doi:10.36487/ACG_repo/2435_D-01
9th International Conference and Exhibition on Mass Mining, Kiruna Sweden 17-19 September 2024

Preliminary results from tests using SLC with 40 and 50 m sublevel height at LKAB with focus on gravity flow

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ABSTRACT

LKAB operates two underground iron ore mines located in the northern part of Sweden, both using sublevel caving as the mining method. Common sublevel heights vary between 25-30 m. Tests with 40 and 50 m sublevel height is on-going in a fairly small orebody called Konsuln located close to the main Kiruna orebody. LKAB has developed three sublevels (436, 486 and 536) in Konsuln to test sublevel caving with 40 and 50 m sublevel height. The objective with these tests is to assess the applicability of large sublevel heights in some of the LKAB future production areas. The production started in March 2021 at level 436 and May 2022 at level 486, level 486 still on-going. About 2,6 Mton has been produced from blasted rings at level 436 and 2,2 Mton so far at level 486. Production at level 536 has just started and scheduled to end 2025. Preparations necessary for planning and for the assessment of the performance of these large sublevel heights includes: (1) measurements of blasthole deviations, (2) measurements of raise hole deviations, (3) measurements of iron grades in selected blastholes, (4) installation of smart markers and (5) opening blast tests. Follow up of the performance of the rings involves collection of data from loaded buckets, recovered markers, blast function (vibrations) and visual inspections as well as laser scanning when appropriate. This paper summarizes results on gravity flow achieved so far.

1 INTRODUCTION

1.1 Sublevel caving and the Kiruna mine

LKAB operates two underground iron ore mines located in the northern part of Sweden in Kiruna and Malmberget. Both mines use sublevel caving as the mining method, see Figure 1. Common sublevel heights at LKAB vary between 25-30 m. This paper focuses on tests using 40 and 50 m sublevel height in a small orebody called Konsuln located close to the main orebody in Kiruna. These mining tests are part of the program called SUM (Sustainable Underground Mining) at LKAB. Sublevel caving (SLC) is a mass mining method based upon the utilization of gravity flow of blasted ore and caved waste rock (Kvapil 1998). The scale has changed substantially during the years, see Figure 2.

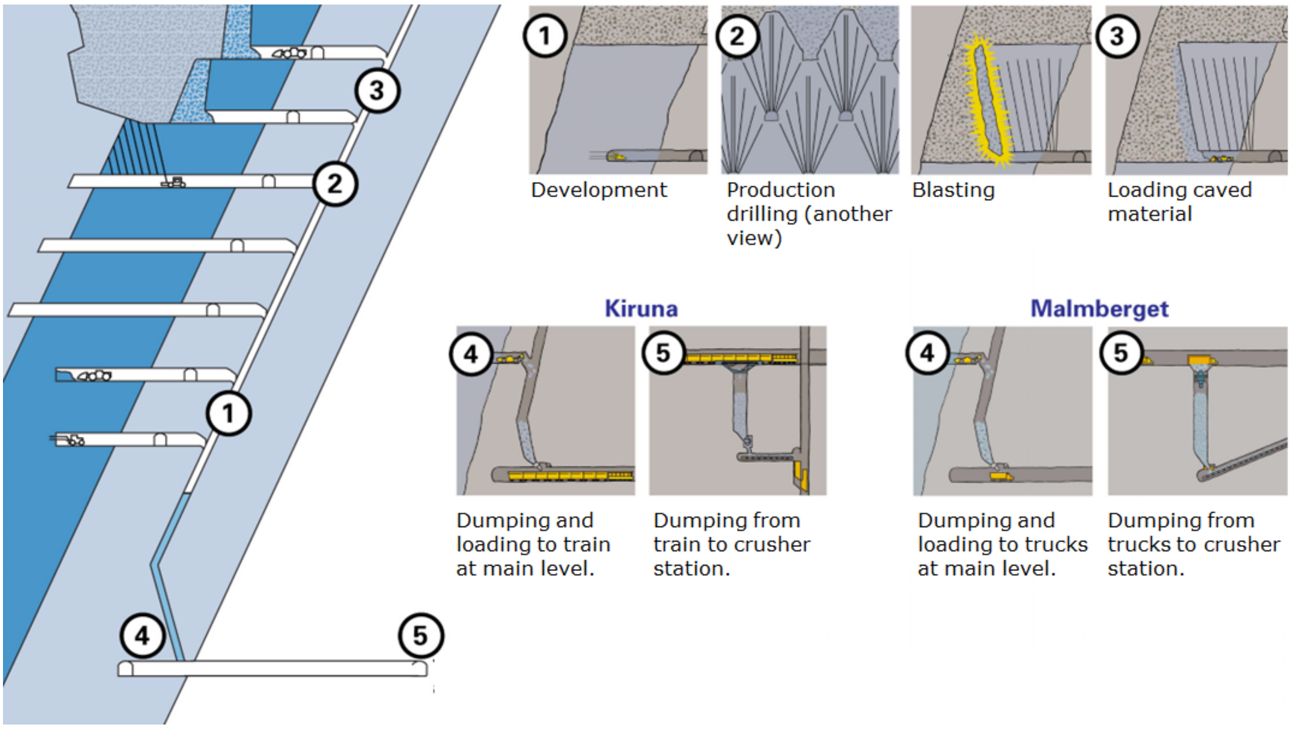

Figure 1 Sublevel caving in LKAB's iron ore mines.

