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Increasing sublevel height from 30 m to 50 m at LKAB

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Abstract

LKAB has decided to try full-scale tests with sublevel caving using 50 m height sublevels and a new layout for sublevel caving at depth known as fork layout. Currently development work is under way in a smaller orebody near the Kiruna mine to prepare for mining three sublevels: the first with 40 m height and the others with 50 m height. The objective of these tests is to assess the applicability of these changes in future underground production areas at LKAB mines. These areas could be as deep as 2,000 m. It is believed that these changes will improve underground ground control since some infrastructure will be moved away from areas of high stress changes. Critical aspects for higher sublevels are fragmentation and gravity flow related issues. This paper presents the current status with the ongoing work and some partial results towards these full-scale tests.

1 Introduction

LKAB is a producer of iron ore pellets having two underground iron ore mines and one open pit in northern Sweden. One of the underground mines is located near the city of Kiruna and the other one near the city of Malmberget. The open pit is located near the town of Svappavaara, about 50 km south of Kiruna. Sublevel caving is the mining method used at the underground mines. LKAB has acquired extensive experience with the use of this mining method, since it has been using it for more than 60 years (Quinteiro et al. 2001a). One of the major improvements at the underground mines at LKAB, in terms of mining layout, was the increased scale of sublevel caving to keep production costs at desirable levels without significant ore losses.

Current mining plans at LKAB indicates the need of a new production infrastructure at both Kiruna and Malmberget underground mines in the beginning of the 2030's. Future underground mining depth is being investigated and assumed to reach the 2,000 m level. The current main levels at underground mines at LKAB are located at level 1,365 in Kiruna and 1,250 in Malmberget. Mining methods suitable for 2,000 m depth and within LKAB requirements are being investigated. One of the important requirements of future underground mining at LKAB is safety, productivity and sustainability. Naturally, sublevel caving is one of the possible candidates for continuing underground mining at depth since it has the potential to fulfil these important requirements. Adjusting the current layout and increasing the sublevel height further could be helpful towards these requirements.

Increasing the scale of sublevel caving means decreasing the amount of development required for ore production and therefore, decreasing mining costs. Sublevel height is a key parameter in the scale of sublevel caving. Higher sublevels lead to less development and less mining costs. The last major change in sublevel height at LKAB was in the 1990's, when the sublevel was increased from 12 m to 27 m. Discussions about increasing further the scale of sublevel caving (sublevel height and crosscut distance) at LKAB have occurred since then but priority for costs reduction in mining was given to other activities first.

This paper is about further efforts to try to increase the sublevel height at LKAB. A simple way to exemplify the importance of the sublevel height in iron ore mining is to consider a 150 m vertical block of ore to be mined. If one uses 30 m sublevel height it will require 5 sublevels to mine this block. However, using 50 m height sublevels, it will need only 3 sublevels. This means a 40% reduction in development work and costs, considering all the other parameters the same. Considering variable costs in sublevel caving at LKAB, development was responsible for about 37% of the total (Quinteiro et al. 2001a). Using this number as a reference, then about 15% reduction in the variable costs of mining could be achieved. This simple example shows the high potential existing in increasing the sublevel heights towards decreasing mining costs in this mining method.

Another potential benefits in increasing sublevel height is the possibility of working in production areas that are subjected to less mining induced stresses and therefore less ground control related problems. Kiruna mine is a seismically active mine and activities towards securing a safe working environment is a top priority at the mine. Proper rock reinforcement of the drifts, mining sequence and 24/7/365 seismic monitoring are some activities in place today. Kiruna mine currently has about 250 installed geophones in its micro-seismic array plus personal and resources allocated for continuous monitoring and analysis. It is expected that as mining becomes deeper the seismicity around the production areas of the mine will continue or even increase due to increased induced mining stresses around the openings.

Regarding increased sublevel height, numerical modelling of stress distributions in sublevel cave mining at LKAB shows high stress concentration at the bottom of the mine, near the production area. Thus, an eventual increase in sublevel height would result in less exposure of personal to high stress areas and therefore improve safety. The exposure is reduced as there are less sublevels per 100 m vertical depth of mining. For example, if one assumes that the higher stresses are up to 150 m below the production area, then by using 30 m sublevel height one would have five sublevels in the higher stresses area. By using 50 m sublevels, one would have only three sublevels in the higher stresses area. That means that the exposure of personal in the higher stress areas would decrease since the working places (sublevels) is reduced from five to three. Prediction of stress distributions in the production areas will be investigated later by using numerical models.

