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# Geotechnical challenges driving the mining method change: transition from sublevel stoping to sublevel caving

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## Abstract

*Kemi Mine is the largest underground mine in Finland with annual ore production of 2.7 Mt. The mine started as an open pit in 1968 and transitioned to underground mining in 2006. Underground mining started with sublevel stoping (SLS) from 500 level (metres below surface).*

*Current mining is challenging due to geotechnical conditions that affect the stope size and tunnel stability. As mining proceeds deeper in depth, the conditions are anticipated to be more difficult than on the upper levels, thus a change in mining method is required.*

*Historically squeezing ground is the principal mechanism that damages the rock mass in the production area (slow displacement of backs and walls inwards) notwithstanding stope collapses due to the exposure of wedges. Increasing geotechnical difficulties result in a reduction stope, dimensions causing sub-optimal and complex production scheduling. These issues led to a process where alternative mining methods were evaluated to replace SLS and increase ore recovery and production reliability. Sublevel caving (SLC) was shortlisted as one potential alternative and led to a series of studies, evaluations and finally to a limited scale trial mining.*

*The introduction of a new mining method within an operating mine is a huge challenge. During pre-trial and trials the execution team established a number of new routines to mitigate the issues. These included, among others, planned information events for all mine personnel, development of new operating procedures specifically for SLC, and a large number of internal workshops with key personnel involved in the geology, mine planning, operations and support services.*

*This paper presents the background, settings and selection criteria for a SLC mining method at Kemi Mine along with the challenges encountered and steps taken in the change management process.*

**Keywords:** *sublevel caving, transition, deep mine, change management*

## 1 Introduction

### 1.1 Kemi Mine history

The Outokumpu's Kemi chromite mine is located near the town of Kemi, in Northern Finland, close to the border between Finland and Sweden (Figure 1). Chromite ore deposits were discovered in Kemi in 1959. Ore production started from an open pit in 1968 with Tornio steel mill (ferrochrome plant) as owner and captive customer. The associated industrial facilities, including the ferrochrome plant and stainless steel works at Tornio were completed in 1976. The mine production was expanded in 1985 with the commissioning of the second ferrochrome smelting furnace, and then expanded further again in 2013 with the third furnace. The underground mine was constructed over the years 1999 to 2003.

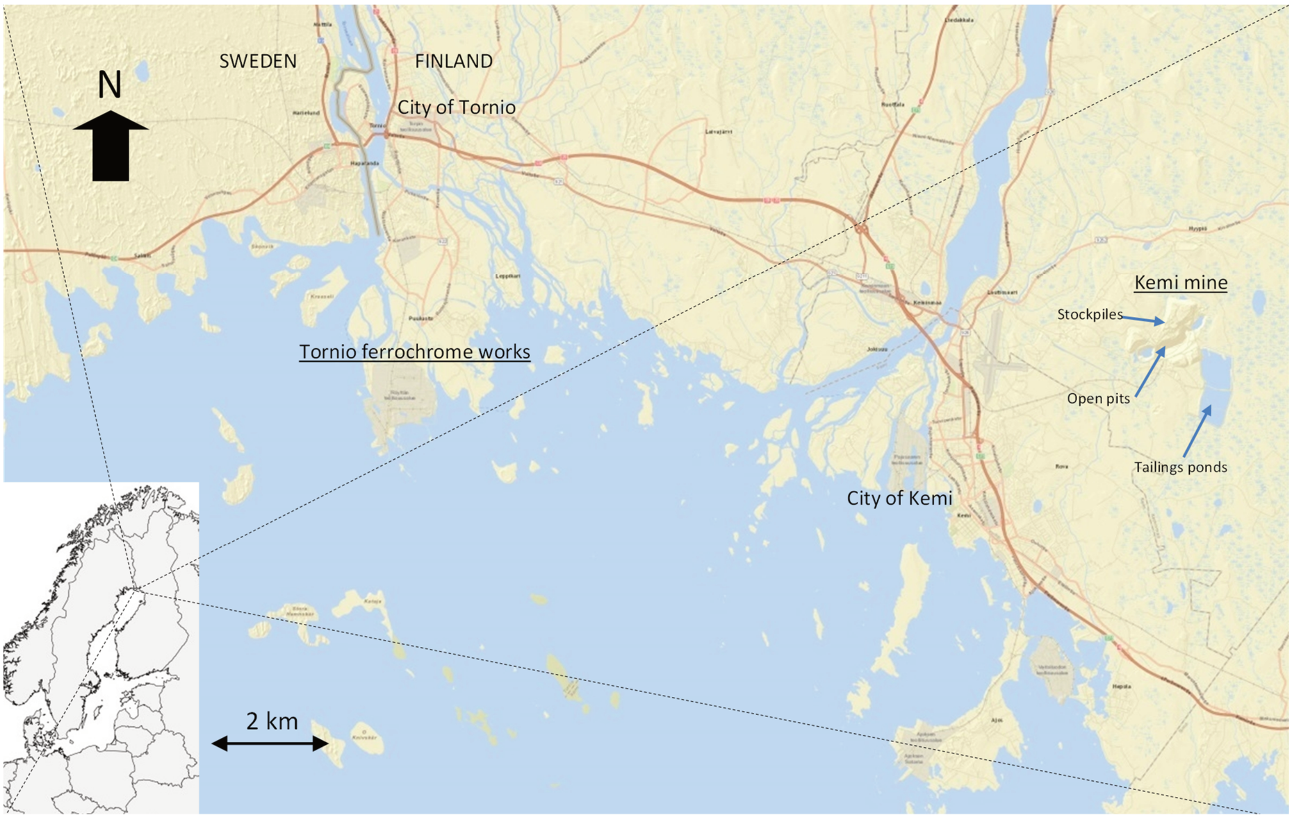

**Figure 1 Location of the Kemi Mine and ferrochrome works in Tornio**

The open pit was exhausted in 2005. Ore output, concentrate production and consequent ferrochrome production were doubled during 2013–2015. The mine name plate capacity is 2.7 Mtpa. All concentrates are transported by truck to the ferrochrome works in Tornio as raw material for the company's own ferrochrome production.

