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Narrow vein mining using sublevel method at Red Lake Gold Mine – Campbell Complex

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1.0 Introduction

The Goldcorp Inc. Red Lake Mines is located in northwestern Ontario, Canada. The Red Lake Gold Mines consists of the Campbell Mine, Red Lake mine, and the Cochenour Mine which is currently at project state.

The Red Lake mine started in 1945 with the first gold pour in 1949. At the end of 1994, the Red Lake Mine was a marginal operation. In 1995 a 7 million dollars exploration program was initiated and lead to the discovery of a high grade zone (HGZ) of gold mineralization. The mineralization was discovered at a depth and location previously thought to have no potential. The average reserve grade of this mineralization is 80.6 gram per ton. This discovery makes the Red Lake Mine both the richest gold mine in the world and the largest gold mine in Canada[1].

In its early years the primary mining method were small open stopes mined using jacklegs and slushers as well as shrinkage mining. Longhole open stoping and cut-and-fill mining methods are now used to mine the ore deposits.

The Campbell mine currently uses the sublevel mining method for its main production with ore drift development as a small part of ore production. The low cost and efficiency of the sublevel mining method is the main reason behind this choice. As Campbell mine is approaching its end, the longhole stopes are scattered throughout the different levels and sublevels of the mine.

This paper presents an overview of the mining methods used at the Campbell Complex with a main focus on sublevel stope mining. A case study on the changes made to optimize efficiency and the quality control measures put in place are presented. A comparison is made between the existing and the modified methods of stope blasting.

2.0 Mining methods at Red Lake Gold Mines

Both mechanized and trackless mining methods are used at Red Lake and Campbell mines. These are cut-and -fill (all mechanized equipment) and sublevel (mechanized and captive trackless equipment) mining methods. Cut-and-fill mining employs both overhand and underhand methods.

2.1 Cut-and-Fill

Cut-and-Fill mining is a selective mining method to optimize ore recovery and minimize dilution. It is used to extract ore efficiently for shallow dipping ore bodies or for deposits that have complex geometries [2]. It is more expensive than the sublevel mining method. This method is used in the high grade zone at the Red Lake Complex. There are two versions of Cut-and-Fill mining methods: overhand and underhand methods.

1.1.1 Overhand cut-and-fill

Overhand cut-and-fill consists of driving a drift into the required ore zone, then filling the mined out drift with cemented paste (currently 10% binder content consisting 60% cement and 40% fly ash). Once poured the paste is allowed to cure. Another drift (lift) is then driven above the previously mined out and filled drift. This allows the following of the ore body with better accuracy in order to maximize recovery and minimize dilution.

1.1.2 Underhand Cut-and-Fill

Underhand cut-and-fill consist of driving a drift into the required ore zone, installing fill mats upon completion of mining (as a mean of ground support during the exposure of the back) and filling it with cemented paste. Once poured the paste is allowed to cure. Another drift (lift) is then driven underneath the previously mined out drift that is now filled. This allows the following of the ore body shape more accurately in order to maximize recovery and minimize dilution. This method costs more since it requires the placement of high strength paste for working underneath. It is also a safer method to work under high stress and burst prone conditions compared to the overhand version.

2.2 Sublevel stoping

Sublevel stoping is a non-selective method used to minimize drilling and blasting costs. A drift is driven in, over, under, or aside the ore body for the drill and a drift or a draw point is driven where the broken rock will go to be loaded and hauled. Once drilled, a first blast, called the slot, will create a void for the rest of the block to be blasted into. Unless using the shrinkage mining method where the broken rock serves as the ground for the drillers, it is more than often required to empty the drift or draw points before blasting into the openings again. If more than one block is to be taken in the area, the empty blocks will be filled to ensure rock stability by reducing the hydraulic radius of the open stope [2].

At the Red Lake Mines, we are currently using 3 versions of drilling and blasting patterns for the sublevel method. They are: fan holes from outside the ore body, fanned pattern when the ore width is greater than development width, square pattern when the ore width is lesser than development width.

2.2.1Drilling fan holes from outside the ore body (sill & boxhole blasting in the captive remnant mining areas)

In the 1970's, Campbell complex upper levels were mined using the shrinkage mining method. Some of these stopes were never filled and the ore was left behind because they were close to breaking through on a level, causing multiple issues. What was left from these stopes was named a sill. These portions of ore have great value but are out of reach through conventional sublevel blasting as they are unsafe to work on and in captive areas. The method to longhole these stopes is to drill fanned rings from a side drift and blast them into the empty stopes to fill draw points where the rock will be loaded and hauled from. The shape of the drilling forms a box and was therefore named sill & boxhole blasting as shown in Annexe 1.

2.2.2 Sublevel drilling pattern for ore width greater than development width

This pattern is used for stopes that are wider than the drift from which it will be loaded and hauled. It is currently used when the ore body is larger than the drift or when mining multiple narrow veins close to each other. The first blast is used to create void through an inverse/drop raise including a slot and then the production rings are blasted into that void as shown in Annexe 2.

2.2.3 Sublevel drilling pattern for ore width lesser than development width

This pattern is a standard pattern with 3 holes per ring with the same dip to each hole on a certain number of rings as shown in Annexe 3. It is used for veins that are smaller than 8 feet widte for strike length of up to 60 feet. This method is currently being optimized and is presented in the optimization section.

3.0 Optimization of the drilling & blasting pattern

There are a few factors that were worked on with the same idea behind them all: achieving better results and lowering the cost of drilling and blasting. With the struggling price of gold in the last 6 months, these aspects have been more than important and every change that can help is welcomed.

3.1 Square pattern (Old Drilling & Blasting Pattern)

Through the life of the mine, there have been multiple drilling and blasting patterns used to longhole mine a stope. Before getting to the new revised pattern, the pattern used spacing to burden ratio of 1 with 3 holes across (Annexe 4). Different patterns were tested before and this one proved to work efficiently on most factors. The reason this pattern was modified is to reduce the cost of drilling and blasting (3.2, 3.3, and 3.4), reduce dilution (3.3, 3.5) or achieve smaller fragmentation (3.5).

3.2 Modified dice pattern 4’: Dilution control

The main objective to the pattern change is to reduce the cost related to dilution without compromising the quality of the process. Several options were investigated and tried throughout the years and it came down to a modified dice pattern to obtain a similar fragmentation while reducing the cost of the operation. The main change was reducing spacing while keeping the current burden. As the mine used spacing to burden ratio of 1 and was not willing to go lower than that as it is not recommended [3], it was looked into changing the 4’ burden/4’ spacing to something new. As the optimal pattern tested was three holes across, it came to mind to use a modified version of a dice pattern (Annexe 5). The modified dice pattern 4’ (Annexe 6) has a burden of 4’ between rings but a real burden of 3’ thus giving the option to reduce the spacing from 4’ to 3’ to keep spacing to burden ratio to 1.