There is also a very important potential negative effect on the increased sublevel caving height that needs to be highlighted. These are related with the ability to drill, charge and blast longer boreholes with good quality. The quality of these operations will influence the ore recovery and waste dilution during mining. Bad quality drill and blast results in poor ore recovery and increased dilution. Unfortunately, these parameters are more difficult to quantify when compared with decreased mining development costs in the case of small changes in ore recovery and dilution. Estimation of ore recovery and waste dilution requires good knowledge of parameters such as geometry and grades of the orebody, drilled and blasted tonnages and grades, composition of the caved rock mass, grade and tonnage control from mucking of production areas, mining reconciliation, rock quality, deviations from plan, etc. It is a very elaborate process to carry out a proper quantification of small changes in the ore recovery and waste dilution. However, significant changes in ore recovery and dilution will be easily observed and measured and changes in drilling and blasting will be the first parameters to be adjusted.

The general judgement at LKAB is that there is a good probability that one can mine successfully with higher sublevels than we are doing today. Thus, by considering its potentials positive and negative effects, LKAB has decided to try full scale test of sublevel caving using 50 m height in a small underground orebody near the Kiruna mine known as Konsuln.

This paper describes the preparations and the current status with the field tests of sublevel caving with increased sublevels at LKAB.

2 Conditions for mining with higher sublevel heights at LKAB

There is another reason why LKAB is interested in mining with higher sublevels in their future underground operations. It is expected that the current sublevel caving mining layout used today at LKAB underground mines will not work properly at greater depths. There is a need to change the current layout to be able to better cope with the expected higher stresses at depth. One strategy that LKAB is pursuing is to move the footwall drifts and orepasses away from the current design locations and place them farther inside the footwall. However, if one would apply this strategy on the current sublevel caving layout that would result in a large increase of required development and thus a large increase of mining costs. To mitigate that, a fork layout for sublevel caving is also being tested in Konsuln to lower the development costs when moving infrastructure farther into the footwall. Another positive effect of the fork layout is the increase in productivity of the production areas, since more production units can be fitted in the same space (Quinteiro 2018).

The current sublevel caving layout at Kiruna mine has production crosscuts spaced at 25 m and about 29 m for sublevel height. Figure 1 shows the changes in sublevel height and crosscut spacing for the Kiruna mine through the years. As seen in this figure, there was a significant increase in the dimensions of the sublevel height and crosscut distance at the beginning of the 1 990's at Kiruna Mine. This was possible due to the development by LKAB of the Wassara technology for water powered hammer drilling. This technology allowed drilling of longer boreholes with good efficiency and low deviation from plan meaning straighter holes. This technology has been used since then at LKAB and resulted in more effective mining using higher sublevels.

