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Investigation and determination of the required optimal width of overlap between rings on sublevels at LKAB Malmberget mine

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ABSTRACT

The sublevel caving mining method as the name implies, involves the extraction of the ore from sublevel to sublevel progressing downwards. The width overlap is essential for a safe sequential order of mining (by not creating pillars or bridges of intact rock that may attract seismicity), as well as maximizing ore extraction at lower levels without causing any disturbance to the material flow and SLC functionality. This article describes the investigation and determination of the required optimal width of overlap between rings when planning the production drilling at LKAB Malmberget mine. The determined width of overlap was based on the assessment of a specific active production location in the mine where there is a possible residual pillar between levels that will likely create seismicity and other related problems. The assessment revealed an optimal width overlap as, the number of rings to connect the opening of the drift directly at two levels above plus $(1/4 - 1/3)$ multiplied by the total blasted ring length of that same drift. The overlap = $(1/4 - 1/3)$ represents a safety factor for optimal overlap and maximum recovery, and it determines the ideal overlap width, which is relative to the two levels above. The results, as well as other factors that could affect the optimal width of overlap, have been discussed and specific recommendations for the application and implementation of the assessment have been suggested.

1 INTRODUCTION

The sublevel caving (SLC) mining method involves the extraction of the ore from sublevel to sublevel progressing downwards. A factor that must be taken into consideration is the overlap between rings on the sublevels. The width overlap is essential for a safe sequential order of mining (by not creating pillars or bridges of intact rock that may attract seismicity), as well as maximizing the ore extraction at lower levels without causing any disturbance to the material flow and SLC functionality.

Luossavaara-Kirunavaara Aktiebolag (publ), abbreviated LKAB is a state-owned Swedish mining company that has used the SLC mining method to mine iron ore in Malmfälten (“the Ore Fields”) in northern Sweden after transitioning from open pit to underground mining. The company operates the two largest underground iron ore mines in the world and the method has proven to be viable for the company due to increased production capacities in the operations and the level of automation that can be applied to enhance safety and productivity. Figure 1 gives a schematic overview of the SLC process used in LKAB mines.

2 CASE STUDY MINE

The Malmberget mine (MUJ) consists of about 20 orebodies (see Figure 2) with a surface footprint area of approximately 5km in the E-W direction and 2.5km in the N-S direction (Lund, 2013). Out of the 20 orebodies, about 15 of them are currently being mined at different production rates. The ore is composed of magnetite (95%) and hematite (5%), and the average grade for the different ore bodies varies from 49% to 63% Fe (Lund, 2013). The mine is divided into two parts: Östra Fältet (eastern fields) and Västra Fältet (western field). The ore bodies in the eastern fields are composed of massive magnetite ores with a current known depth of 1600m and provide 80% of the total production.

The western fields consist of small magnetite-hematite deposits with a currently known depth of 950m, (Lund, 2013).