After multiple tests in different areas of the mine, the modified dice proved to be effective on drilling and blasting. The visual fragmentation did not change and there were no oversize blast required, showing itself to be as effective as the standard square pattern. The major cost savings comes from dilution control provided by using the modified dice 4’ pattern with a small part attributed to the reduction of the raise size.

The ore at Campbell mine is usually located in small veins of 6’’ to 8’ width. It is important to control dilution. Therefore minimizing the amount of dilution will have a major impact on both grade and cost. The costs to haul, hoist, and process the ore represents 75% of the operating cost for a ton which makes it important to minimize dilution. For a standard block of 60’ strike length and a height of 45’ using a regular square pattern of 8’ width represents roughly 1975 tons. Reducing the size of the stope to 6’ width roughly represents a diminution of 500 tons, or 25% diminution of planned dilution and a saving of 18.75% on the total cost of the stope.

On the drilling and blasting aspect, the raise represents 60% of the cost in drilling and blasting for a strike length of 60’. Usually the first 8’ would serve for the drop raise but the modified pattern requires a 6’ therefore saving 3.5% of the cost for the raise, representing 2.1% overall savings. There are no real savings on the production holes as the same amount of holes will be drilled and blasted.

3.3 Modified dice pattern 4’: Drilling and blasting reduction

The main objective to the pattern change is to reduce the cost of drilling and blasting without compromising the quality of the process. The main change was having a bigger burden while keeping the same spacing. The previous drilling and blasting pattern using a burden of 3’ and a spacing of 3’, it came to mind to use the same modified dice pattern 4’ (Annexe 6) to reduce the cost of drilling and blasting.

As with the previous change, the modified dice proved to be effective on both drilling and blasting. The visual fragmentation did not change and there were no oversize blast required, showing itself as effective as the standard rectangular pattern. The percentage of drilling and blasting saved represents a small amount compared to the previous change but is still significant on a larger scale.

The raise represents 60% of the cost in drilling and blasting for a strike length of 60’. The first 6’ are used for the raise with no difference. Where the savings occur is on production holes where 25% less production holes are required to drill and blast the same amount of tons. This pattern allows saving 10% of the overall drilling and blasting cost.

3.4 Modified dice pattern 3’: Dilution reduction and fragmentation amelioration

The main objective to the pattern change is to reduce dilution and fragmentation size. The reduction of burden and spacing on narrow veins offers these wanted changes. The previous drilling and blasting pattern was using a burden of 3’ and a spacing of 3’. It was suggested to reduce the real burden to 2’ and the real spacing to 2.5’ through the modified pattern 3’ (Annexe 7). This would allow veins smaller than 6’ to be mined with less dilution and better fragmentation both reducing the final cost of the operation.

The changes on the pattern were beneficial as visual fragmentation was smaller and a 16% dilution reduction was observed.

As per the dilution control, the savings are significant on the 60% of the rest of the mining costs. For a block of 60’ strike length and a height of 45’ using a square pattern of 6’ width represents 1475 tons. Reducing the size of the stope to 5’ width represents a diminution of 250 tons representing 16.9% diminution of planned dilution and savings of 12.7% of the total cost of the stope. The reduction of the size of fragmentation is hard to quantify as it affects variables such has a diminution of power used at the crusher for that specific block, a diminution of wear and tear on the equipment, a diminution of downtime on equipment, and much more [4].

4.0 Quality Control

- 4.1 Hole Probing

As a mean to ensure the quality and accuracy of the drilling, probing is an important part of quality control. The lack of manpower has made this step difficult for a certain period of time as our trained personnel were busy with more critical work but Campbell mine has been able to catch up recently with the help of co-op students and surveyors.

The critical part of a drilling pattern is more than often the inverse raise, especially if it is drilled without breakthrough. For now, the four corner holes and the four cut holes are probed for most inverse raises. This practice is slowly getting better and more efficient and it will eventually be possible to probe most of the holes that are non-breakthrough for any given pattern.

- 4.2 Blast monitors

The mine has a few blast monitors on site. They are currently used on critical electronic blasts. They are currently used to verify the timing that is programmed by the blasters and to record any rock burst occurring after the blast but they have the potential for a better usage.

In a relatively close future this practice will become regular and the mine will try to optimize the delays in every zone according to the data obtained through the various upcoming blasts.

- 4.3 Reconciliation using CMS (Cavity Monitoring Survey)

The stope reconciliation is a practice that started in March 2013. In order to make every department accountable to their work, most of the stopes at the Campbell complex go through reconciliation. This consist of looking at what the plan was for ounces, tons, drilling pattern, dilution, and compare them to what actually happened. In this regard, it is possible to obtain better information on rock mechanics aspects (ELOS, hanging wall/back/footwall failure), operation aspects (accuracy of drilling and blasting), geology aspects (better definition through historical data for the next stopes), and planning and design aspects for the zone (which patterns to use). It was noted through reconciliation that some zones would cause more problems when using the modified pattern because hanging wall failure would create oversized rock.

5.0 Case Study

5.1 33-699_0 Block 2 Down

This case study is the second stope that has been mined in the R-Zone. A lot of follow-up is being done on this zone as the new drilling patterns are being tested to achieve the most efficient ratio between low cost for drilling and blasting and good fragmentation. It also is an interesting zone regarding rock mechanics aspects because it has a shear zone close to it and there are chances that it will unravel and add a lot of dilution (Annexe 8). The drilling and blasting pattern used here is the modified pattern 4'.

On the first block on this zone, a major hanging wall failure occurred with a strike length of 60'. It was decided to reduce the strike length of the following blocks to 40' and to install 8' cable bolts into the walls of the drilling drift to avoid such a failure again. The drilling and blasting were followed on a daily basis by both operation and engineering to obtain the best results possible as seen on Figure 1 and Figure 2. The drilling and blasting specifications are presented in Table 1.

Table 1: Drilling and blasting specifications

Burden	3 ft
Spacing	3 ft
Strike length	40 ft
Height	59 ft
Dump	0°
Dip	61°

Hole Diameter	2.5''
Powder Factor	3 lbs/ton
Explosives	Dyno SL
Cap Type	Nonel
Grade	0.28 oz/ton
Tons Blasted	1400 tons

Figure 1: Photo of the drilling setup

Figure 2: Cable bolts in the hanging wall of the drift

The results were convincing. The hanging wall did not fail while the crew was mucking the stope. Dilution from the shear zone represented 500 tons and was expected. The cable bolts were effective and it has been recommended to follow this method to control the failure of the hanging wall side of the drift. 878 ounces were recovered from that stope compared to the 392 planned.