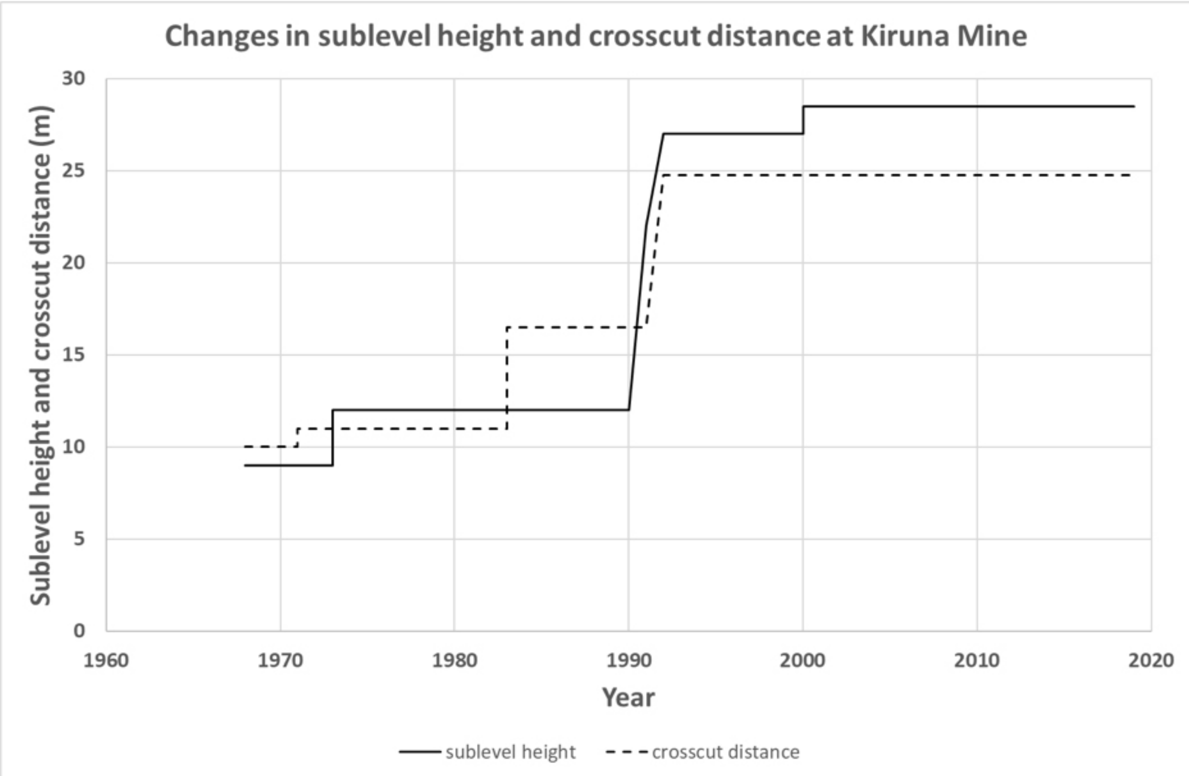
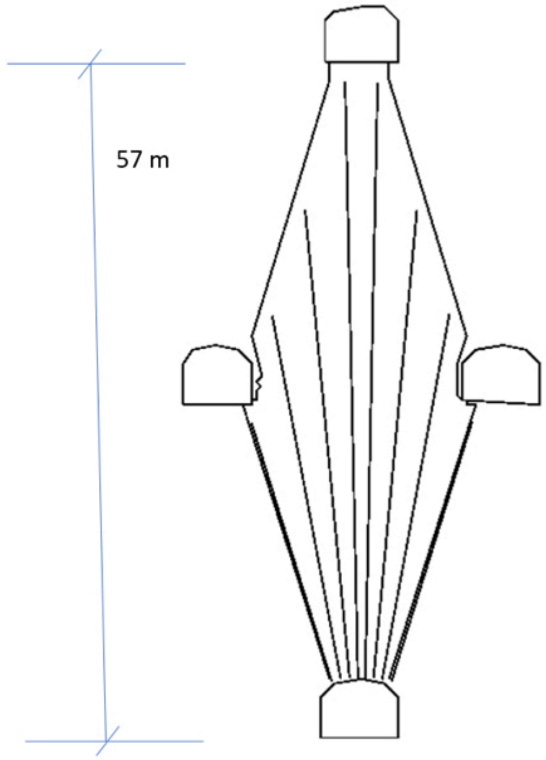


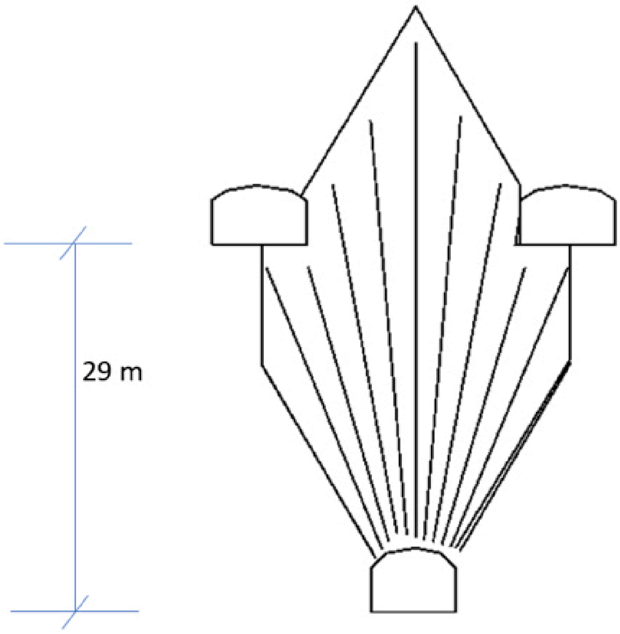
Figure 1 Changes in sublevel height and crosscut distance at Kiruna Mine through the years