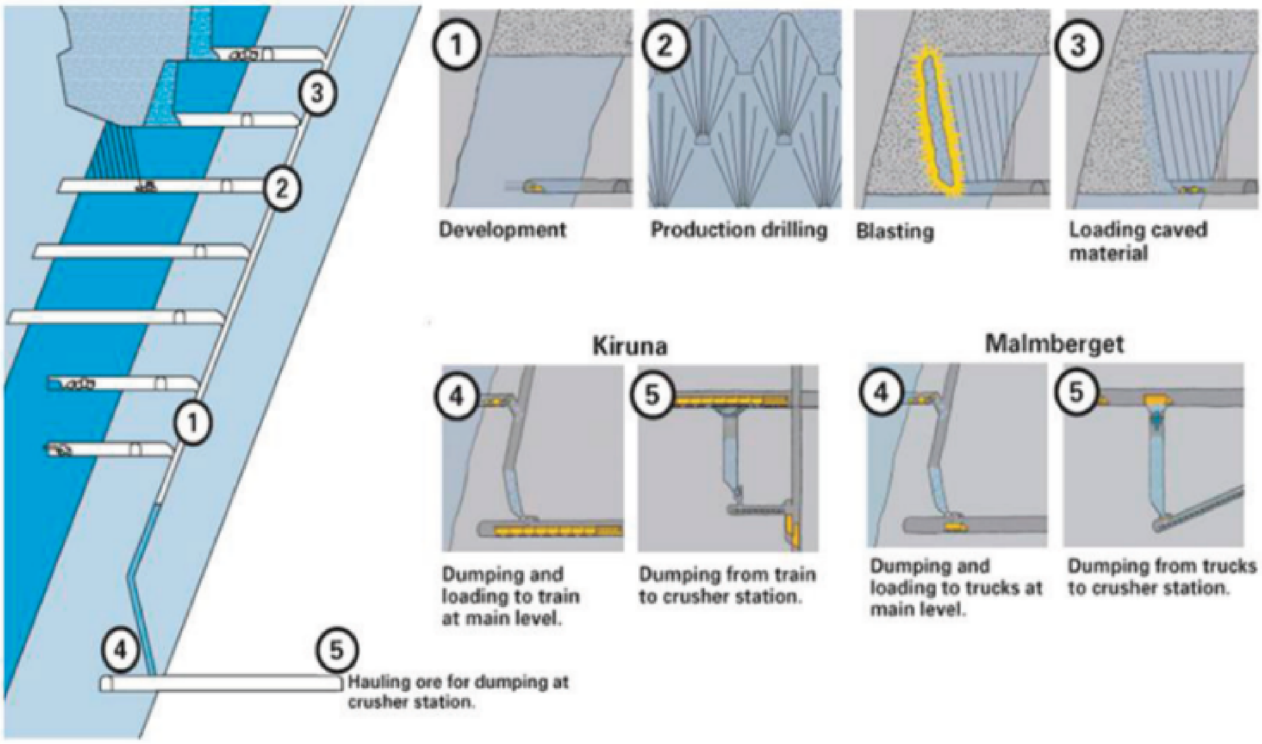

Figure 1 Sublevel caving in LKAB's iron ore mines.