5.2 Special design: “Snake Eye”

This stope was brought up by the geology team early in 2013 as a potential for gold but needed some test holes to confirm the ore body that the block model provided. After doing test holes on a stope that should have been 50’ high, 50’ strike length and 6’ wide, only a few test holes reported some gold up to 15’ high on a vein of 6” to a foot wide. After reviewing the mapping of the drift and the test holes it came to mind to try something different on the whole strike length of the mapped drift.

A 122’ long, 15’ high, and 2.5’ wide stope would be mined using a pattern similar to surface trench blasting onto the back of the drift. The “Snake Eye” pattern was brought up (Annexe 9). This pattern allows the stope to be mined with a strong control over dilution meaning the stope would now be profitable.

To get results, the engineering department along with the geology department had to plan this differently. Both planner and geologist went underground to the heading to mark up the ore on the back of the drift (Figure 3). Using the block model and the survey has-built the drilling was planned to certain specifications (Table 2). The drillers had to report any holes that were not drilled around the marked up ore body. After the first shift of drilling, it was reported that the whole drilling would miss the ore shape. It then occurred that something was wrong and a site visit was conducted before any more drilling would be done. The results were that the actual ore was 2 feet off to the left. The drilling plans were then adjusted to what was seen on the field. Figure 4 presents the loading of the 4th blast in stope

Table 2: Drilling and blasting specifications

Burden	1 ft
Spacing	2.5 ft
Strike length	122 ft
Height	15 ft
Dump	0 - 15°
Dip	67°

Hole Diameter	2.5''
Powder Factor	10 lbs/ton
Explosives	Dyno SL +
Cap Type	Nonel
Forecast Grade	0.50 oz/ton
Tons Blasted	350 tons

Figure 3: Photo of the ore mark up

Figure 4: Photo of the drilling pattern ready to blast

The stope produced around 300 tons for 134 ounces. It was lower than expected, but the vein was so narrow that it is suspected that the samples were not representative as geology random samples ran over 0.7 ounces per ton during the mucking. The fragmentation was uniform, being smaller than 12’’ for about 95% of the tons. This pattern was successful on an operation aspect and it is recommended to keep a record of this test in the eventuality something similar could be done. Figure 7 and Figure 8 show the blasted stope and the fragmentation of the rock.

Figure 7: Photo of the stope after blasting

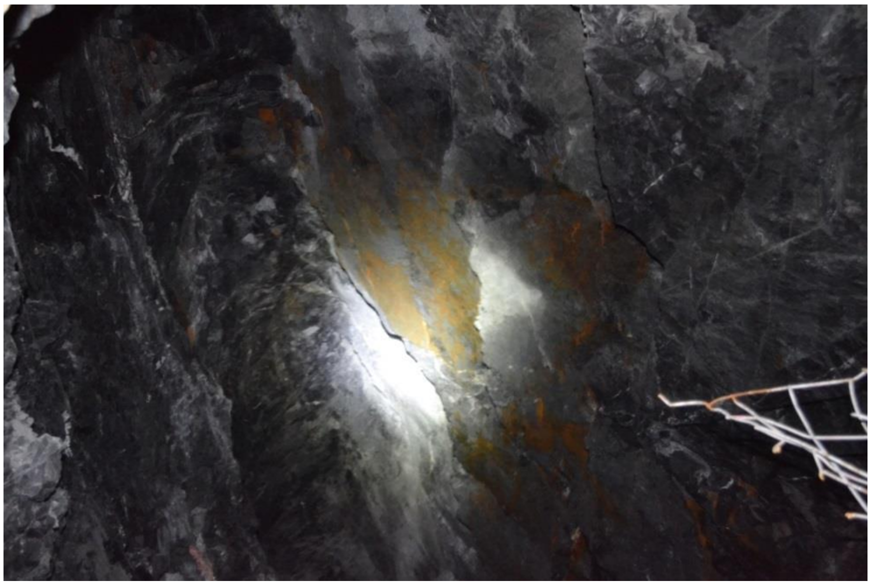

Figure 8: Photo of the fragmentation

6.0 Conclusion

Through the various modifications of the drilling pattern, it was observed that reduced drilling and blasting could achieve similar results on fragmentation. It was then possible to reduce the cost per ton by reducing the size of this operation. The biggest saving potential relies on a strong dilution control. Every ton of waste that does not get loaded and hauled out from a stope represents great savings.

Quality control is an important part of the operations. It is known that it was only done whenever time was found which is now being corrected.

After reviewing the pattern and the ground conditions, it has been proven successful to reduce the strike length of the blocks and installing cable bolts in the drift's wall on the hanging wall side of the stope. This has saved a lot of trouble by avoiding the need to backfill the drift in order to mine the stopes above the drift. The modified dice 4' also proved successful, as no oversize was reported and after every inspection fragmentation was acceptable.

The "Snake-Eye" pattern was a test to try to get the ore of an old stope that could not be mined otherwise with a profit. This pattern proved to be a success as to the ounces recovered and the tons mucked. It is something that RLGM will consider again if a similar situation occurs.

7.0 Acknowledgment

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The whole team consisted of:

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Alexandre Dorval (Longhole Planner, ing. Jr.)
Matthew Barrow (Longhole Planner, Lead)
Ron Scherby (Senior Planner)
Mekoya Wondrad (Chief Engineer, P. Eng.)

9.0 References

[1] Site Web, www.goldcorp.com, Septembre 2013

[2] HUSTRULID William A., BULLOCK Richard L., Underground Mining Methods: Engineering Fundamentals and International Case Studies, 2001, p.728

[3] De la Vergne, Jack (2003). *Hard Rock Miner's Handbook. Tempe/North Bay*: McIntosh Engineering. pp. Forward.