No major changes have occurred since the beginning of the 1990's in relation to the sublevel height at Kiruna mine. One change though was the implementation of the silo layout in the drilling pattern in the beginning of the millennium to improve primary recovery of ore. Studies towards a better understanding of gravity flow were undertaken at LKAB through the years such as Sublevel Caving 2 000 (Quinteiro et al. 2001b). These studies have helped support the changes in ring geometry. The current silo layout used at Kiruna Mine is shown in Figure 2. The figure depicts the ring with the boreholes and the four crosscuts. This silo layout has 8 boreholes with a diameter of 115 mm. Boreholes number 4 and 5 (in the middle of the ring) are the longest with a length of about 53 m. These two boreholes are planned to reach just under the crosscut two levels above the drilling level. Boreholes number 1 and 8 are planned to reach the corner of the crosscuts one level above the drilling level. Figure 2 shows also a total drilled meter per ring of about 300 m and a specific drilling of the ring of about 33 ton per drilled meter for iron ore.



Borehole	L(m)
1	24
2	33
3	42
4	53
5	53
6	42
7	33
8	24
Total:	304
Ton/m:	33

Figure 2 Silo layout used at Kiruna mine with 8 boreholes



Borehole	L(m)
1	18
2	25
3	23
4	29
5	34
6	41
7	35
8	30
9	24
10	25
11	18
Total:	302
Ton/m:	33

Figure 3 Fan layout once used at Kiruna mine with 11 boreholes

Another layout used at the Kiruna mine until the beginning of the millennium was the fan layout drilling pattern using 11 boreholes. A typical fan layout is shown in Figure 3. In this layout, boreholes number 2 and 3 are planned to be under the crosscut one level above drilling level. The same is planned for boreholes number 9 and 10. Borehole number 6 does not reach the full two levels above drilling level. Figure 3 shows also a total drilled meter per ring of about 300 m and a specific drilling of the ring of about 33 ton per drilled meter for iron ore.

These two types of layouts were used with sublevel height of 29 m and drift spacing of 25 m. The main difference in these two layouts besides the number of boreholes is the length of the boreholes. As seen in the Figure 3, in the fan layout there is only one borehole that is longer than 40 m but in the silo layout there are four boreholes. The length of the borehole is an important parameter in sublevel caving since it requires technology to drill it with efficiency and good accuracy for optimal blasting results. As mentioned before, the water hammer technology has made it possible to change from the fan layout to the silo layout at Kiruna mine.

This fan layout has been used for many years at Kiruna mine and it has worked well. This is an important fact, since the path chosen to test an increased sublevel height at Konsuln uses this previous local experience.

The strategy used at LKAB for the selection of the maximum possible sublevel height for the field test was to use the current production drilling equipment at LKAB. These machines have a drilling capacity for boreholes with a length of 60 m without any modifications. This strategy meant that we did not have to developed new production drilling machines for this field test. However, this strategy led us to the choose the fan layout for drilling pattern. A maximum sublevel height of 50 m was then possible to test using the current production drilling equipment together with the fan layout.

However, there was a need to have another machine to drill the opening holes to start caving since the one used at Kiruna mine had a capacity to drill up of 40 m. 50 m sublevels require a machine to drill opening holes up to 54 m. A machine from Epiroc called the Easer L was available on the market to drill longer opening holes, this machine has the capacity to drill up to 60 m long opening holes with a diameter of 750 mm.

Charging of boreholes up to 60 m long was considered not a problem, since it had been done before at LKAB in a special project. Thus, all machines needed for a test with higher sublevels were available either at LKAB or on the market. The only thing left was to find an orebody to carry out the field tests.