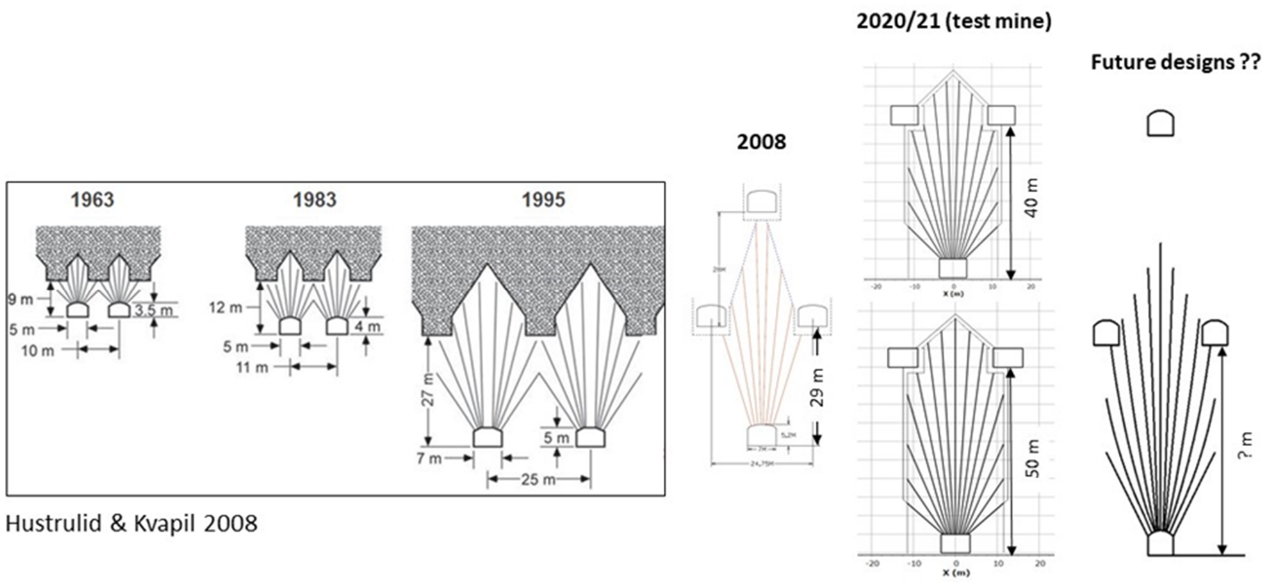

Figure 2 Evolution of scale and design for SLC rings, Kiruna mine

1.2 Testing sublevel caving with higher sublevels to meet future challenges mine

LKAB is investigating sustainable ways to mine its current orebodies at depth. Concept studies started already in 2017 which resulted in a recommendation to start a field test for SLC using 40 and 50 m high sublevels at Konsuln mine in Kiruna. Two papers were written about the setup of these tests (Quinteiro, 2018 and Quinteiro, 2020) and one paper about the initial results with SLC 40 m (Quinteiro and Nordqvist, 2022). These three published papers contain background information about these tests and will not be repeated here in this paper. These three published papers are readily available at the online repository of Australian Centre for Geomechanics. This paper summarizes results achieved so far using SLC40 and SLC50 with a focus on gravity flow. Production started at level 436 (40 m sublevel height) in March 2021 and was completed in January 2024. At level 486 production started (50 m sublevel height) in May 2022 and by end of January 2024 is about 50% mined out, mostly from the southern part of the orebody. Production started at level 536, also using 50 m sublevel height, in December 2023 and will not be considered in this paper. The amount of data available for this paper regarding levels 436 and 486, is already large enough to allow confident conclusions. With continuing mining of levels 486 and 536, and further collection and analysis of the data, confidence will increase.

2 TESTS

Following tests/measurements are carried out in Konsuln (Quinteiro & Nordqvist, 2022).

- 40 and 50 m sublevel height.
- Blasting test cuts, blasting an entire opening is planned later this year.
- Fe content in blastholes.
- Borehole deviation measurements.
- Blast performance using geophones.
- Draw control.
- Laser scanning when a cavity exits.
- Monitoring gravity flow using so called Smart Markers.

2.1 Gravity flow

Recent work on gravity flow has been carried out in the main Kiruna orebody where the sublevel height is 29 m (Nordqvist et al 2014, 2016 and 2020). This paper focuses on gravity flow in the Konsuln orebody where the sublevel height is 40 (level 436) and 50 m (level 486 and 536).