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10.0 Annexes

Annexe 1: Longitudinal section of a sill & boxhole blasting ring

Annexe 2: Longitudinal section of sublevel drilling pattern for ore width greater than development width

Annexe 3: Longitudinal section of sublevel drilling pattern for ore width lesser than development width

Annexe 4: Square drilling and blasting pattern

Annexe 5: Standard dice drilling and blasting pattern

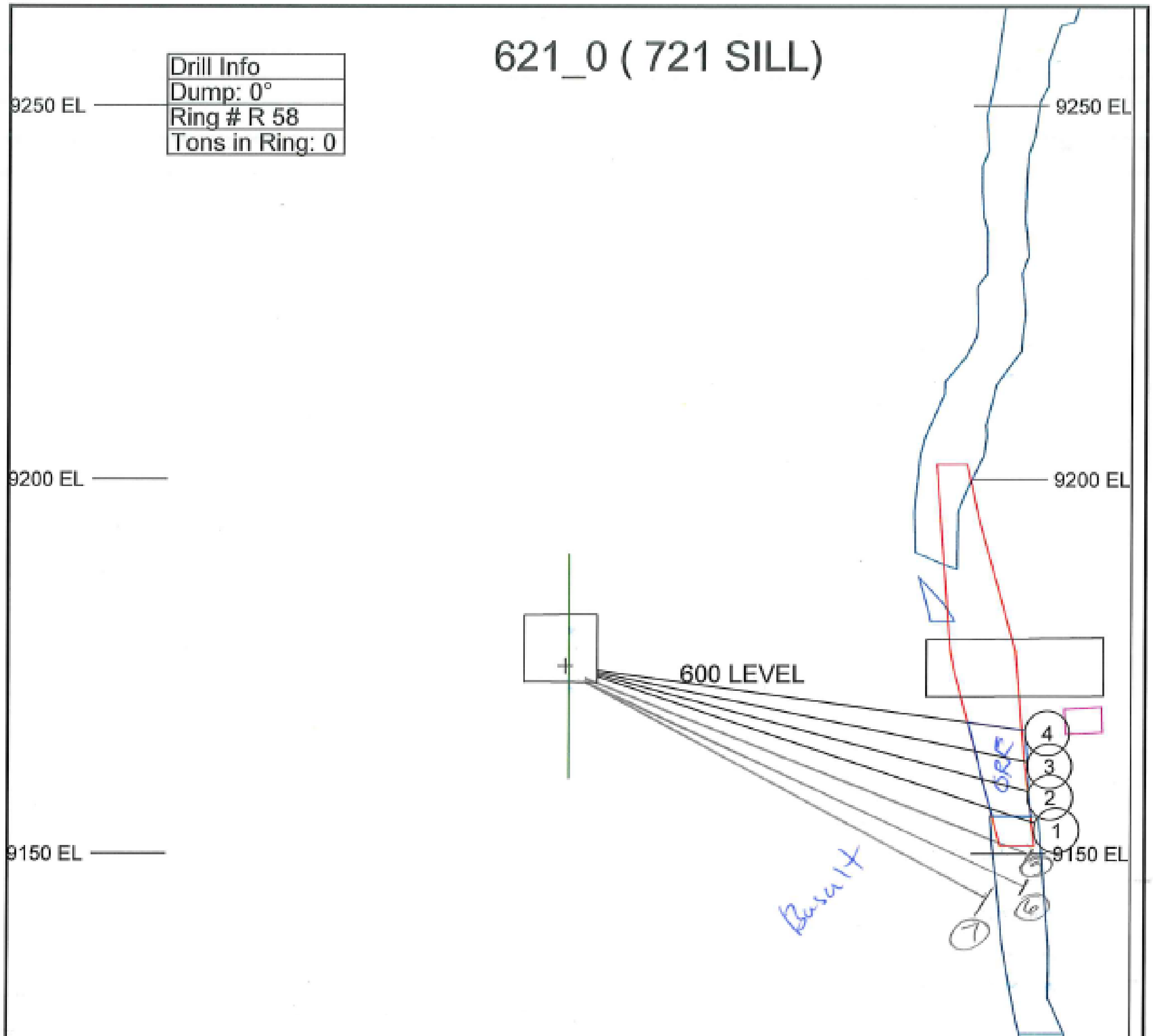
Annexe 6: Modified dice 4' drilling and blasting pattern

Annexe 7: Modified dice 3' drilling and blasting pattern

Annexe 8: Study case of 33-699_0 Block 2 Down longhole stope

Annexe 9: Study case of the Snake-eye pattern

Annexe 1: Longitudinal section of a sill & boxhole blasting ring



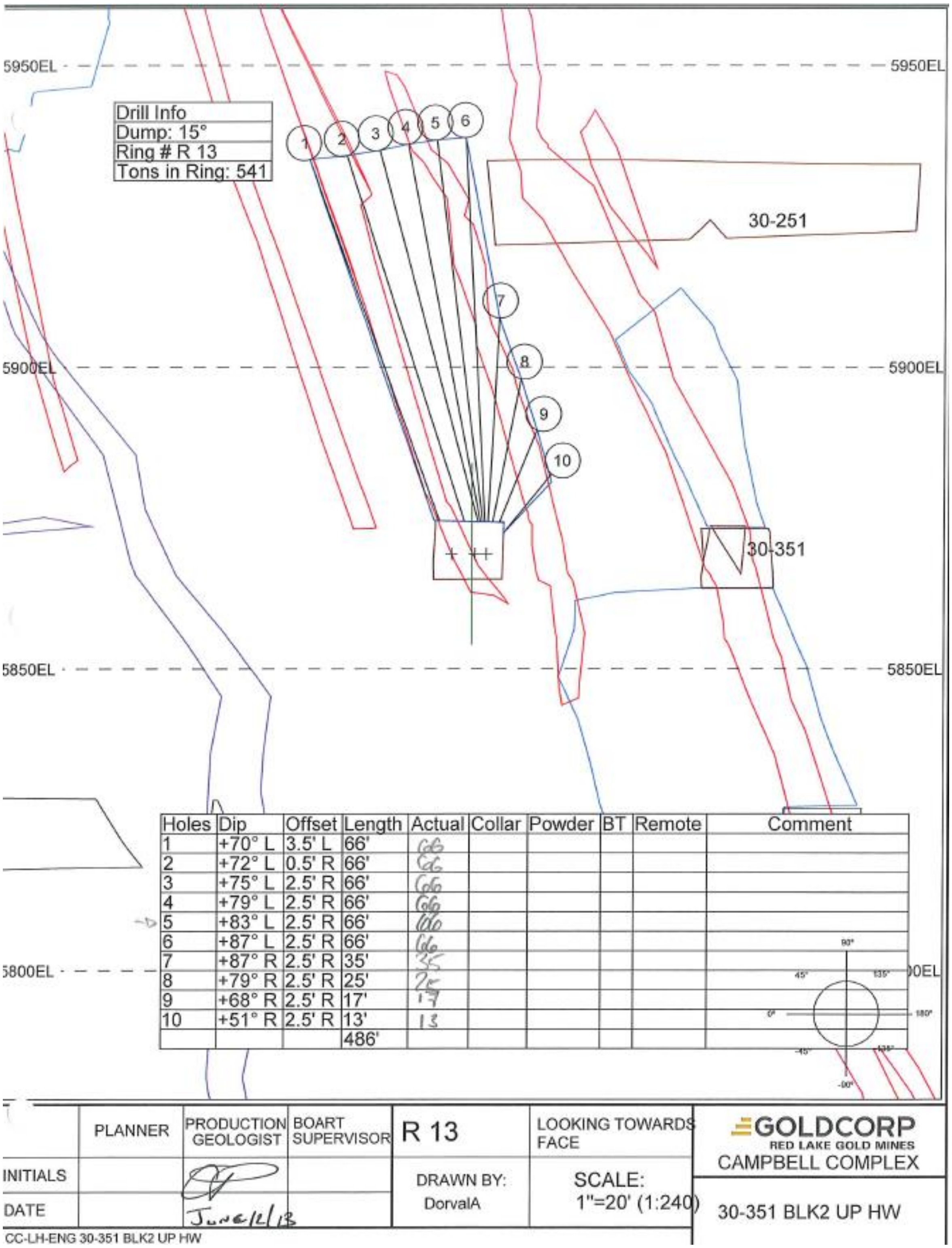
Holes	Dip	Offset	Length	Actual	Collar	Powder	BT	Remote	Comment
1	-18° R	0.5' L	62'	62			N		
2	-15° R	0.5' L	60'	50			Y		Ground closed
3	-12° R	0.5' L	59'	36			Y		
4	-8° R	0.5' L	58'	30			Y		
			239'						