## 1.2 Geology

Kemi Mine's geology is based upon a magma intrusion with additional metamorphism that created the current layered intrusion. Chromite (ore) accumulations occur inside ultramafic rocks i.e. talc-carbonate-chlorite rocks in the Kemi layered intrusion (2.5–2.4 Ga). Total length of the intrusion is over 15 km. The economically viable chromite bearing part is 4.5 km along strike. The formation and ore dip at 70° to the northwest. The contact between the intrusion and the granitic basement is tectonic and represented by a mylonite shear zone. The hanging wall of the ore consists of metaperidotite, talc-carbonate and pyroxenite rocks (Alapieti et al. 1989). The ore's footwall contact is an almost non-visible grade cutoff boundary from chromite bearing serpentinite/talc-carbonate to talc-carbonate. In some areas the hanging wall contact can be poor rock quality, sheared with a clearly visible contact surface (Figure 2). Based on the current information, the geology can be extrapolated to depth with confidence (Figure 3).

The depth of the formation and ore are still unknown, however seismic measurements indicate that the formation has a vertical extent of several kilometres. The deepest ore intercepted by drilling lies at a depth of 1 km.

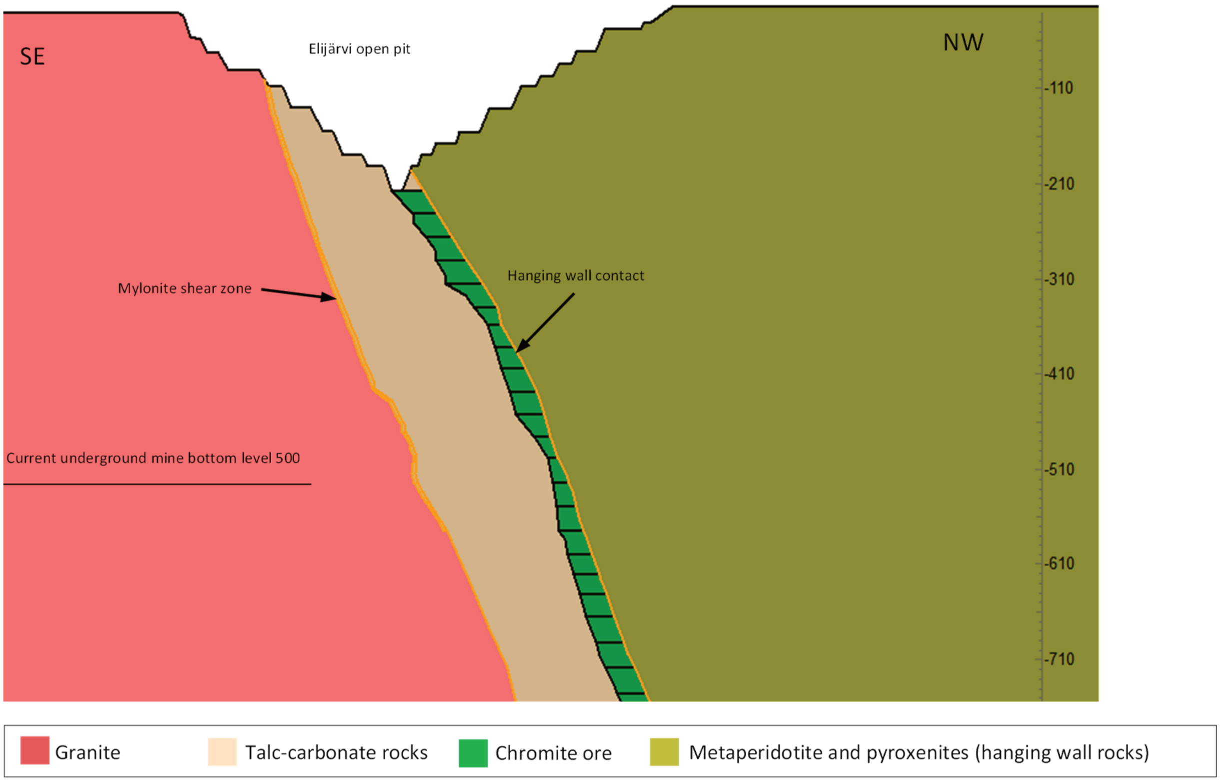

Figure 2 Simplified cross-section of the geology in the Kemi intrusion

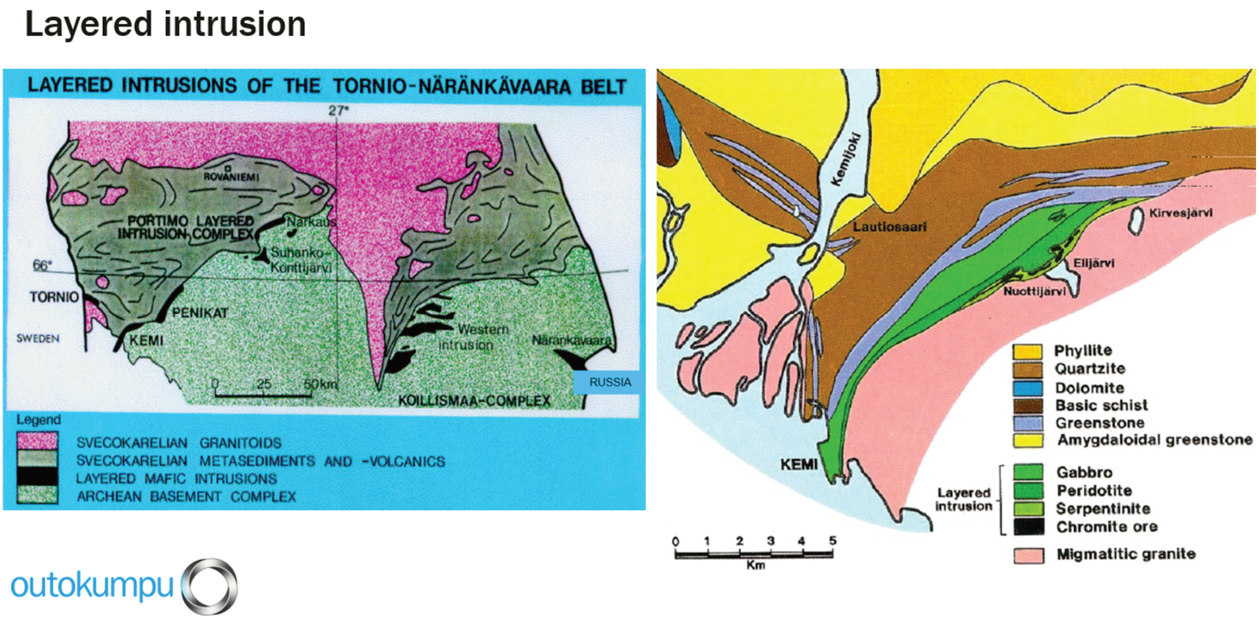

Figure 3 Overview of regional layer intrusion – Kemi Mine

## 1.3 Geotechnical setting and stability problems

The stability problems in the current underground mine are linked to poor rock mass quality and low strength rocks that are a result from the metamorphosed geological environment in the Kemi Mine. Underground tunnel and stope stability in the Kemi Mine have been problematic in some of the production areas.

Ore access tunnels and footwall drives inside intrusion rocks suffer strong deformation after stope production is initiated in the vicinity. Heavy multilayer ground support is installed as a standard operating procedure. The squeezing ground conditions are caused mainly by the elevated rock stresses from the excavations acting in the soft, low strength talc-carbonate rocks. The squeezing ground conditions occur in the production areas i.e. within the layered intrusion rock mass (Figure 4).