3 Testing sublevel caving using 50 m sublevel height

Konsuln orebody is a small orebody located south of the Kiruna mine. This orebody has a dip of about 75° to the east, which is steeper than the main Kiruna orebody. Its thickness varies from 15 to 50 m. The geology of this orebody is very complex with varying thickness and grades of iron.

Figure 4 illustrates the location of the orebody in relation to the Kiruna mine and the Kiruna city. Konsuln orebody is shown in the south part of this figure marked by a circle. The area of the Kiruna mine is marked in the figure with an ellipse formed shape. Every square in this figure represents 1,000 m. Thus, one can observe that the Konsuln orebody is located approximately 1 km south of the Kiruna mine.

The Konsuln orebody is being currently mined at level 396 but it will be mined out soon. Several levels of this orebody were mined recently by using both transverse and longitudinal sublevel caving with 25 m sublevel height. The lower levels of this orebody had not yet been included in the long-term production plan of the mine. This fact together with its independent location in relation to the Kiruna mine made it a good candidate for the field tests. Konsuln was then selected as the place for the field test regarding sublevel caving using higher sublevels.

In 2018 the LKAB Board decided to carry out field tests to mine this orebody below level 396 using 50 m high sublevels. The main idea was to test new mining technology that LKAB could use in its underground mines in the future. This test is part of the overall LKAB development program called Mine 5.0. The mining test in Konsuln is part of the subprogram in Mine 5.0 called SUM (Sustainable Underground Mining).