Smart markers are installed from three sublevels, 436, 486 and 536. However, markers were also installed in semi-horizontal boreholes at level 396. The total number of all installed markers at the end of the project will exceed 10000.

2.1.1 Installed markers

Level 396

During planning/development of the first test level 436 it was decided to install markers on the level above, 396. Semi-horizontal holes were drilled through the pillar between adjacent crosscuts. Figure 3 shows a top view of installed markers. Detection of these markers shows if the draw from level 436 has reached level 396.

Level 436

Marker rings with 3 holes were drilled in the center of each burden, see Figure 5. In total, 3 marker rings in every crosscut in most cases. Short relatively flat holes were drilled into the burden of rings drilled from level 486. Two holes in each marker ring and in total 3 rings in each crosscut in most cases. Figure 4 shows a typical marker ring with two short holes and two blast rings drilled from level 486.

Level 486

A denser marker approach, more marker holes in each ring, was adopted on level 486. Marker rings with 5 and 7 holes were drilled in the center of each burden, see Figure 5. In total, 3 marker rings in every crosscut in most cases (2 with 5 holes and 1 with 7 holes). Short relatively flat holes were drilled into the burden of rings drilled from level 536. Two holes in each marker ring, see Figure 4, and in total 3 rings in each crosscut in most cases.

Level 536

Marker rings with 7 holes were drilled similar with level 486, see Figure 5. However short relatively flat holes have not been drilled.

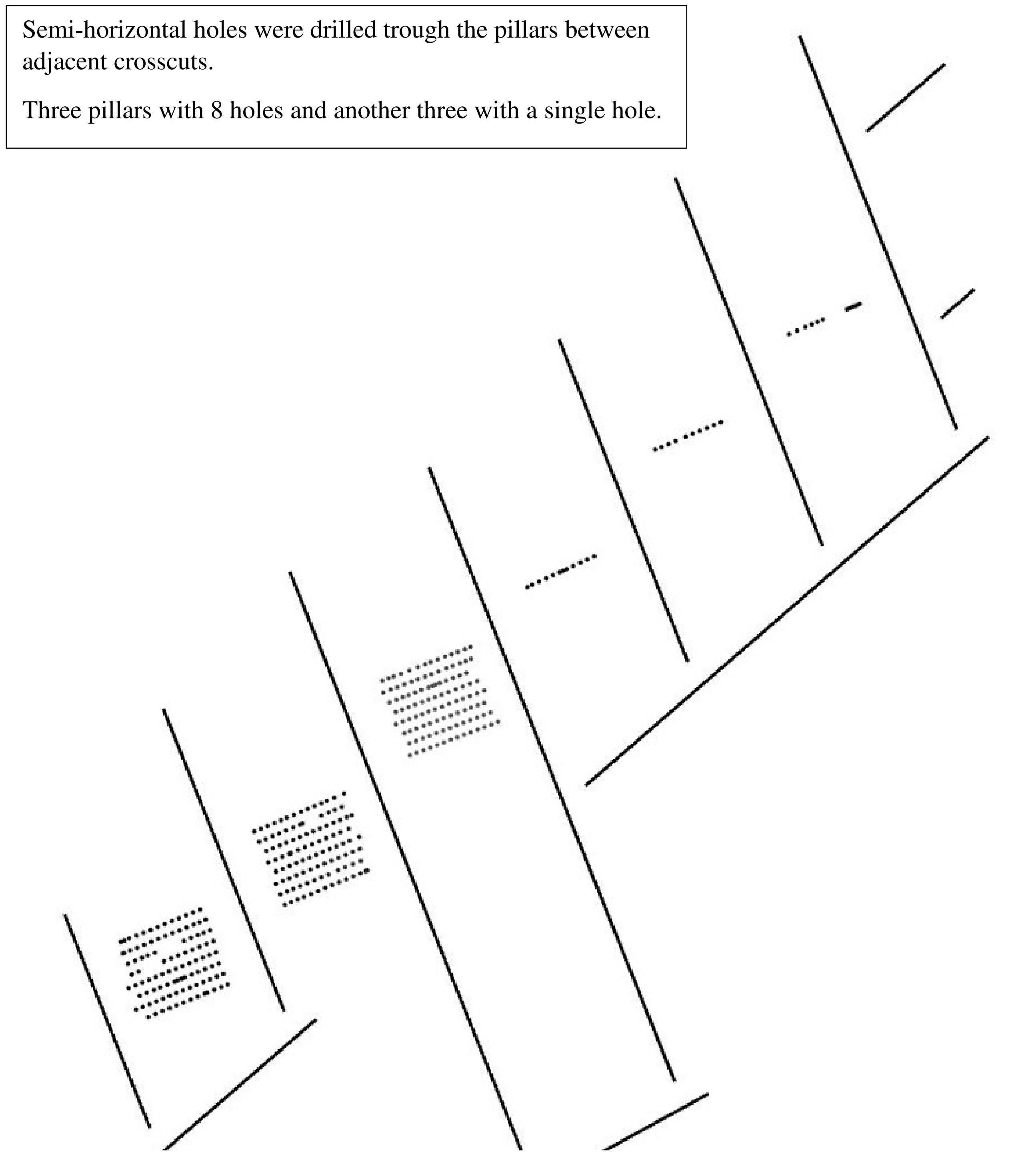

Figure 3 Top view of installed markers at level 396. Each marker is symbolized with a black dot. Planned drifts center lines at level 396 are shown in black.