**Figure 4 Typical view of a production drive in squeezing ground**

All the permanent mine facilities are located in the granitic basement. The separate ‘pinch outs’ of the talc-chlorite-carbonate rocks, outside of the main intrusion, are considered as the magma’s feeder channel (Kemppainen 2002). The feeder channel and its branches may cause local tunnel instabilities when tunnels are excavated. The feeder channel has the same strike as the geological formation; hence, it is expected that the feeder channel is intersected in deeper parts of the mine as well.

Veins and fault zones cause local stability issues in tunnels in the granitic basement. Diabase/amphibole veins and fault zones are quite common among the granitic rock mass and can cause local stability issues, although they are not common.

The tunnels in granitic rocks encounter seismicity and spalling at depths of approximately 950 m below surface.

In situ stress measurements utilising the LVDT-cell (Hakala et al. 2019) at 900 m depth indicate a maximum stress component ($\sigma_1$) of 52 MPa, dipping 18° to the southeast (145° local mine coordinate). The intermediate principal stress ($\sigma_2$) is 35 MPa and the minor principal stress ($\sigma_3$) is 23 MPa.

Rock derivation of rock mass characterisation parameters for the geological/geotechnical units illustrates the strength and rock quality differences between the various units (Table 1).

**Table 1 Kemi Mine geotechnical units, GSI and intact rock properties**

| Rock unit | GSI | UCS (MPa) | Density (kg/m$^3$) | Young's modulus (GPa) | Poisson's ratio |
|---|---|---|---|---|---|
| Pohjois-Viia Ore | 59 | 62 | 3,841 | 45 | 0.27 |
| Elijärvi Ore | 66 | 72 | 3,604 | 56 | 0.33 |
| SP Ore | | 154 | 3,252 | 75 | 0.28 |
| Serpentinite | | 260 | 2,729 | 69 | 0.26 |
| Talc-carbonate rocks at Viia hanging wall | 59 | 53 | 2,990 | 39 | 0.30 |
| Talc-carbonate rocks at Viia footwall | 58 | 45 | 2,990 | 39 | 0.30 |
| Talc-carbonate rocks at Elijärvi footwall | 63 | 57 | 2,990 | 39 | 0.30 |
| Peridotite and metaperidotie at Elijärvi hanging wall | 62 | 170 | 2,751 | 81 | 0.27 |
| Granitic basement | 62 | 150 | 2,650 | 62 | 0.20 |

GSI – geological strength index; UCS – unconfined compressive strength.