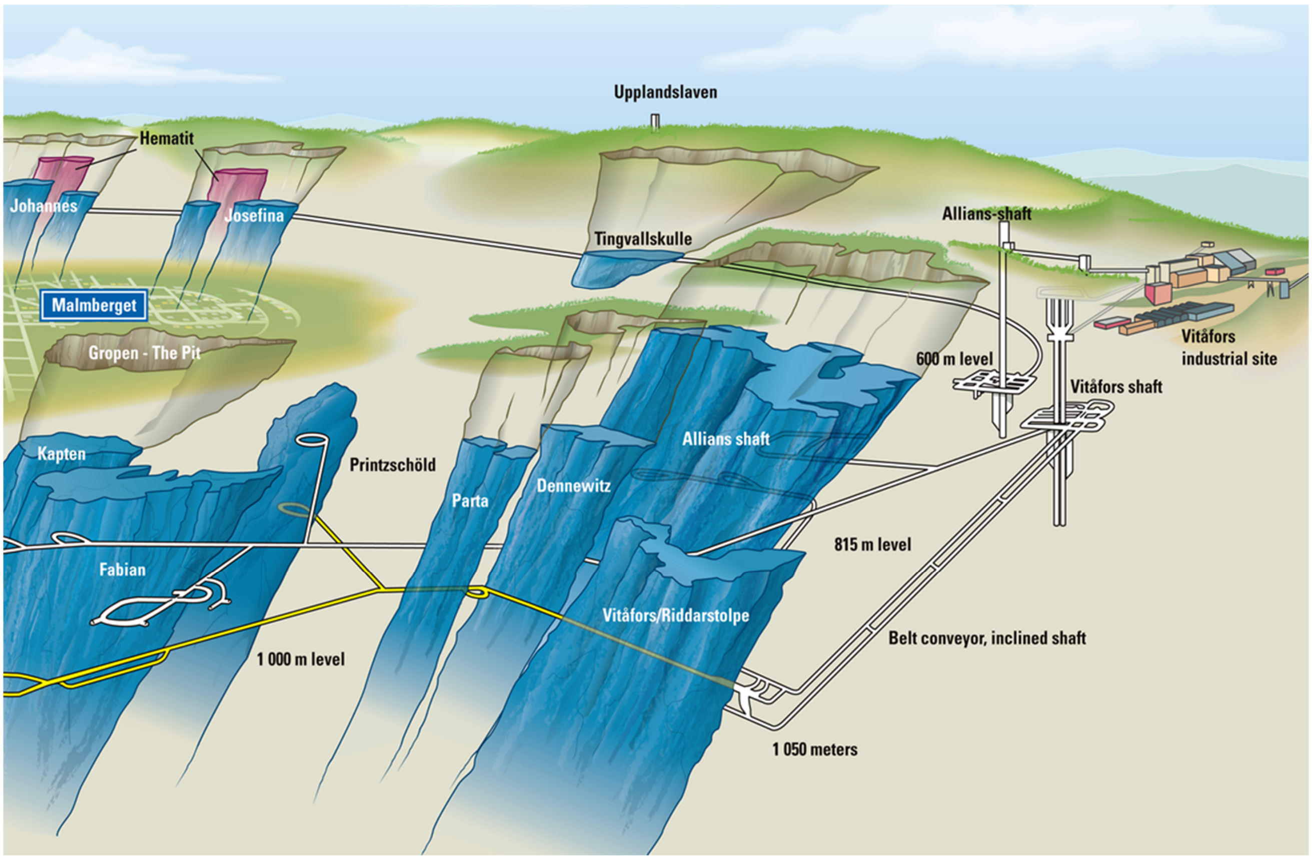

Figure 2 Overview of Malmberget mine with different orebodies.

3 BACKGROUND AND MOTIVATION

Ring overlap between levels needs to be taken into consideration when planning the production drilling. If there is not enough overlap, this will lead to ore loss and potential seismic problems in the mine since the ore pillars (between the drifts) will not be drilled, blasted, and mucked out. Leaving pillars of intact rock may attract seismicity. The SLC functionality (gravity flow) will also be affected and disturbed due to lack of overlap.

In cases where there are crown pillars left, caving of the crown pillar is prevented, because the caving process depends on the material being loaded out so that space is created to cave into (Tallfjärd, 2020). An example of this situation at the Malmberget mine is observed at the Printzsköld (PR) orebody level 996 (drifts 3850 – 3810), where the final rings end before reaching the opening rings at the upper level 970 (see Figure 3).

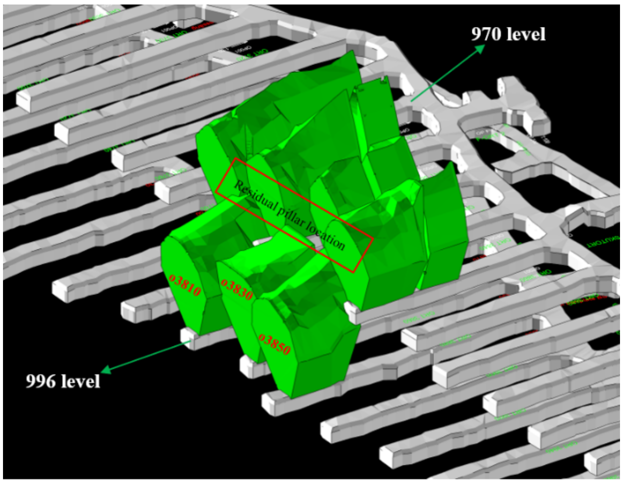

Figure 3 Printzsköld level 996 (drift 3850-3810) with final rings end before reaching opening rings on level 970.

This means that there will be a remaining (residual) pillar between the levels (see Figure 4) that will likely create seismicity and other SLC functionality issues.

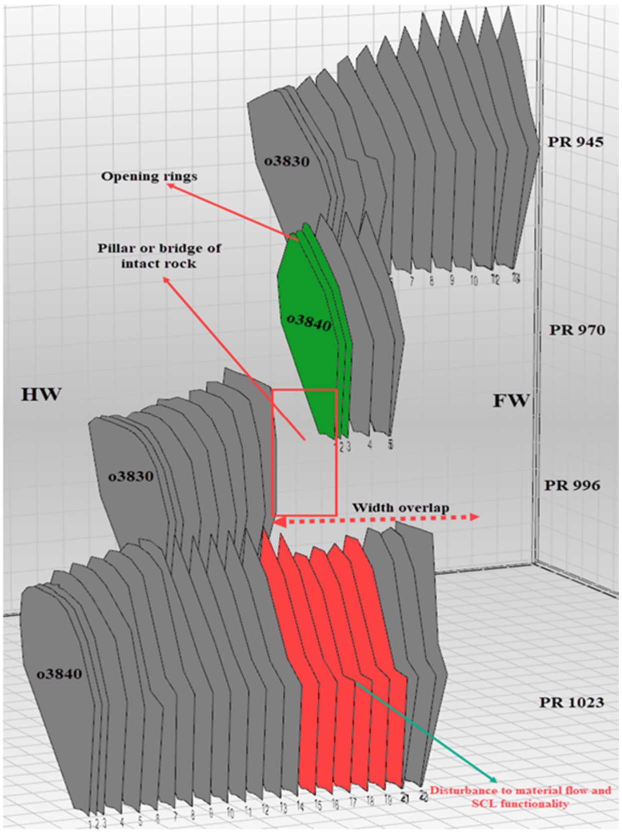

Figure 4 Isometric view illustration of width overlap between rings on sublevels.