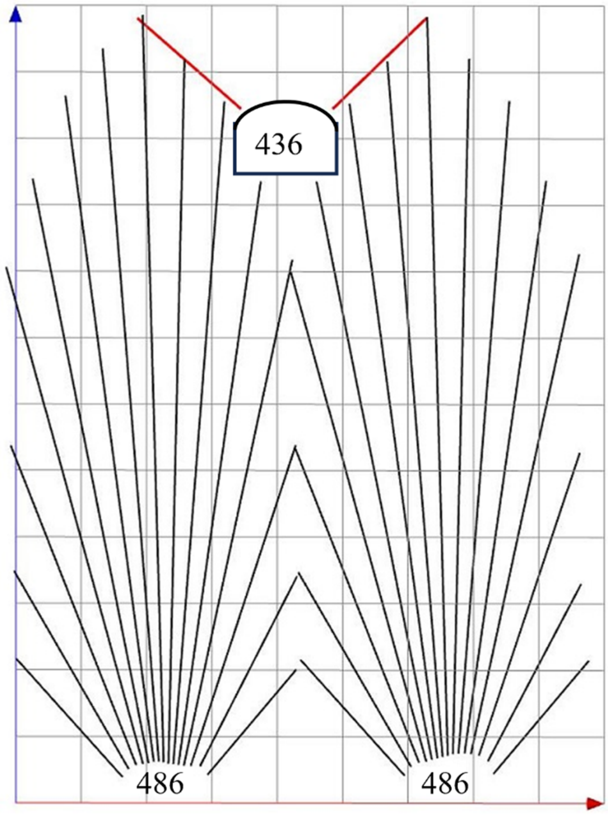

Figure 4 Front view of a marker ring with two short holes in red drilled from level 436. Markers are intended to be primary detected at level 486, see the two blast rings. Grid size is 5 x 5 m.