The rocks mass parameters are based on previous studies (Kuula & Lamberg 2015) and drilling and laboratory tests. The weak mylonite contact with low shear strength between granitic rocks and talc-carbonate rocks was assumed to continue similarly in depth. The hanging wall in the Easternmost ore domain, Viia, consists mostly of low strength talc-carbonate rocks with pyroxenite interceptions whereas the hanging wall at Elijärvi and Surmaoja domains (towards the West) consists mostly of good quality and high strength metaperidotite rocks with pyroxenite interceptions. This clear difference in the hanging wall rock quality also means a difference in the behaviour of the hanging wall during mining. The strong metaperidotite rocks at the hanging wall will encounter less deformation during mining rather than the weaker talc-carbonate rocks.

## 1.4 Current mining

The current mining method is sublevel stoping (SLS) with backfill (Figure 5). Both rockfill (RF) and cemented rockfill (CRF) are used, depending of the stope sequence and position. Mining is executed through access drives developed from a decline located in granite rock. Production drives in the ore are mainly positioned in transverse configuration with 25 m level heights. Extraction follows a primary/secondary sequence with primary stopes filled with CRF and secondary stopes with RF. Slurry for CRF is produced up on the surface and delivered to mixing cuddies through boreholes and pipelines. Near the mixing cuddy, there is a drawpoint from a waste pass. Mixing of CRF is done with a load–haul–dump unit (LHD) alternating with waste rock and batches of slurry and loaded into trucks for transport to stopes. A typical level consists of footwall drive along the full orebody length connecting all three ore domains, ore access drives and production drives (Figure 6).