9100 EL — 9100 EL

5	-22	62	N
6	-26	64	N
7	-30	60	Y

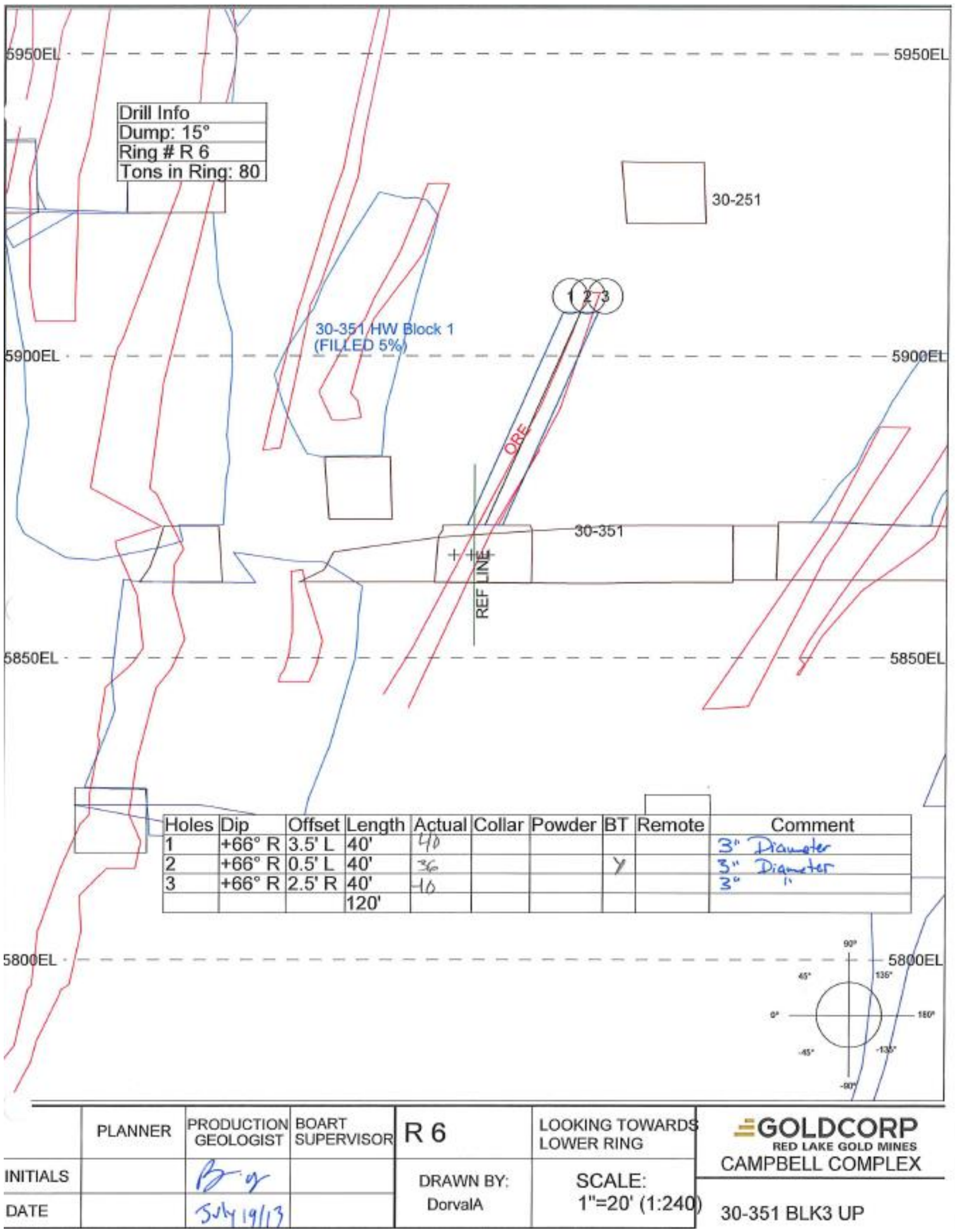
	PLANNER	LONGHOLE SUPERVISOR	R 58	LOOKING TOWARDS LOWER RING	GOLDCORP RED LAKE GOLD MINES C COMPLEX
INITIALS			HOLE DIA.: 3.5"	DUMP: 0°	
DATE			DRAWN BYDorvalA	SCALE:1"=20' (1:240)	621_0 (721 SILL)
Not saved					

Annexe 2: Longitudinal section of sublevel drilling pattern for ore width greater than development width