These issues and discussions call for an assessment and determination of the required optimal width overlap to ensure good overlap between rings at MUJ.

3.1 *Objectives*

The purpose of this study was to investigate and determine the required optimal width of overlap between rings to ensure good SLC functionality (gravity flow) of the fragmented rock, as well as to reduce seismic activity in the mine and ore loss from lower levels in the mine during loading operations.

3.2 *Limitations*

The results from this investigation are limited to the assessment of loading and operational challenges at MUJ, data analysis from a specific area (Printzsköld), and recommended actions for possible implementation in the Malmberget mine. Its applicability outside MUJ may need further re-assessment and possible modification to the recommendations outlined in this paper.

3.3 Background data or information

A literature study on the loading operations at MUJ was carried out. Internal documents, protocols, personal communication, and internal programs (E.g., Giron plot tool) were also used for the assessment. Findings, comments, and inputs from these activities were then used as the base case to carry out the assessment. The assessment of the optimal width overlap was carried out at the Printzsköld orebody level 996 (drifts 3850-3810) where there is a possible residual pillar between levels 996 and 970 that will likely create seismicity and other related problems in the mine.

4 METHOD OF ASSESSMENT

SLC operations have been scaled up over the years (see Figure 5) as a measure to reduce drift development and remain profitable and this has been made possible due to progress in drilling technology (Nordqvist et al., 2020). Along with the evolution of ring designs, current ring designs have the longest boreholes beyond an above level in SLC operations (see Figure 6). It was therefore desirable and better to observe three levels for the assessment rather than two levels in order to obtain the best overlap when planning the production drilling at MUJ.

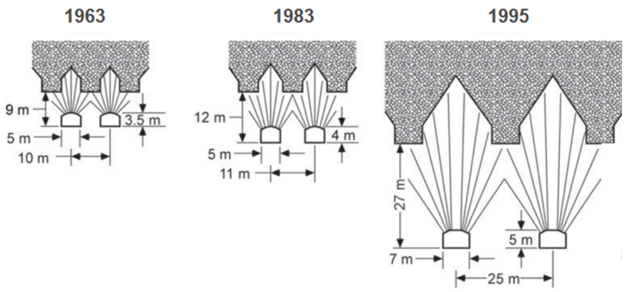

Figure 5 SLC scale-up evolution, Kiruna mine (Marklund & Hustrulid 1995).

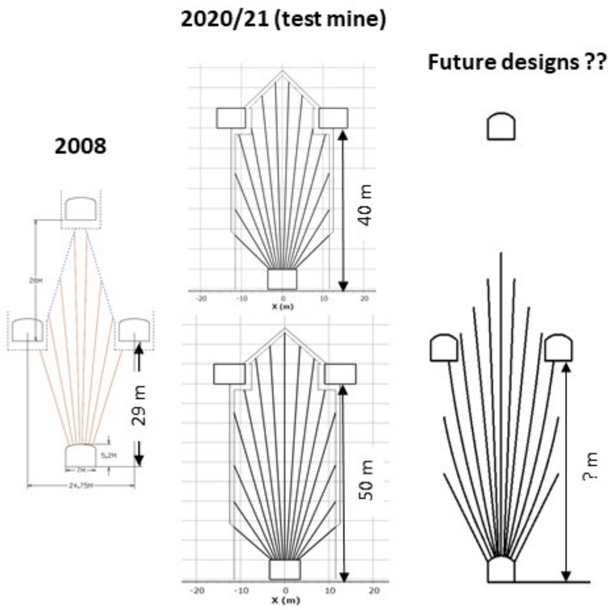

Figure 6 Current designs for SLC rings, Kiruna mine (Nordqvist et al., 2020).

Figure 3 shows the example in the Printzsköld orebody level 996 (drifts 3850-3810) where there is a possible residual pillar between levels 996 and 970 that will likely create seismicity and other related problems in the mine. This area was analyzed to determine the optimum width of overlap. Although limited to Printzsköld orebody in this example, it is anticipated that the results will be applicable in all areas of the mine with similar issues (Gyamfi, 2023).

The isometric view from above the internal program, Giron plot (rings polygons) used in the analysis is presented in Figure 8.