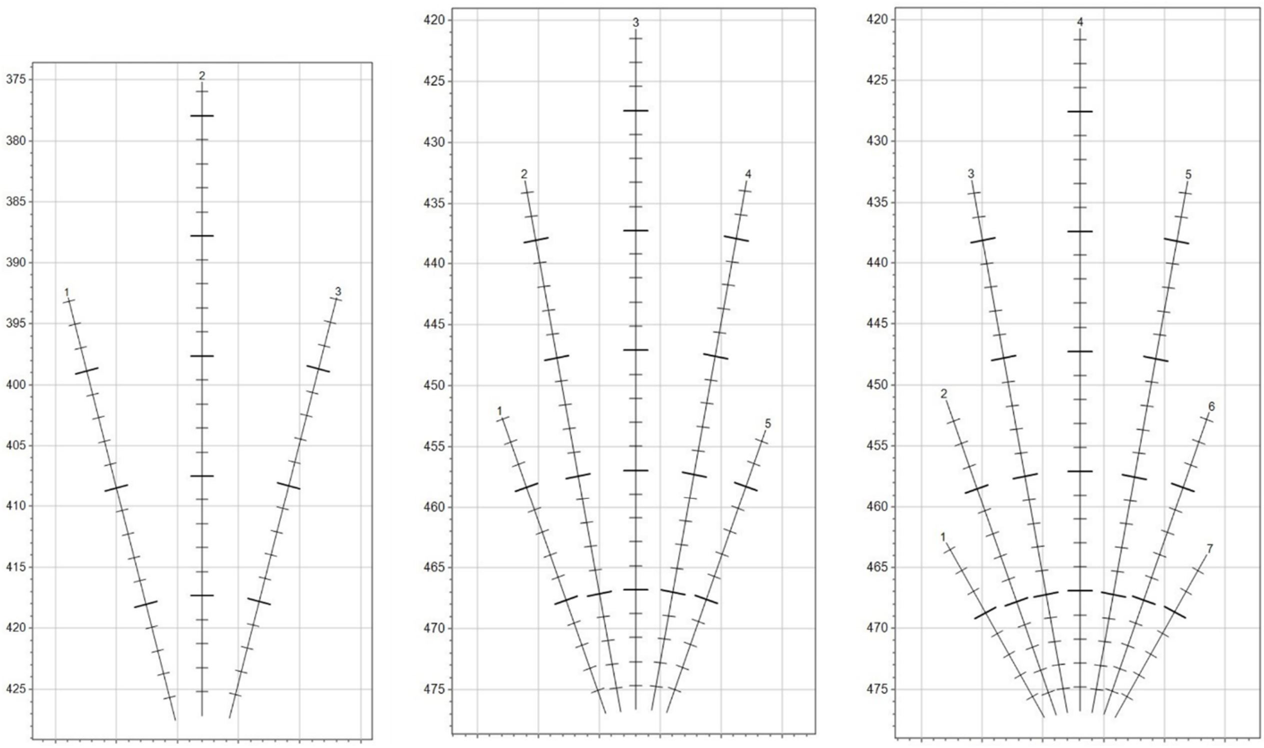

Figure 5 Front view of marker rings at level 436 (3 holes), 486 (5 and 7 holes) and 536 (7 holes).

3 EXPLOSIVES AND BLASTING PLANS

Micro balloon sensitized bulk emulsion is the mainly used explosive and 90 mm emulsion cartridges in wet holes only. The blasthole diameter is 115 mm. Blasting large openings is a special challenge. All blasting plans in the main orebody at LKAB in Kiruna are based on straight boreholes (not surveyed). However, it was decided for Konsuln to survey holes in large openings since these openings are most critical for successful mining. In the beginning of the project electronic detonators were used in the large openings since they offer much more flexibility compared with standard detonators. However, issues with current leakage and other practical problems lead to the use of standard detonators.

4 MARKER RECOVERY

4.1 Detection of markers

Detection of markers have not been 100 % successful. Reader power failures caused by production blasting is a common problem. Safety fuses trips on a power unit feeding Readers, finding the problem and resetting the fuse has unfortunately taken some days in many cases. Another issue is Reader antennas being damaged during mucking. All markers entering the muck pile might not be detected. They might be buried deep into the pile or located close to the walls in the crosscut. Markers could also be damaged by detonating blastholes. An open cavity might exist in front of a ring to be blasted, e.g. in a hang-up situation. Installed markers will be thrown forward during the blast and probably not primary detected in this situation. The marker recovery would be higher than the figures presented in this paper if detection works perfect.

A lot of waste and low grades are present in the northern part of the orebody, the middle part is narrow. These areas are not representative for the large main orebody in Kiruna. This paper focus on the southern part where the orebody is wide, and the Fe grade is high in most cases.

4.2 Markers installed from level 396

Markers installed from level 396 have been detected at level 436 (primary recovery) and level 486 (secondary recovery). Figure 6 shows a top view of installed and detected markers.