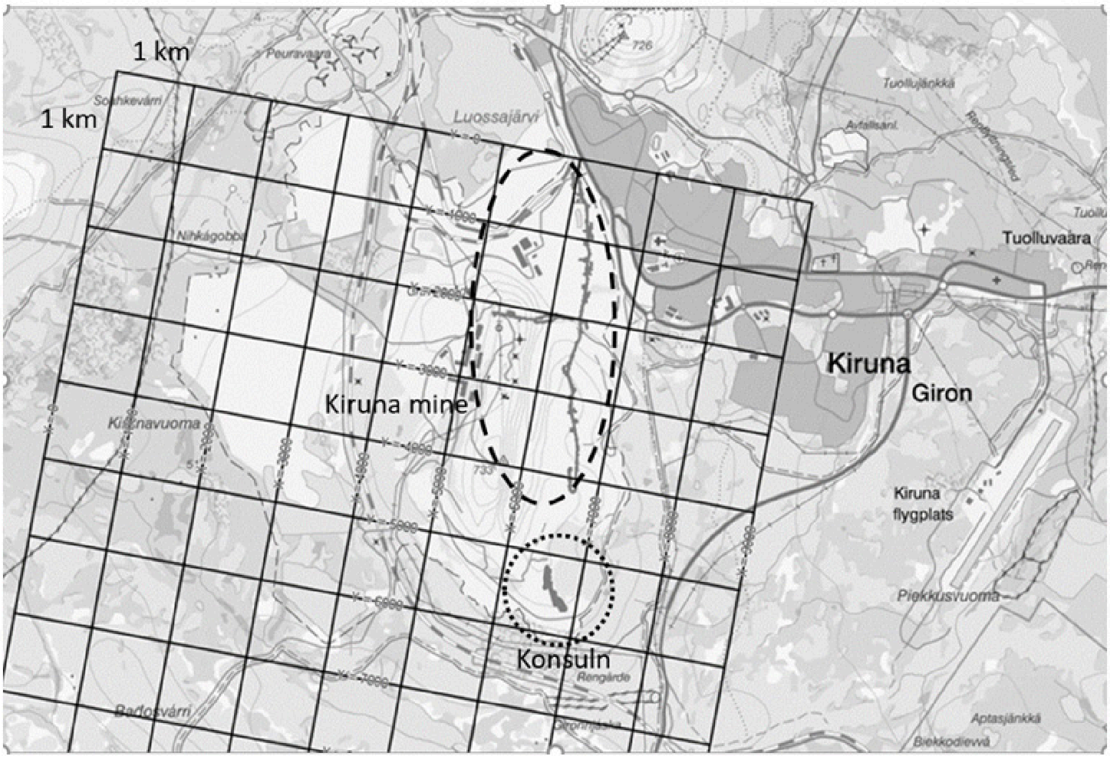


Figure 4 Location of the Konsuln orebody in relation to the Kiruna mine

Three sublevels are planned to be mined in Konsuln with higher sublevels: the first one having 40 m height and the others having 50 m height. The levels to be mined are denominated 436, 486 and 536. The first level is a transition level. The sublevels are named in relation to a zero level at the top of the Kiirunavaara mountain. That means that level 436 is located 436 m below the original top of the Kiirunavaara mountain. A strategic decision to start developing a footwall ramp was taken in early 2018 to get access to levels below 396. The pace of development work was increased when the decision was taken to test mining with higher sublevels.

The current situation with the development work at the end of February 2020 is as follow:

- level 436 is completely developed
- level 486 is under development and it will be completed during 2020
- level 536 is about to start development

Figure 5 shows a plan view of the layout of the drifts and the orebody for level 486 in Konsuln. Every square in this figure represents 100 m. The transverse sublevel caving layout was designed to have two different drift spacing for this orebody. At the south part of the orebody (towards the right in the figure below) the drift spacing is 22 m and in the north part of the orebody the drift spacing is 25 m. The size of the crosscuts is kept the same as in the Kiruna mine: 7 m wide and 5 m high. This figure shows also the fork layout for transport of blasted ore from the rings using LHD to trucks in the loading place. In this fork layout the LHD and trucks share the same physical boundaries. There are no physical barriers between them. By using trucks, the orepasses can be moved further away from the production area. Another type of the fork layout for the loading part is to have LHD and trucks separated by a physical boundaries or barriers, if needed. This is accomplished by changing the layout for the place where the LHD loads into the truck. Instead of using the intersection, one changes the layout to have a truck drift going parallel to the LHD drift and a crosscut to link them. This would form an “M” type layout for the loading part of the fork layout. The centre drift is used by the LHD and to permit access to the production area and on the sides two parallel drifts for the trucks. The need for the fork layout is described in more detail in (Quinteiro 2018).

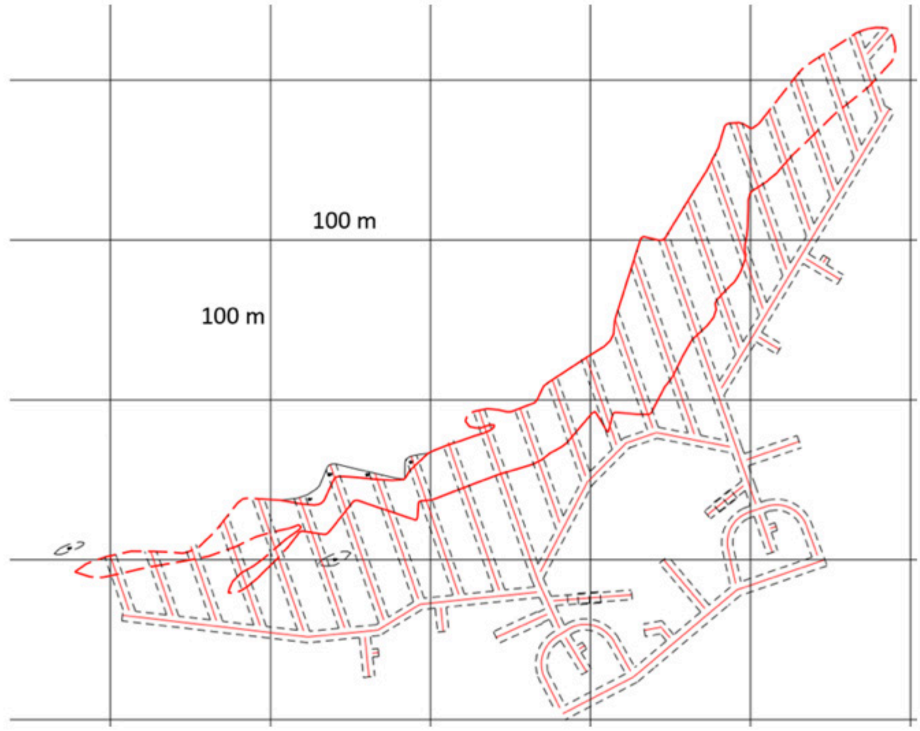
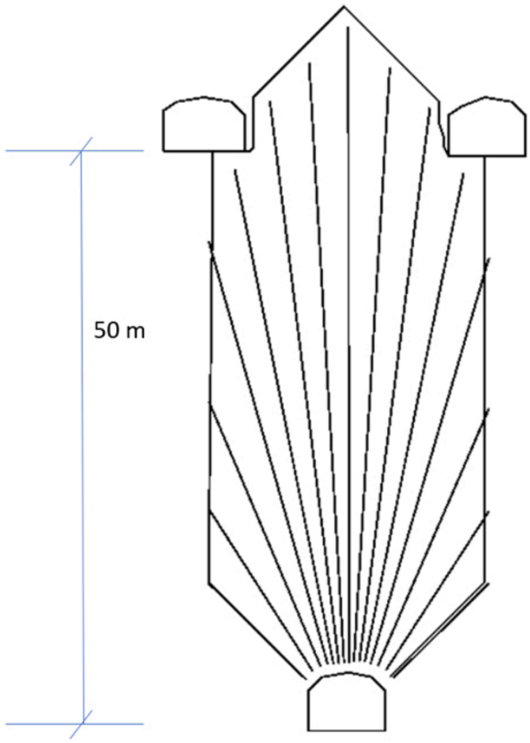