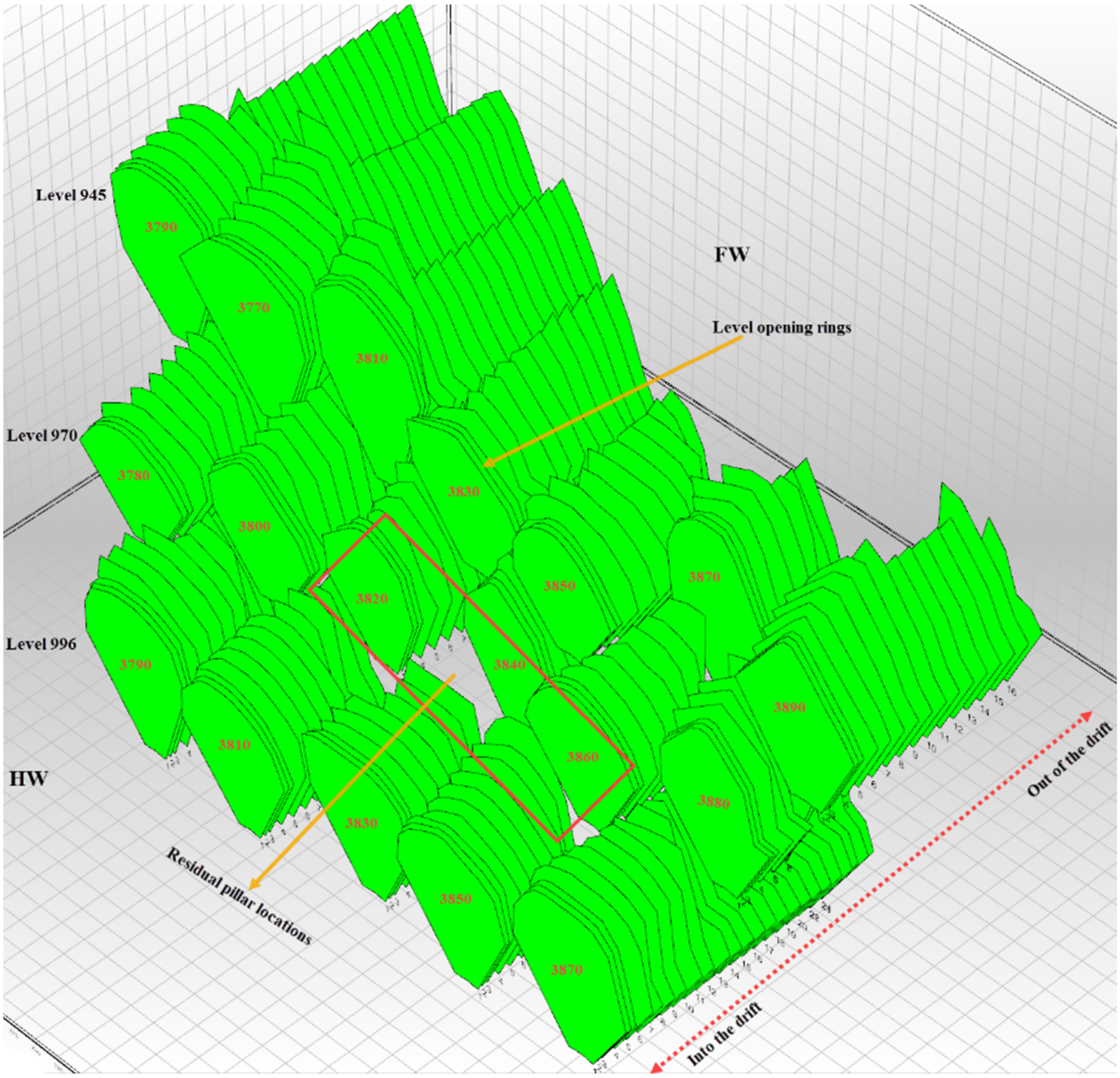

Figure 7 **Isometric view from above of the Giron plot (rings polygons) used in the analysis (not to scale).**

From Figure 7, the optimal width overlap analysis was carried out as outlined below (reference on level 996);

- Drift 3810
  - (11-12 rings mined out including openings). The last ring number 12 was mined out on 08/07/2020 with an extraction rate of 191.2%.
  - The current last ring is in contact with the opening at level 970 (between drifts 3800 and 3820).
  - 4-5 additional rings required to reach level 945 (2 levels above) – drift 3810. It has 16 – 17 rings mined out including openings. The last ring number 17 was mined out on 16/09/2017 with an extraction rate of 66.2%.
- Drift 3830
  - (8 - 9 rings mined out including openings). The last ring number 9 was mined out on 16/07/2020 with an extraction rate of 141.5%.
  - The current last ring is not in contact with the opening on levels 945 and 970.
  - 1-2 additional rings to reach level 970 above, between drifts 3820 and 3840.
  - 4 - 5 additional rings to reach level 945 (2 levels above) – drift 3830. It has 13 – 14 rings mined out including openings. The last ring number 14 was mined out on 14/09/2017 with an extraction rate of 96.2%.