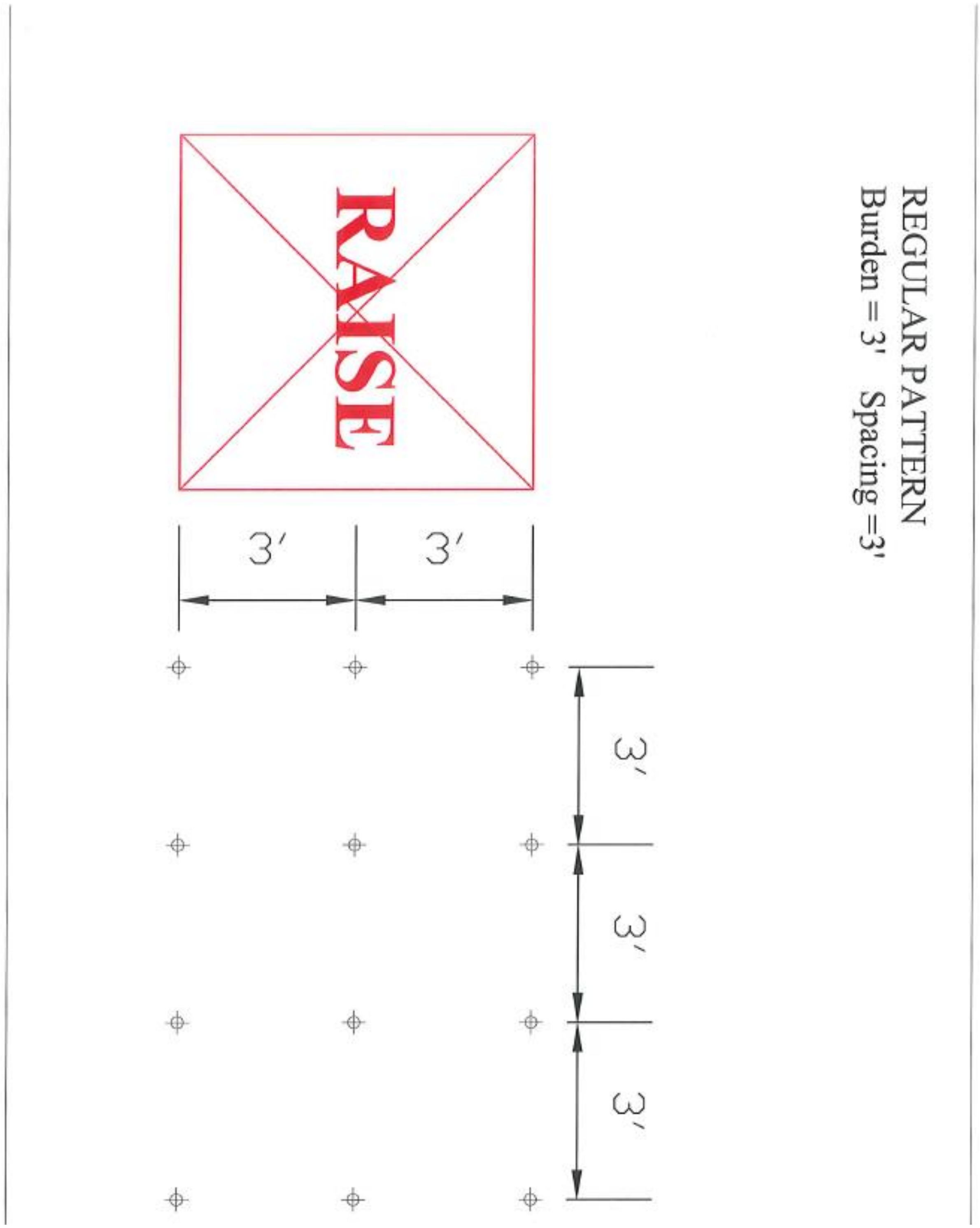


Holes	Dip	Offset	Length	Actual	Collar	Powder	BT	Remote	Comment
1	+70° L	3.5' L	66'	66					
2	+72° L	0.5' R	66'	66					
3	+75° L	2.5' R	66'	66					
4	+79° L	2.5' R	66'	66					
5	+83° L	2.5' R	66'	66					
6	+87° L	2.5' R	66'	66					
7	+87° R	2.5' R	35'	35					
8	+79° R	2.5' R	25'	25					
9	+68° R	2.5' R	17'	17					
10	+51° R	2.5' R	13'	13					
			486'						

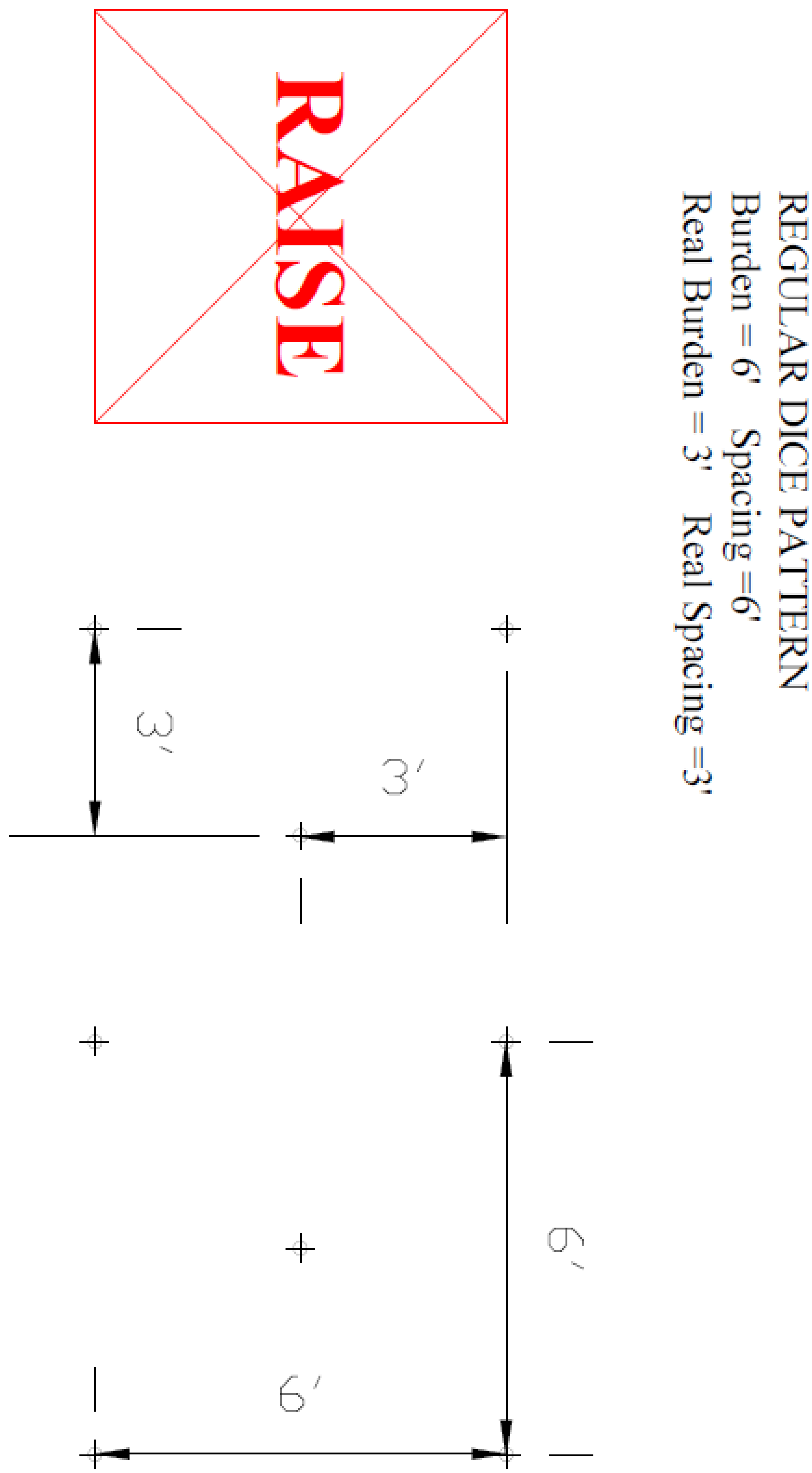
Annexe 3: Longitudinal section of sublevel drilling pattern for ore width lesser than development width