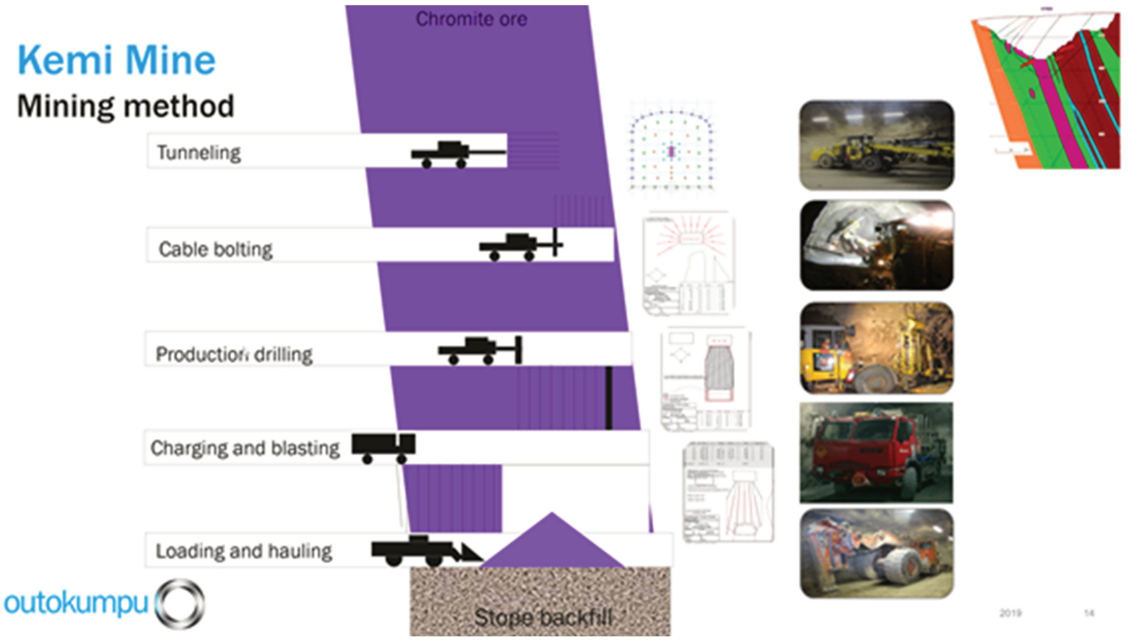

Figure 5 Sublevel-stoping principle at Kemi Mine

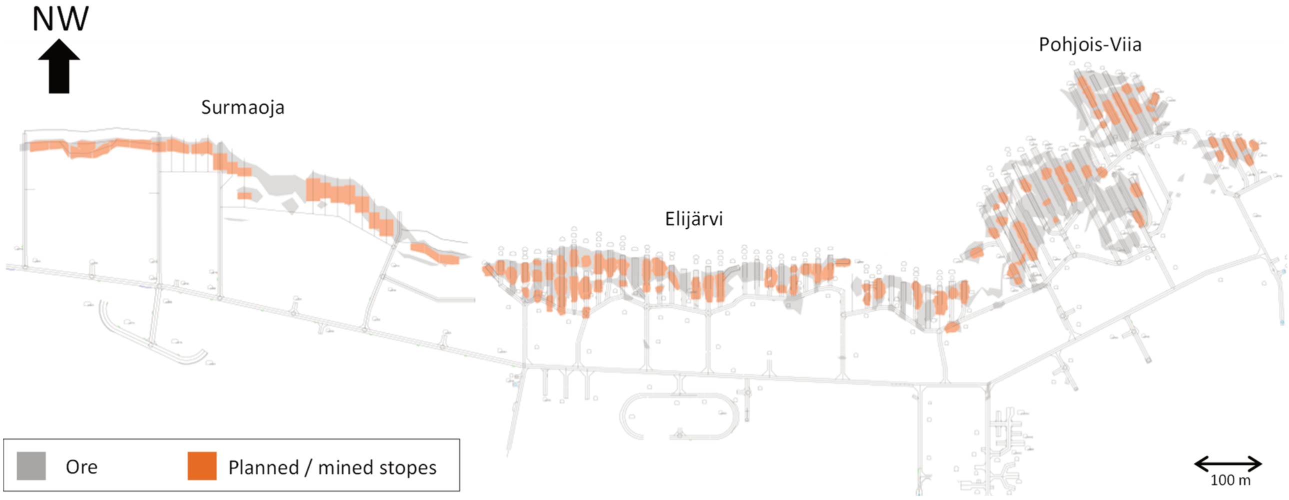

Figure 6 Typical level layout at Kemi Mine

Preparations for mining beneath 500 level are due for completion during 2022 (Figure 7). This stage includes construction of a new surface hoist from the 1000 level, a new underground crusher, rock silos, workshop and personnel facilities, all located at the 1000 level. In conjunction with the Deep Mine completion a mill capacity expansion is planned in order to meet demand for low-grade run-of-mine feed.

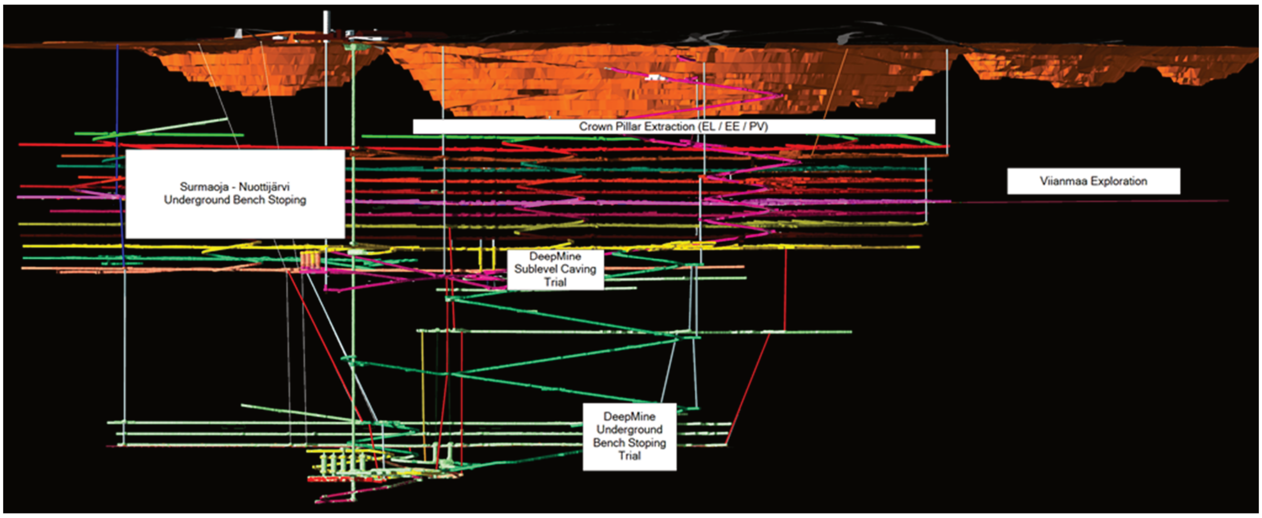

Figure 7 Longitudinal section of the Kemi Mine

# 2 Changing the mining method

## 2.1 Driving factor

As ground conditions deteriorate with depth, a change in mining method was required not only from a cost perspective but also related to maintaining the production output.

Historically squeezing ground is the principal mechanism that damages the rock mass in the production area (slow displacement of backs and walls inwards) notwithstanding stope collapses due to the formation of wedges. Increasing geotechnical difficulties result in a reduction in stope dimensions causing sub-optimal and complex production scheduling.

As a result of frequent stope collapses, the planned average size of a stope has declined over the years, Figure 8. This in turn results in an increased number of stopes to meet the production target, which in turn results in a complex, time and resource consuming operation. The risk of production shortfalls equally increases (Figure 8).

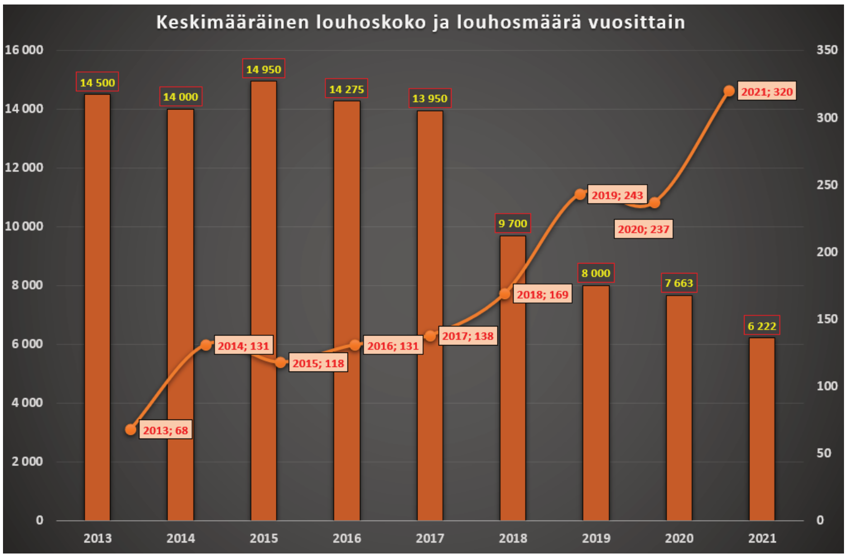

Figure 8 Planned stope sizes and number of stopes mined annually

For mining of ore below 500 level a SLS mining method was initially approved and applied. During a trial at the 925–950 levels the high stress environment caused more severe geotechnical problems in the 500 level mining above. As a consequence alternative mining methods were evaluated to replace SLS and increase ore recovery and production reliability. Sublevel caving (SLC) was shortlisted as one potential alternative, and a series of studies, evaluations and finally a limited scale mining trial was launched.