Figure 5 Plan view of level 486 in the Konsuln orebody

Figure 6 illustrates one possible layout for the drilling pattern of the rings in Konsuln with 50 m sublevel height. This layout has 15 boreholes and an insitu tonnage of about 18 kton. This layout resembles that one that has been used before at Kiruna mine and shown in Figure 3. However, one major difference is its size and, therefore, the length of the boreholes. In this layout they are much longer than the ones used in the layout shown in Figure 3. The maximum length of the boreholes in this layout is about 57 m. This is only about 4 m longer than the ones used in the silo layout and shown in Figure 2. In this layout there are five boreholes that are longer than 50 m which is three more than the silo layout. The challenges with this layout will be to keep the drilling quality in relation to borehole deviation as well as the chargeability of the boreholes. These parameters are very important to achieve a good blasting performance and thus good fragmentation and subsequently good gravity flow during mucking. These will impact on ore recovery and dilution and ultimately on the success of the method. The primary recovery of this layout is expected to be lower than the silo layout, but, on the other hand, it is expected that secondary recovery will be higher. The most important is the total ore recovery and total dilution of the area. One very important parameter that will be measured in the test area is the width of draw during gravity flow. Smart markers will be installed horizontally from the crosscuts into the pillars to provide this information in a very cost-effective manner. Even markers to be installed near the floor of the crosscuts will provide information on primary and secondary recovery. It is expected that most of the central part of the ore in the ring will be recovery as primary, that is, when mucking from the same level as the ring was drilled. It is also expected that the lateral parts of the ore in the ring will be recovered as secondary, that is, when mucking from one level below the ring was drilled. This expectation is based on previous measurements with markers at Kiruna mine (Quinteiro et al. 2001b). The now planned measurements with markers will give us information about these types of ore recovery for the rings (primary and secondary).

Charging of these boreholes are expected to be carried out without major problems at Konsuln since it has been done before at LKAB. It is important to mention that in these tests we are keeping constant, at least in the initial phase, the ring inclination, burden, explosives used and borehole diameter. In a later stage in Konsuln, the influence of some of these parameters can be studied by trials.



Borehole	L(m)
1	12
2	17
3	26
4	39
5	45
6	51
7	54
8	57
9	53
10	50
11	45
12	38
13	25
14	17
15	12
Total:	541
Ton/m:	33

Figure 6 Example of drilling pattern for 50m sublevel height at Konsuln

Another critical part in sublevel caving mining with higher sublevels is the ability to start caving on the uppermost level. Naturally, the difficulties in start caving increases as the sublevels increase in height. The opening holes used at Kiruna mine today, to start caving, are up to about 32 m long and have a diameter of 700 mm. Figure 7, on the left-hand side, illustrates the standard drilling layout for the opening hole at Kiruna mine. This layout consists of 8 blastholes having 115 m in diameter and one opening hole having 700 m in diameter. The spacing between boreholes is 1 m. This layout has worked fine at Kiruna mine for many years using 29 m sublevel height.