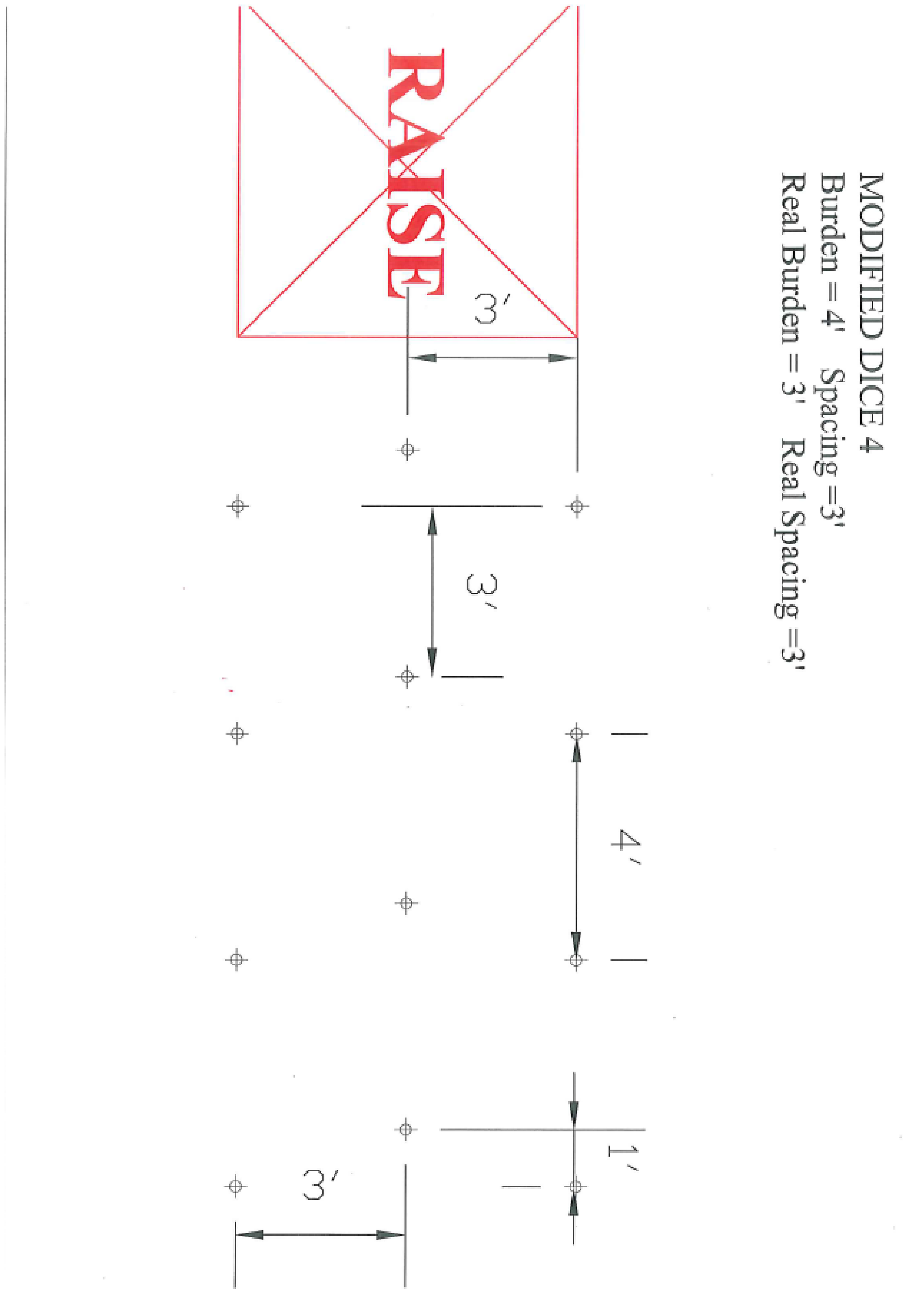
Annexe 4: Square drilling and blasting pattern



