North Regional Pillar Destress Mass Blast at Brunswick Mine

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ABSTRACT:

Following the success of the West Ore Zone destress mass blast in 2001, a similar approach was taken to destress the North Regional Pillar (NRP) which contained over 3 million tonnes of high grade ore. The NRP is located on the 1000 m Level with very poor hanging-wall (H/W) rock mass qualities. After extensive geotechnical review, the destress slot is located close to the foot-wall (F/W) of the NRP in order to have the competent ore as H/W. The longitudinal area to destress covers 115 m along the strike and 85 m high from 1000 1-sub to 850 Sill. Prior to the final mass blast, 3 voids were created to allow rock swelling: the North void, the South void and the trench just below the mass blast. After over one year of preparation, the mass blast of 202,000 tonnes was successfully initiated on February 7, 2003 with 1558 i-kon electronic detonators and 210,000 kg of emulsion explosives. The blast achieved its objective of destressing the NRP as indicated the mine-wide micro-seismic monitoring system. This paper describes different stages of the project from void preparation to the mass blast itself, as well as some detailed aspects such as muck-pile prediction for mucking sequence with the help of Orica's DMC_Blast code and i-kon electronic detonators.

1. INTRODUCTION

Brunswick Mine has been operating since 1964 and currently produces 10,000 metric tonnes per day. Over the past 20 years of underground mining at the #12 ore-body, there were two large regional pillars established on the 1000 m Level to support the ground for safe extraction of the surrounding ore. The South Regional Pillar contains about 5 million tonnes of ore and the North Regional Pillar has about 3 million tonnes of ore. In the fall of 2000 mining activities in the South Regional Pillar were suspended following a series of ground movements along several weak geological structures between the main ore vein and the west ore zone (WOZ) on the H/W side. After extensive geotechnical investigations, a decision was made to carry out a mass destress blast in the West Ore Zone (WOZ) to cut the principal stress across an area of 165 m along the strike and 86 m high. At the end of July 2001, the WOZ mass blast was successfully initiated. The whole South Regional Pillar became seismically quiet after the mass blast. After mucking out the WOZ, the mining activities resumed immediately at planned production rates.

Following this success the mine management decided to take a similar approach to destress the North Regional Pillar (NRP). Figure 1 shows the longitudinal of Brunswick Mine and the NRP location. Compared to the WOZ, the hanging-wall in the NRP is much weaker. The soft H/W rock is so weak that some parts of the H/W drift floor lifted up resulting in much smaller drift sections. In addition, there is no separate narrow ore zone in the NRP to take out as in the case of WOZ. After extensive geomechanical investigations, the best location of a destress slot is located along the F/W of the NRP (Andrieux and Brummer, Nov 2001). The ore body in NRP is generally more competent with less geological structures going through the orebody. The length along the strike measures about 140 m, with a vertical height of 86 m. Figure 2 shows the plan views on 2-sub and 3-sub for the destress slot, as well as the South Void and North Void. The two voids are located at two ends of the destress slot, providing room for muck displacement while maintaining the safe access of NRP during drilling and blasting the destress slot. The blast strategy is thus divided into two stages: the preparation stage for the voids and the final stage for mass blast. Additional void is also created below the central portion of the mass blast, called the Trench. The final mass blast is initiated towards the north and south voids simultaneously with 6 free-faces on 3 sub-levels. Figure 3 shows the overall blasting strategy.

With the destress slot on the F/W side, the slot must be paste-filled as soon as the muck is taken out. After a reasonable curing period, there will be development to be driven through the paste-fill material to regain access to the main ore body.

On the project management side, unlike the WOZ with a special team dedicated for the project, the NRP was integrated into the overall mine production plan in terms of engineering and underground supervision. However, all the blasthole drilling were done by a contractor Boart-Longyear and the loading of the final mass blast was carried out by ETI explosives.