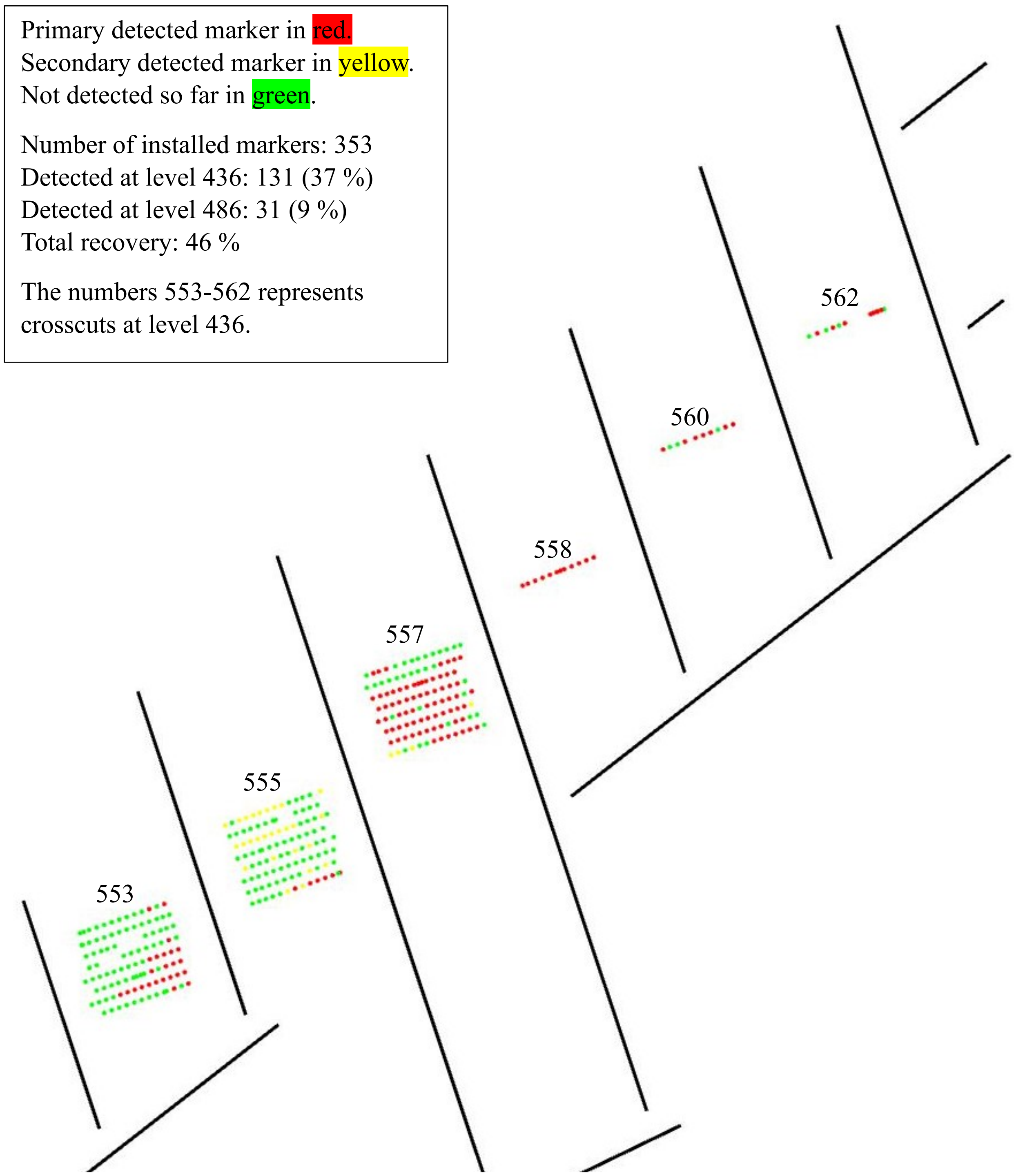

Figure 6 Top view of markers installed at level 396 and detected at level 436 and 486. Planned drifts center lines at level 396 are shown in black.

Note the good consecutive primary recovery in crosscut 557, it indicates a draw width greater than about 12-13 m. The rather poor primary recovery in crosscuts 553 and 555 are probably related to frozen rock issues when blasting the large openings. The draw in both crosscuts reached the upper level but it occurred later than planned. Note the number of secondary detected markers in crosscut 555. Secondary recovery is an important part for successful SLC especially for a layout utilizing flat side holes as in Konsuln.

4.3 Markers installed from level 436 (40 m sublevel height)

Table 1 summarizes the marker recovery from marker rings with three holes located in the southern part of the orebody at level 436. Markers were installed in seven adjacent crosscuts (553-564). In total, 607 installed markers in 21 marker rings. The highest primary recovery (52 %) is in borehole 2, i.e. in the middle of the ring as expected. The highest secondary recovery, 26-27 %, is at the sides also as expected. The overall marker recovery, primary and secondary, varies between 62-70 % for the three holes. The number of installed and detected markers have been calculated in 3 m long intervals along each hole. The number of installed markers in each depth interval varies between 16-21 in most cases. Exceptions are 3 datapoints highest up in borehole 2 (8-13 installed markers). The left chart in Figure 7 shows the total marker recovery (primary + secondary) in a modified bubble chart. The numbers at each borehole represents the lowest and highest recovery.

4.4 Markers installed from level 486 (50 m sublevel height)

Table 2 summarizes the primary marker recovery from marker rings with 5 and 7 holes at level 486. Markers were installed in seven adjacent crosscuts (554-564) located in the southern part of the orebody. In total, 1341 installed markers in 21 marker rings. The highest primary recovery (54-58 %) is in the middle of the ring and the lowest at the sides. The overall primary marker recovery is somewhat lower for the 7 holes rings probably due to flatter side holes.

Table 1 Marker recovery for marker rings with 3 holes at level 436

Bore-hole	Installed markers	Recovery (%)		
		P=Prim.	S=Secon.	P+S
1	167	37	26	62
2	267	52	16	69
3	173	43	27	70
All	607	45	22	67

Table 2 Marker recovery for marker rings with 5 and 7 holes at level 486

Ring-type	Bore-hole	Installed markers	Primary recovery (%)
5 holes In total 14 rings	1	156	17
	2	168	37
	3	248	54
	4	190	52
	5	143	13
	All	905	37
7 holes In total 7 rings	1	40	3
	2	65	15
	3	77	27
	4	102	58
	5	64	48
	6	55	29
	7	33	12
	All	436	33

Bubble charts have been created using a method similar with level 436, see Figure 7. The number of installed markers in each depth interval varies between 10-28. Note that the primary marker recovery is highest in the middle part of the ring and lowest towards the sides. It is also clear that the draw has reached the cave.