## 2.2 When to implement

Ideally a major change in the mining method should be accompanied by any relevant infrastructure modifications – change in orebody geometry in order to optimise the performance from the mine. A step-change in production technique, such as moving from open pit to underground mining, provides good opportunity to select and implement an optimal extraction method.

At Kemi Mine the change coincides with exhaustion of ore at higher levels of the deposit, thus creating an opportunity to 'start over' below the current lowest mining at the 500 level. SLS mining of ore above 500 level is planned to be exhausted within the next ten years and the last area to be mined is expected to be the crown pillars under two separate open pits. The principal differences between the mining methods are the: direction of mining (Figure 9); and the backfill stope support versus hanging wall caving.

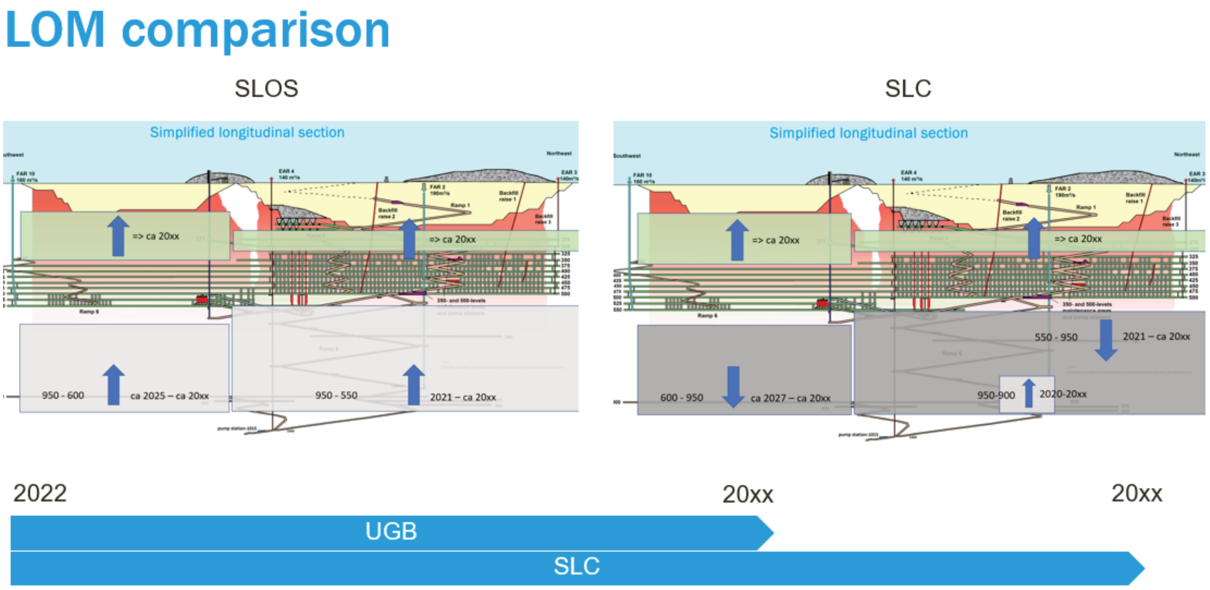

**Figure 9** **Schematic presentation of the principal differences between mining methods, and the relative impact on life-of-mine**

The mining plan – encompassing a declining production capacity from SLS during the years 2022–2031 – is to maintain production output with the introduction of SLC. The ongoing construction of the Deep Mine materials handling system will be utilised for ore and waste logistics for SLC also, without the loss of investment.

## 2.3 How to prepare

Investigations for an alternative mining method were initiated in 2013. During the following years more detailed studies and geotechnical modelling were conducted to assess the viability of the concept of SLC for Kemi Mine. Key expectations from modelling were that none or only low risks would exist for the existing fixed installation and infrastructure (including the planned hoisting shaft from 1000 level). Ore flow modelling indicated a decrease in ROM grade, mainly due to increase in waste rock dilution, but with an increase in long-term ore recovery. Key pre-requisites for SLC implementation were identified as an increase in mill capacity and execution of a successful limited scale trial mining. Also an update of the Environmental Impact Assessment was initiated to meet the changed conditions associated with SLC mining.

# 3 SLC proof-of-concept

## 3.1 Technical testing

Besides a limited scale of panel caving below the open pit, SLC has not been used at Kemi Mine. To evaluate how successful SLC related practises might be, mining at the crown pillar in the EL-ore domain was considered as a sub-trial of SLC in regards to drill and blast techniques and ore flow. Mining of the crown pillar took place over four crosscuts, each located approximately 50 m under the pit floor. With a drillhole length of 25 m a successful ore flow from the unblasted portion of crown pillar was achieved. Movement within the backfill in the open pit was detected (Figure 10), confirming a breakthrough from blasted rings to the pit floor through 20 m of solid rock.

