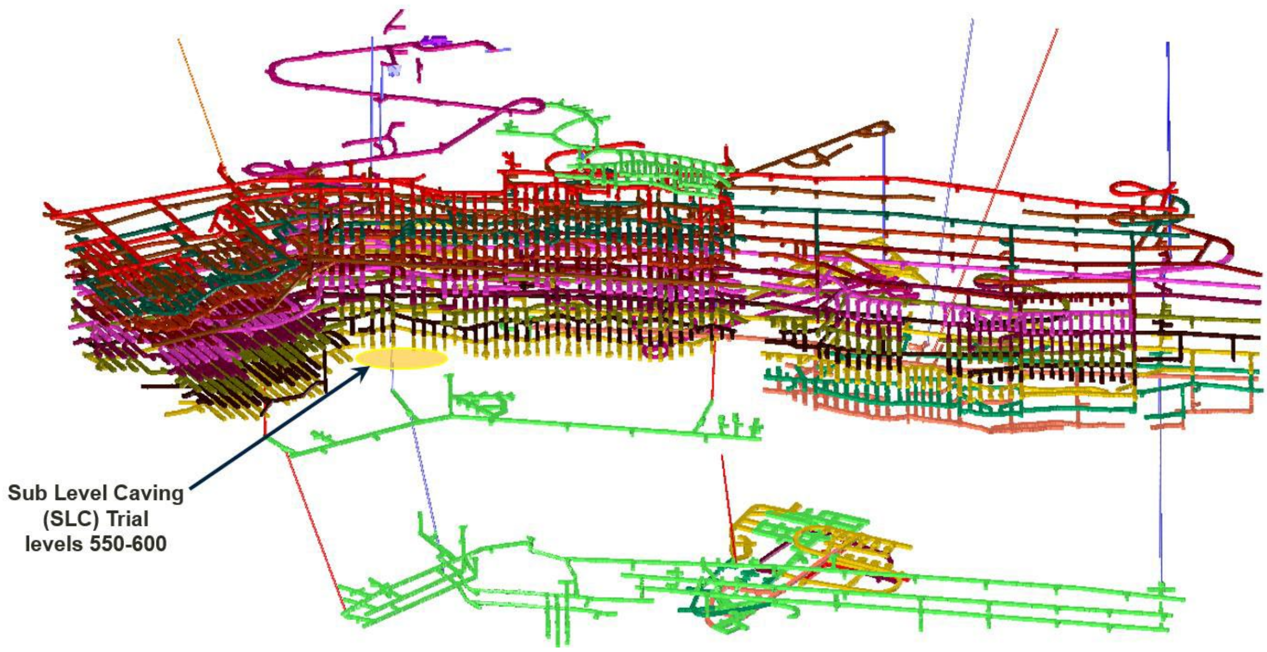

Figure 8 Location of sublevel caving trial

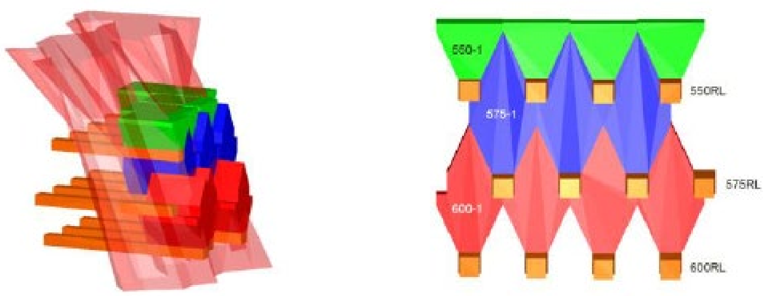

Figure 9 Sublevel caving trial principle and extent

3 Ramp-up phase

3.1 Actuals performance versus planned

Actualised performance (Table 1) has been somewhat lower than initial projections, mainly due to prioritising SLOS mining areas. Geotechnical issues in the form of tunnel deformations at the footwall have slowed down the opening rate of new SLC production drives.

Table 1 Sublevel caving production tonnes

Year	Ore [t]
2021	59,974
2022	181,451
2023	237,022
2024	413,570
2025	603,118
Total	1,495,135

3.2 Plan forward

The planned ramp-up is to accelerate SLC mining in order to realise cost benefits of the method in comparison to SLOS. This plan is outlined in Figure 9. Due to deposit shape and size, the mine will host several mining methods in addition to SLC in the future. However, SLC will be the main method, covering up to 80% of production.