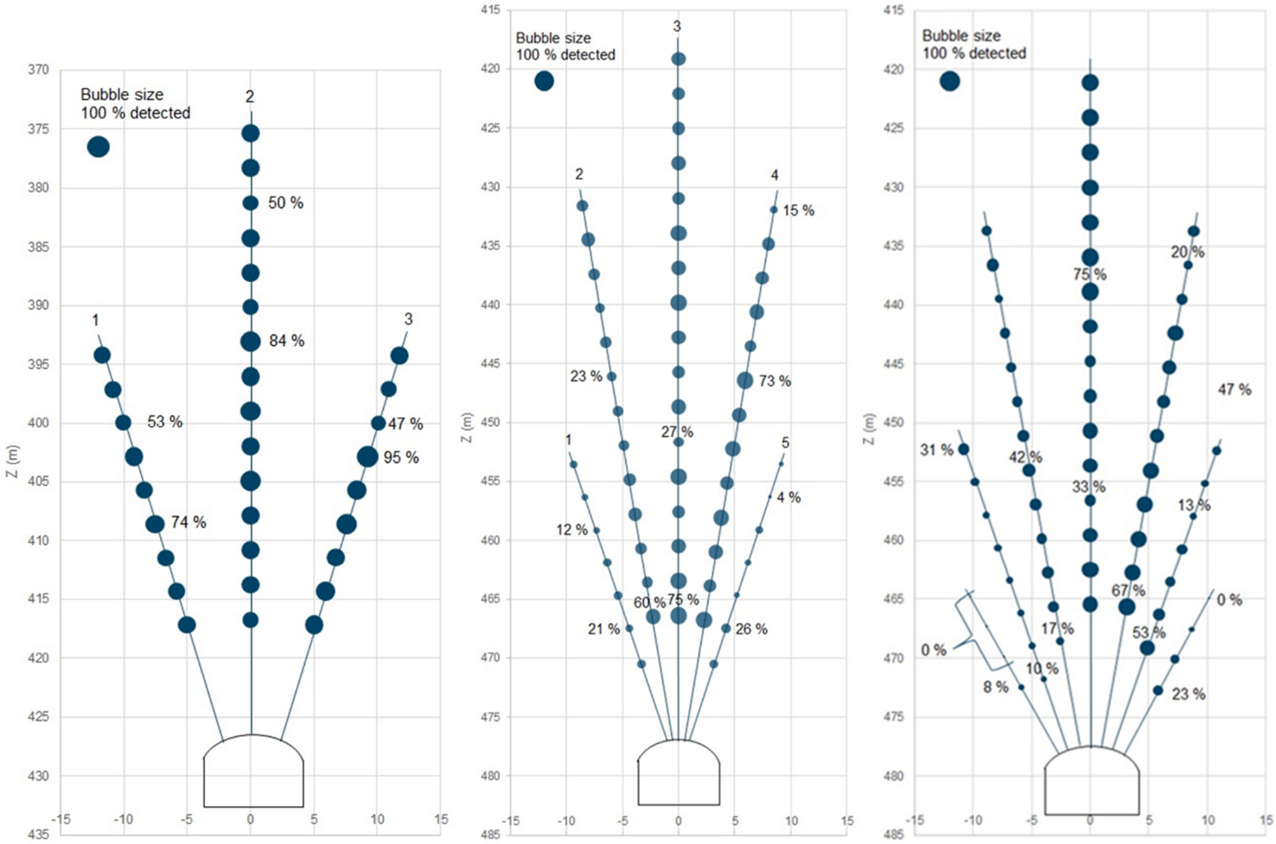

Figure 7 Modified bubble charts showing marker recovery in each hole at different depths. Left) Total recovery (primary+secondary) in 21 marker rings at level 436. Middle) Primary recovery in 14 marker rings at level 486. Right) Primary recovery in 7 marker rings at level 486.

Short marker holes have been drilled from level 436 into the burden of rings drilled from level 486. A top view of markers is shown in Figure 8. Some markers have been detected early, i.e. when blasting occurred at level 436 close to the marker rings. The primary marker recovery is 61 % for the studied rings in five consecutive crosscuts. Again, it is clear that the draw has reached the cave.