**Figure 10 Picture of the open pit floor after blasting the crown pillar rings and consequent mucking**

Further to evaluate and verify SLC performance key indicators, trial mining was initiated.

## 3.2 Trial mining

### *3.2.1 Process description*

Key aspects in the selection of the SLC trial location were to achieve the footprint required on the undercut level (to initiate natural caving), and have comparable geotechnical conditions as expected in Deep Mine and quick access to the area and consequent production. The area selected was near the main decline, 50 m below the 500 level and located over three levels in order to test both undercut extraction practices and ore flow behaviour between levels. Mining parameters were chosen to be conservative and based on best practices and case studies, nevertheless, during the trial a number of sub-tests were conducted. These included for example, changes in drill pattern, front dump, charging lengths and initiation timing.

The scope for the SLC trial at Kemi Mine was to ensure that the method can be applied from geotechnical and production reliability perspectives. Key success parameters were safe operation, compliance to planned ore production and confirmation of ore flow between extraction levels.

### *3.2.2 Trial area details*

The trial area consisted of three levels between levels 550 and 600, located roughly in the middle of the orebody (Figure 11). This particular area was chosen due to proximity of access drives in the footwall and short haul to the underground crusher. In total 12 transverse x-cuts were prepared for the trial of which nine were mined in the first phase; four drives at 550 level, three at 575 level and two at 600 level (Figure 12). X-cut distance and level heights were set to be similar to those in SLS mining, 18 m (centre-to-centre) and 25 m (floor-to-floor), respectively.