- Drift 3850
  - (9 -10 rings mined out including openings). The last ring number 10 was mined out on 07/07/2020 with an extraction rate of 174.9%.
  - The current last ring is in contact with the opening of drift 3860 on level 970.
  - 1-2 additional rings to reach drift 3840 on level 970 above.
  - 3 - 4 additional rings to reach level 945 (2 levels above) – drift 3850. It has 11 – 12 rings mined out including openings. The last ring number 12 was mined out on 19/03/2015 with an extraction rate of 91%.

A range (Min-Max) of safety factor for the total blasted ring length of the previous drift at two levels directly above was determined for drifts 3810 and 3850. Drift 3830 was not considered since it had the same 4-5 additional rings required to reach level 945 (2 levels above) as 3810. For drift 3810, the minimum safety factor (1/4) was determined as a fraction of the minimum additional ring (4) to reach level 945 (2 levels above) and the actual number of rings mined out (16) including openings on the same level 945 (2 levels above). Similarly for drift 3850, the maximum safety factor (1/3) was determined as a fraction of the maximum number of additional rings (4) to reach level 945 (2 levels above) and the actual number of rings mined out (12) including openings on level 945 (2 levels above).

The optimal width may not be solely determined by this assessment only, but also by other factors such as the expected extraction rate from a lower level drift in relation to how much material was mucked from the nearest drifts at one or two levels above the said drift. For this reason, an actual mucking rates analysis for all the rings in the drifts under consideration on levels 945 and 970 was carried out. Behind this approach lies the assumption that variances between rings are not dramatically large. The approach can be further investigated for extraction rates for individual rings for each level where greater differences could for instance also imply charging/blasting issues.

Figure 8 summarizes the total planned and actual mucked tonnage considered for all the rings in each drift. The analysis includes all tonnage, from "skalning" (Swedish mining term for loading blasted rings along the hanging wall contact that are not yet in contact with the caved material on a level above) to full-sized rings in the individual crosscuts.