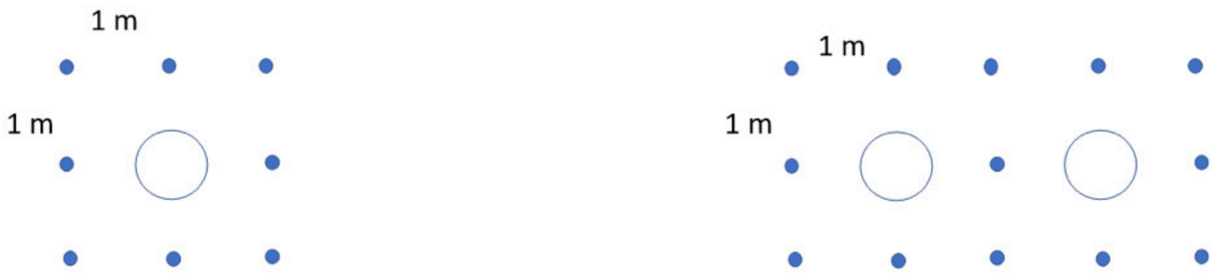


Figure 7 Opening layout used at Kiruna mine (on the left) and a layout to be tested (on the right)

For a sublevel having 50 m in height, one needs an opening hole with about 53 m in length. This has never been tried before at LKAB and, therefore, there is no experience and no drilling layout for such opening. It was decided then to carry out field tests with different opening layouts to select the best one to be used in Konsuln. Three different layouts were selected for the tests: one using the current opening layout shown in Figure 7 (left-hand side) and two others by using two parallel opening holes. One of the layouts using two opening holes is shown on the right-hand side of Figure 7.

The area for this blasting test was placed in the north part of level 436, in an area that was not planned for ore production. The blasting test will be conduct in waste rock. The objective of these tests is to quantify the effectiveness of three different layouts in 50 m openings. These openings will be evaluated by laser scanning to measure the 3D shapes after blasting. At the moment of writing this paper, these opening holes are being drilled. A total of 5 opening holes have been drilled so far with a length of 50 m and diameter 750 mm. Measurements of opening holes deviation for these show an average deviation within 1% at 50 m height. The results of these blasting test will be used in the selection of the opening layout to be used in Konsuln for mining with higher sublevels.

The performance of the 50 m sublevel height will be followed up by a comprehensive monitoring program including:

- Installation and follow up of smart markers installed in the rings to get data on gravity flow of broken ore
- Measurements of opening holes deviation to assess needed changes
- Measurements of selected blasthole deviation to adjust charging/blasting parameters
- Measurements of insitu iron content in the rings before blasting to help in the assessment of external dilution
- Near field ground vibrations measurements during the blasting of the rings to help in the assessment of blasting
- Measurement of the weight of the LHD bucket to help quantify dilution and ore recovery
- Ore production of the area to assess productivity of the fork layout
- Measurements of boulders requiring size reduction to help in quantification of blasting efficiency
- Visual observations

The plan is to have the first level ready for production by Q4 2020 and these tests will continue until 2024.

It is intended that the mining of all three levels in Konsuln will generate a large amount of data to assess, with high confidence, the feasibility of mining iron ore using sublevel caving with 50 m sublevels.

4 Conclusions

This paper has described the status with the preparations for the mining tests with increased sublevel height at LKAB. These field tests are part of the overall development program called Mine 5.0 and the subprogram called SUM. If, successful, these tests could lead to the future implementation of an increased sublevel height from about 30 m to 50 m. This could help LKAB to continue mining its mineral resources existing under its current main levels with higher productivity and safety. A full-scale test area is under development to enable the tests to be carried out. A total of three sublevels will be mined, monitored and evaluated to assess its applicability at LKAB.

Acknowledgement

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