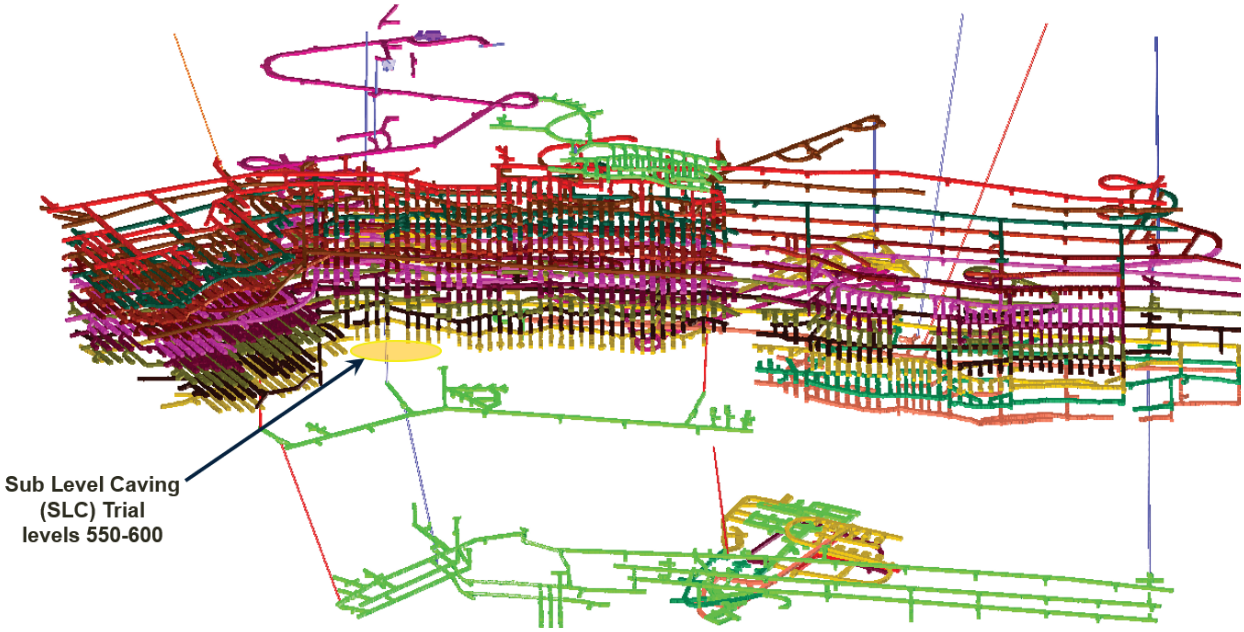

**Figure 11 Overview of the location of SLC trial**

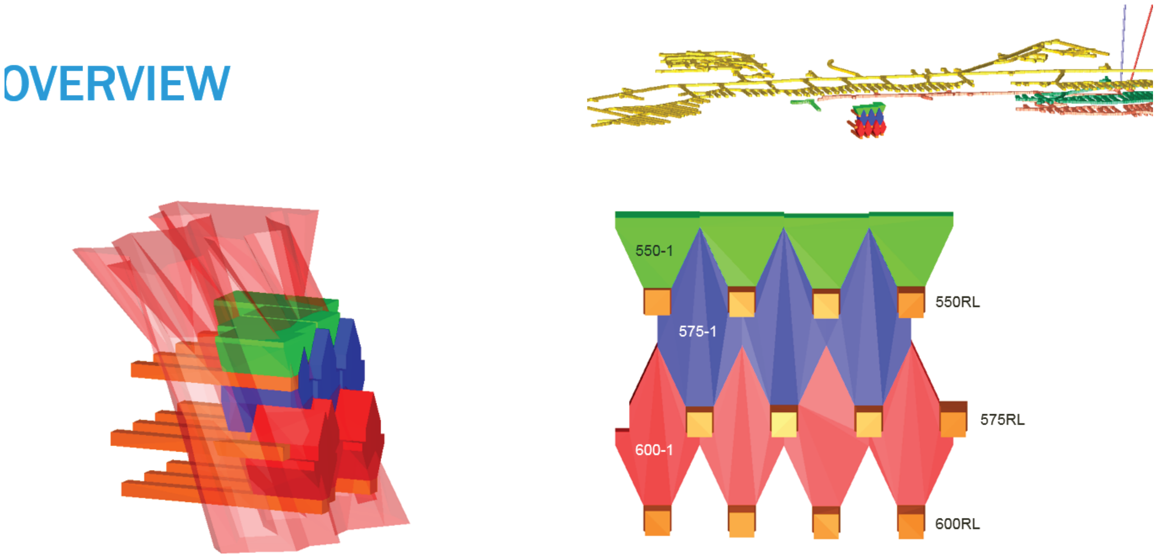

**Figure 12 SLC trial stope configuration**

The trial area consisted of four crosscuts on 550 level, three on 575 and two on 600 level. In order to increase the area, one additional crosscut was included from each level towards the east. Total development for the trial area was 1,520 m.

### *3.2.3 Planning parameters*

Early studies indicated that a hydraulic radius of 50 m was required to initiate natural caving. This was achieved by crosscut centre-to-centre (centre-c) spacing of 18 m, opening of four adjacent drives and ore thickness of 30 m or more. For monitoring the caving progress, an inclinometer was installed in the hanging wall of the 550 level stopes. Smart Markers were also installed on all primary trial drives and between each ring on the 550 and 575 levels to measure the ore flow and in-ring performance.

Planned draw rates were set to 40%, 80% and 100%, on levels 550, 575 and 600, respectively.

### *3.2.4 Approval and success criteria*

During the trial, all key success criteria's were fulfilled: no unmanageable safety risks recognised, production target achieved, ore flow from upper level to level below confirmed and hanging wall caving confirmed.

# 4 Change management

## 4.1 Challenges encountered

During technical evaluations of the feasibility of the method to Kemi Mine, little attention was given for the engagement of the larger stakeholder groups, but information and discussions were directed to technical and management personnel. This served the purpose of technical evaluation well but provided little preparation for the other stakeholders for further method development or implementation.

Introduction of a new mining method and incorporating it within an operating mine is a huge challenge. To mitigate the issue, the SLC Trial Execution Team established a number of new routines in the early phase of the trial. These included, among others, a series of information events for all mine personnel, the development of new operating procedures that were SLC specific, for example fan drilling guidance, logsheets for uphand charging, mucking control routine, changes in production planning routines, changes to stope naming convention and a large number of internal workshops with key personnel involved in the geology, mine planning, operations and support services.

In addition to process changes, many activities in the production cycle were new or rarely used for the mine, for example marker installation, instrumentation, draw rate and oversize reporting from drawpoints. New working procedures were also introduced, like installation and function monitoring of ground support, estimation of mucked grade through reconciliation, ore/waste identification and respective actions guidance, monitoring drill and blast results, fragmentation monitoring and integration of short- to mid-term production planning along with SLS production.

The SLC mining at Kemi Mine is first-of-a-kind in Finland, and this alone possesses challenges for service suppliers and authorities.

## 4.2 Mitigation measures

Key matters used to mitigate the issues of SLC introduction were sufficient general method-related information provided for all involved, positive commitment of management and other stakeholders, ensuring sufficient resources to undertake new or changed work procedures during trial mining. For key stakeholders targeted information was provided at several occasions before and during the trial. For specific technical details workshops were arranged to further enhance the engagement. Prior to the trial starting, external reviews were conducted to ensure the chosen path. The most important success factor was allocating a dedicated project team to handle matters related to drill and blast, draw strategy, ground support and collaboration with mine production on a daily basis.

Going forward to the implementation of the SLC method, an Implementation Team will provide production and mine planning team support for the wide range of questions related to application of the method. These are, for example, selection of layout, equipment selection, material handling, reconciliation routine, cave tracking, instrumentation, ore flow modelling, grade tracking and forecast, geotechnical modelling and extraction sequence.

### 4.3 Achievements

The SLC proof-of-concept process has been successful in a number of fields. Of these, the following can be mentioned; longhole drilling (little hole deviation with existing equipment), stope opening principle and longhole charging (inclusive of the pre-charging trial).

### 4.4 Lessons learned

Based on experience from Kemi Mine, it can safely be stated that information at an early stage is important. Providing the fundamental and basic information to as many of the stakeholders and mine staff as often as possible is recommended. In the early stage of a project, a clear presentation of the key personnel in the project and clarification of their roles are essential in order to create an open and transparent line of communication within the mine. At a later stage, nomination of SLC ‘champions’ or ‘ambassadors’ will further strengthen the organisation and benefit the transition process.

## 5 Conclusion

Due to future mining at greater depths, the geotechnical conditions are expected to be worse than before. With limited understanding of the current mining methods, a change in mining method was warranted.

A change in mining method is partly technical, and partly a change in management culture. To focus on one sub-area only is prone to failure. In the case of Kemi Mine, a large effort was placed on the technical work in order to evaluate the feasibility of SLC at the mine. During the technical process little attention was directed to stakeholder engagement, however this was improved during the latter stage of the proof-of-concept process. When a streamlined mining method development is targeted, all key stakeholders are recommended to be engaged at an early stage. Regardless of information provided, a successful execution of a proof-of-concept and implementation is still a sum of many more variables which all need to be balanced during the change process journey.

## Acknowledgement

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