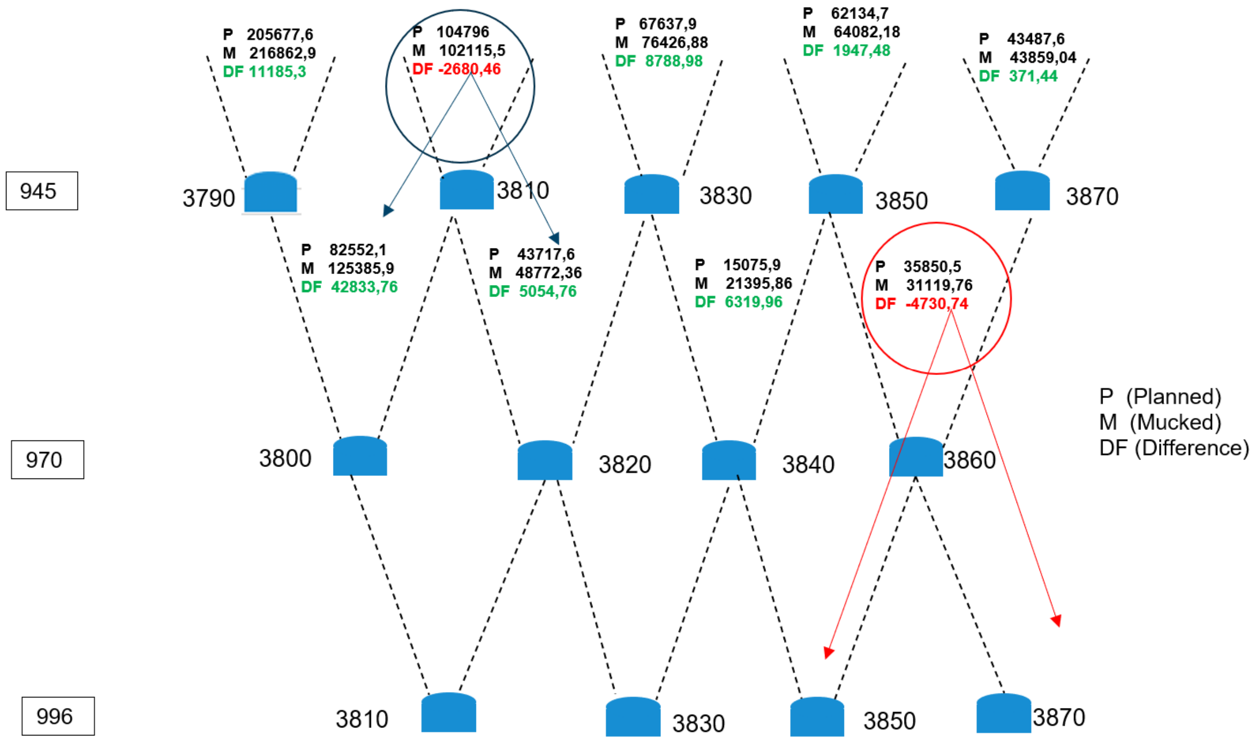

Figure 8 Total planned and actual tonnages for all the rings in each drift.

From this analysis in Figure 8, it can be observed that the unrecovered material from drift 3810 on level 945 might have been recovered and accounted for by the positive difference for drifts 3800 and 3820 on level 970. On level 996, much recovery is expected from drift 3850 or the next drift (3870) to account for the unrecovered material on level 970 drift 3860, hence a higher safety factor ($> 1/4$) should be used when determining the optimal width overlap for drifts 3850 and 3870 on level 996. This is to ensure that additional rings are blasted for optimal ore recovery.

5 RESULTS AND DISCUSSIONS

5.1 Results

The assessment of the Printzsköld orebody scenario on level 996 (drifts 3850-3810) where there is a possible residual pillar between levels 996 and 970 that will likely create seismicity and other related problems in the mine (see Figure 7) revealed an optimal width overlap as, the number of rings to connect the opening of the drift directly at two levels above plus $(1/4 - 1/3)$ multiplied by the total blasted ring length of the previous drift at two levels directly above it (the reference level). Figure 9 presents an example schematic diagram for the assessment of the scenario outlined.