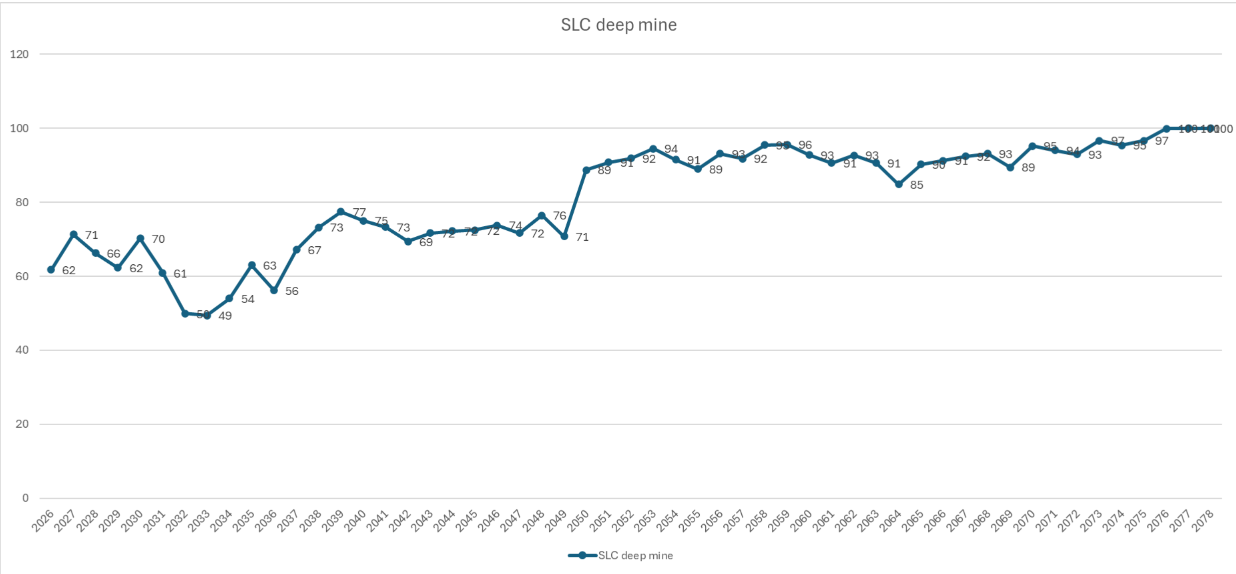

Figure 10 Sublevel caving production plan forward

4 Learnings from ramp-up period so far

4.1 What worked well

4.1.1 Slot design

From initial trial parameters, the slot height has been increased in other parts of the undercut level. The methodology is tested in the crown pillar mining area with a high success rate. In SLC this translates to a smaller-than-planned sill pillar between the SLC mining front and old backfills SLOS stopes. The first tests show that less than 10 m of solid rock enables safe operating condition in the undercut level while providing sufficient flow of ore to drawpoint.

4.1.2 Hanging wall slot drives

A drive along the orebody hanging wall contact is mined for dual purposes:

- to provide a blast void for transverse production crosscuts
- to provide protection from lateral rock stress.

Early indication is that for opening purposes the method works, although it is not favourable from a task scheduling point of view. Impact on rock stress redistribution is still to be verified.

4.1.3 Webgen initiation

The application of Webgen detonators was first trialled during crown pillar mining in high slots and then in the SLC rings in cases where pre-charging was required. Access to ring collars was limited due to brow back-break.

4.1.4 Pre-charging

It was deemed as a necessity to apply pre-charging, due to frequent back-break causing damage to unblasted rings. Currently 2–3 rings ahead of blasted ring are pre-charged.

4.1.5 Validation of charging initiation

Vibration monitoring was done to validate initiation quality during early drill and blast design changes. This was completed using temporary sensors placed near the blast area.

4.2 What didn't work so well

4.2.1 Geotechnical

Excessive back-break occurred during production blasting in initial SLC mining, and has been an ongoing challenge at the mine. This is thought to be both a drill and blast design issue in combination with prevailing geotechnical conditions.

Squeezing ground is a common issue, particularly in the soft talc-carbonate rocks, as shown in Figure 11. Magnitude and rate of squeezing are expected to increase with increasing with depth.

Figure 11 Squeezing conditions in a production crosscut

4.2.2 Pre-drilling

The mine initially aimed to maximise pre-drilling to improve efficiency. However, maximum of 2 uncharged rings ahead of pre-charged rings was adopted to minimise redrilling requirements adopted. At times drill holes were completely blocked, leading to delays in new ring design and drilling

4.2.3 Selective mucking

Early attempts to muck from side-to-side in cross were discontinued. The selected loading equipment was too wide with respect to the tunnel width to allow any meaningful loading from each side sequentially.

4.2.4 Ore flow monitoring

A routine ore flow monitoring program using a dummy or smart markers was considered, but not implemented due to lack of resources. Currently, ring-specific tonnes reporting is used as flow validation. The current plan includes application of a smart marker campaign when changes are made in drill pattern, level height or production drives centre-to-centre distance.

5 Future improvements

5.1 Production ramp-up rate

The mine is set to achieve more than 50% of total mine output from SLC production during 2026.

5.2 Geotechnical data feedback loop

An increase in understanding the changes in the geotechnical environment is required, as the SLC differs greatly from benching and stoping mining methods. One initiative to overcome this is a feedback system collecting data from operator experiences and observations, together with monitored data. This will provided guidance for mine planners when a new SLC level is established.

5.3 Monitor selected key performance indicators against peers

Being a new cave mine, the Kemi Mine is eager to benchmark itself against suitable peers. Key comparisons include factors like lateral development per ore tonne, overall ore recovery and dilution, ring turnover time, and tonnes per day per crosscut.

5.4 Production improvement

Further increases to the production crosscut spacing will be trialled. The anticipated benefit is an increase in pillar stability with minimal loss of ore recovery.

Trial for a layout change in crosscut configuration to a ‘fork-layout’ is underway. The anticipated benefits are better alignment of drive direction with principal stress direction, thus minimising exposure time of the open drives and minimisation of drives through weak talc-carbonate rock mass.

Mechanical excavation in areas of weak ground will also be trialled. The anticipated benefits are less blast damage, including less damage to the rock mass in proximity to development, and improved stability.

6 Conclusions

From a technical perspective, the SLC ramp-up has followed the initial plans from early studies. Changes and evolution of design and operational parameters are considered a normal part of a functioning SLC mine and continuous improvement. Geotechnical conditions were largely as expected; however, the full extent of the damage mechanism is still not completely understood, and will be studied further during SLC operation as the mine extends deeper.

So far, the ore flow between levels has been as expected. However, when mining proceeds deeper, the rock stress will play a more pronounced role in affecting the flow. The total ore output has been less than predicted, mainly caused by the acceleration of other mining methods in the mine, which in turn were dictated by factors such as seasonality in the mining of the crown pillar, delays in lateral development in the SLC area and overall cost pressures.

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