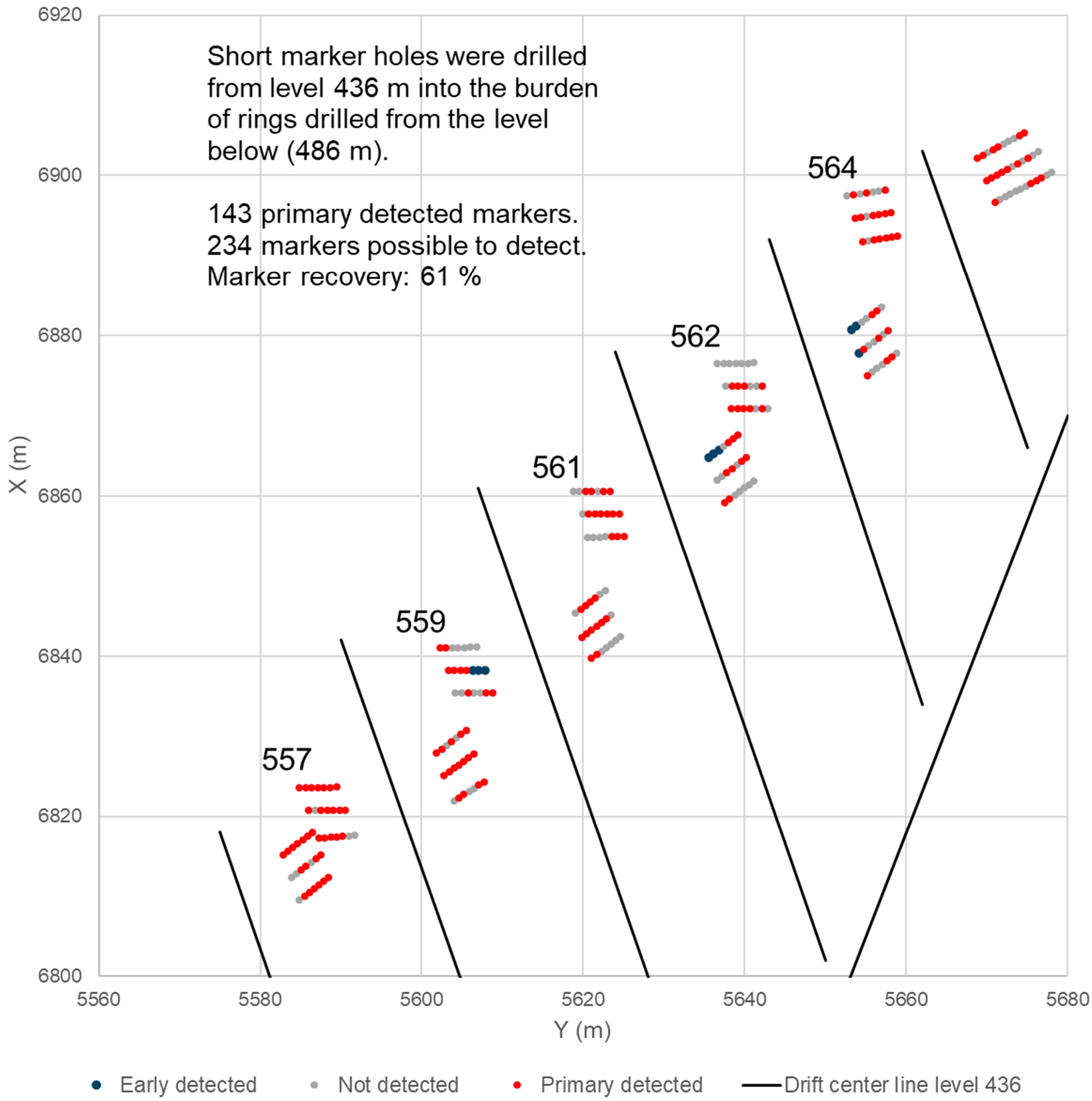

Figure 8 **Top view of markers installed in short holes at level 436 and primary detected at level 486. Planned drifts center lines at level 436 are shown in black. The numbers 557-564 represents crosscuts at level 486.**

5 PERCENTAGE EXTRACTION

The overall extraction ratio in the southern part of the orebody at level 436 (40 m sublevel height) is 91 % and 122 % for full size rings, i.e. when rings should be in contact with the upper level. Mining in the southern part of the orebody at level 486 is still on-going, extraction figures are preliminary but expected not to change much. Interestingly, the corresponding figures for level 486 (50 m sublevel height) are 112 % and 151 %. The percentage extraction is better for level 486, probably due to secondary recovery and learnings during the test period. Details on KPIs are presented by (Quinteiro & Nordqvist 2024).

6 CONCLUSIONS

This paper focuses on gravity flow and summarizes results achieved so far from tests using 40 m and 50 sublevel height at LKAB in Kiruna. These tests are carried out at Konsuln mine, a small orebody located close to the main

Kiruna orebody. Extreme sublevel heights are challenging. Frozen rock, especially after blasting large openings is common even though improvements have been made during the tests. Issues with clogged boreholes during charging as well as wet holes resulting in extensive use of 90 mm cartridges instead of bulk emulsion has been a problem in some crosscuts and openings. Borehole deviations are also an issue even though we have mitigated it by surveying boreholes in large openings and adapted blasting plans. There are many reasons why markers are not detected besides issues with the gravity low. However, the marker recovery from these tests clearly shows that the draw has reached the cave. It basically confirms observed high extraction rates for full size rings, 122 % at level 436 (40 m sublevel height) and 151 % at level 486 (50 m sublevel height). The percentage extraction is better for level 486, probably due to secondary recovery and learnings during the test period. It is concluded that mining with sublevel caving using 40 and 50 m sublevel heights is possible. Further improvements on SLC using extreme sublevel heights are possible: (1) continued trials with openings (2) even more accurate drilling (3) improved handling of clogged boreholes (4) improved technique for charging wet boreholes.

ACKNOWLEDGEMENT

We are grateful to LKAB for the support when conducting R&D work during a long period of time and for approval to publish this paper. The authors also acknowledge colleagues and other personnel at LKAB for their support during planning and execution of the field test. Special thanks to our technicians at the R & D department, without their help this would not be achievable.

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