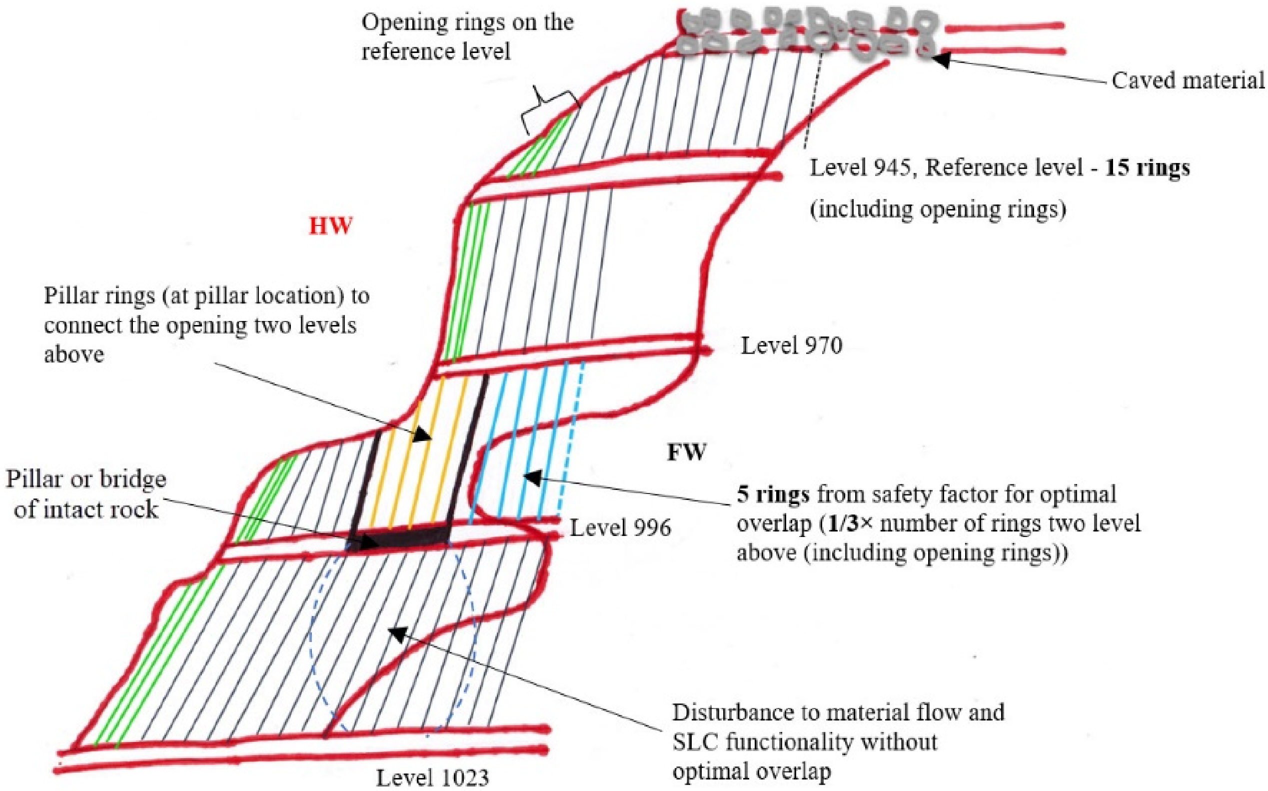

Figure 9 Schematic diagram for the assessment of the scenario.

The overlap = $(1/4 - 1/3)$ represents a safety factor for optimal overlap, and maximum recovery based on the expected extraction rate from a lower level drift in relation to how much material was mucked from the nearest drifts at one or two levels above the said drift.

The safety factor determines the ideal overlap width, which is relative to two levels above. The motivation for this is highlighted under section 4 (see also Figure 5 and Figure 6). The safety factor could be higher in some cases, hence the range. For example, drifts that will be opened, blasted, and loaded earlier on a level may have a minimum safety factor ($1/4$) and the later ones could have a higher safety factor ($> 1/4$) to recover more materials from the nearest drifts provided the conditions at that level and draw points warrants it. Another example could also be if the extraction rate has been low on a level above, then a higher safety factor ($>1/4$) can be used where applicable.

From the assessment carried out, the optimal width overlaps for drifts 3810, 3830, and 3850 are presented in Table 1. In the assessment, the minimum distance (width overlap, m) is when the number of rings required to connect an opening two levels above, was considered to be exactly below the opening at two levels above. For example, in Table 1, the optimal width overlap of ≈ 21m – 27m for drift 3830 means that 21m is the minimum width overlap to connect exactly to the opening two levels above 3830.

Table 1 Optimal overlap for drift 3810, 3830, and 3850

Drifts	Optimal width overlap (m)	Equivalent rings	Safety factor
3810	≈ 24 - 27	8 – 9	0.25
3830	≈ 21 - 27	7 – 9	0.25
3850	≈ 21 - 24	7 – 8	0.33

5.2 Discussion

Although the optimal width overlap is determined by rings on levels above, it may be ideal in certain situations to consider, the immediate level below the reference level in the selection of the safety factor ($1/4 - 1/3$). For instance, the immediate level below (1023) may reveal more rings to be blasted on level 996 to avoid disturbance to material flow and SLC functionality on level 1023 where there may not be a residual pillar. For example, in Figure 9, the overlap is determined on level 996 with reference to levels 945 and 970 above, hence the immediate level 1023 below the reference level 996 can be checked if applicable (using a preliminary and forecast ring design approach on the level), in the selection of the safety factor for level 996.

Nevertheless, when planning the production drilling for the determined and required optimal width of overlap between the rings at the residual pillar location, it must be noted that;

1) If a blast will be loaded in the residual pillar locations for optimal width overlap, standard drilling and blasting can be performed. Where the overlap width is very small, drilling and fragmentation can be performed as usual and loaded with an acceptable dilution.
2) If the blast will not be loaded (due to a high percentage of waste intrusion from the overlap width) but some swell still needs to be loaded, a course drill pattern design and blasting may be performed to produce coarse fragmentation (to reduce dilution) and large caved rock materials that improve gravity flow (here the attention is on good SLC functionality for the levels below rather than recovery on the current drift where loading is taking place).

6 CONCLUSIONS, RECOMMENDATIONS, AND FUTURE WORK

This paper outlines an assessment of optimal width overlap between rings on sublevels at LKAB Malmberget mine to ensure good SLC functionality (gravity flow) of the fragmented rock, as well as to reduce seismic activities and ore loss from lower levels in the mine during loading operations. It is determined that the optimal width overlap should be the number of rings to connect the opening of drifts at two levels above plus a safety factor ($1/4 - 1/3$) multiplied by the total blasted ring length of the previous drift at two levels directly above it. The safety factor determines the ideal overlap width, which is relative to the two levels above.

The application of the aforementioned assessment of optimal width of overlap should be considered during the drilling and blasting design phase of the mine operation. For future studies, Rebop gravity flow modeling software can be used for further evaluation of different scenarios of the optimal width overlap to provide a further understanding of the issue to SLC functionality.

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