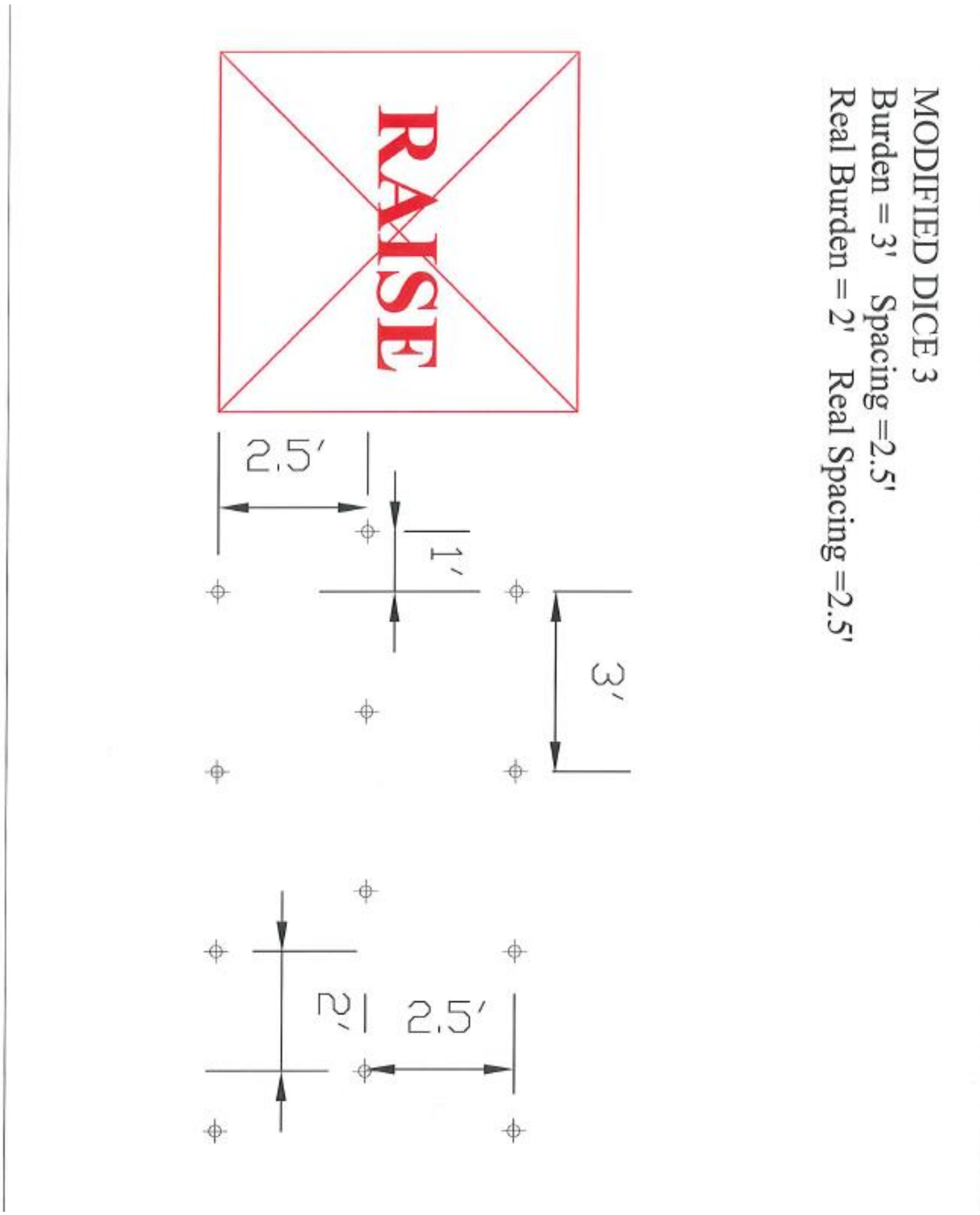
Annexe 5: Standard dice drilling and blasting pattern



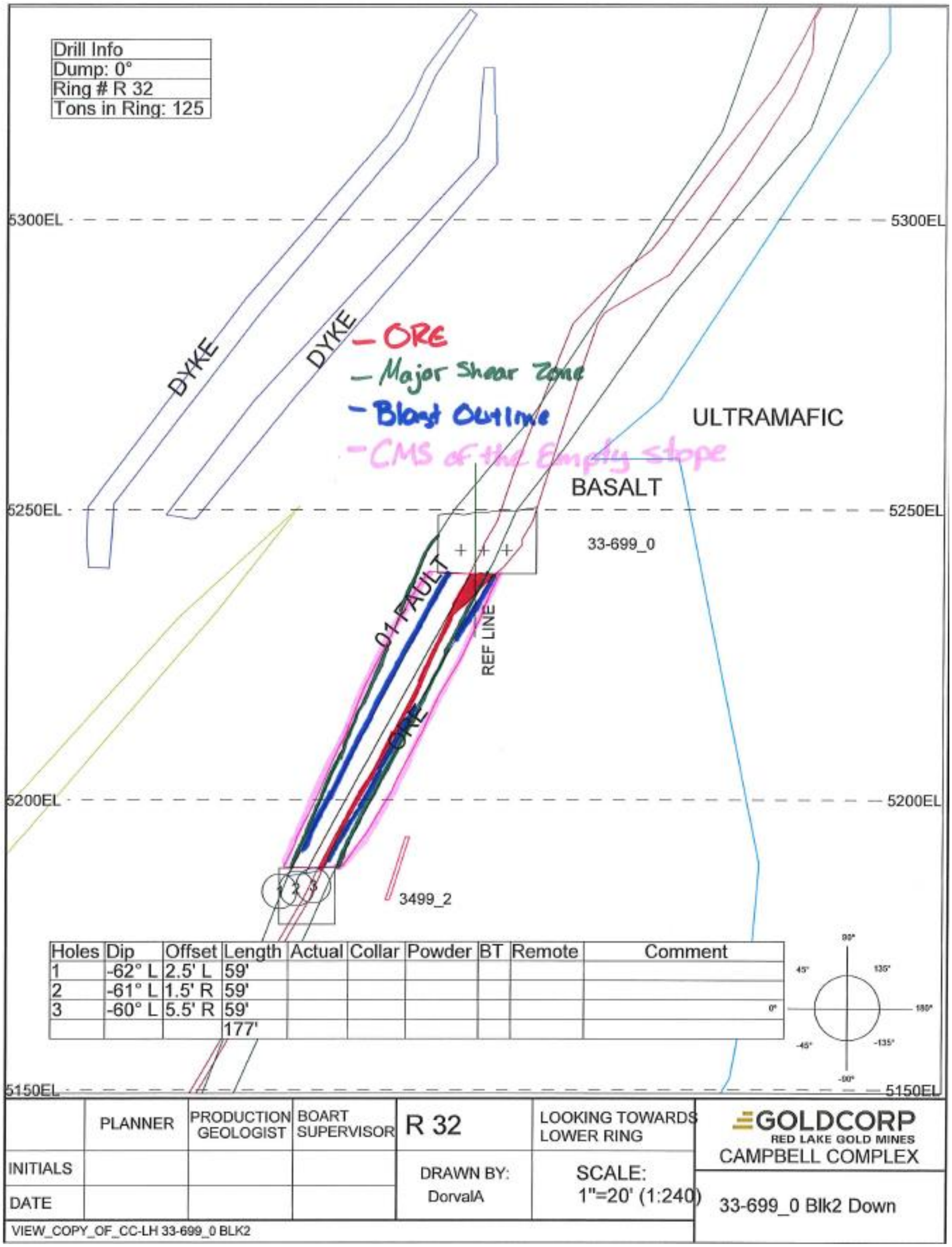
Annexe 6: Modified dice 4’ drilling and blasting pattern



Annexe 7: Modified dice 3’ drilling and blasting pattern



Annexe 8: Study case of 33-699_0 Block 2 Down longhole stope



Annexe 9: Study case of the Snake-eye pattern