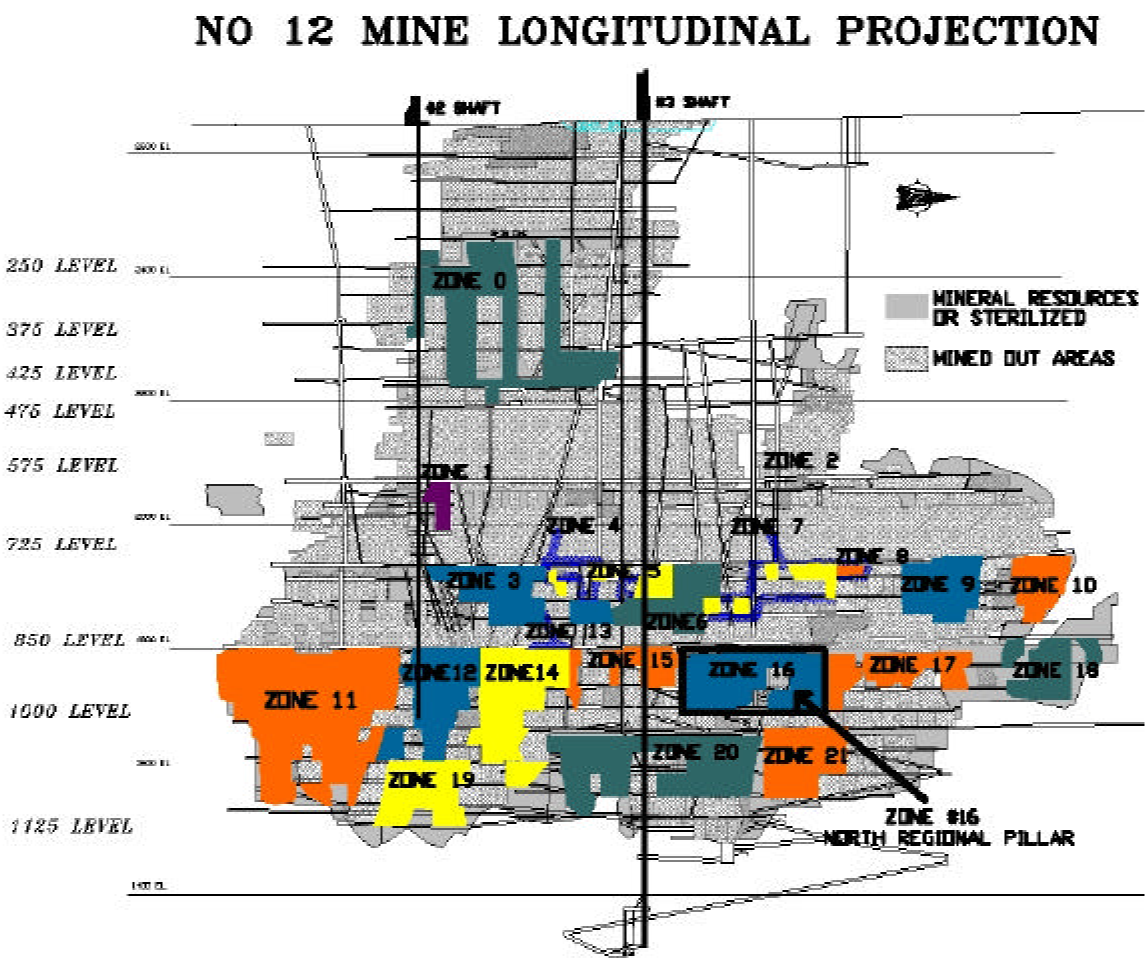

Figure 1. Longitudinal of Brunswick Mine.

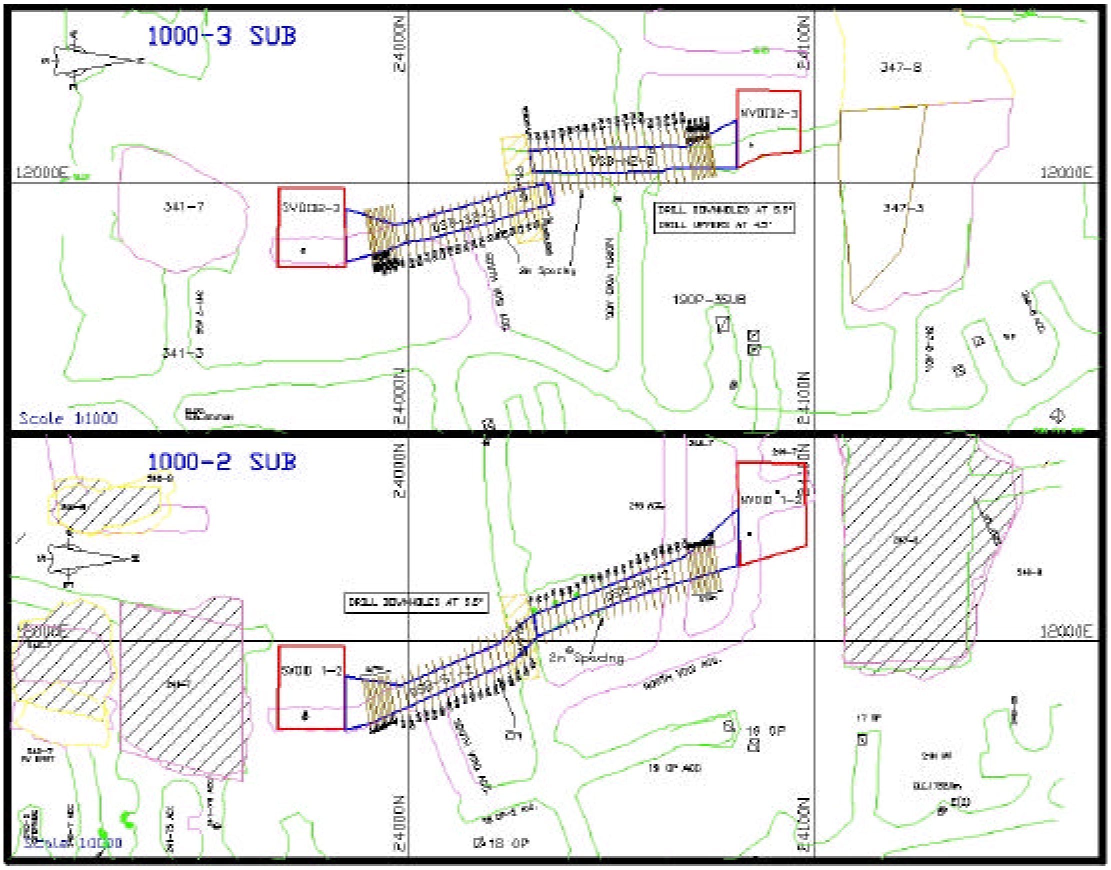

Figure 2. Plan view on 2-sub and 3-sub of 1000 m Level

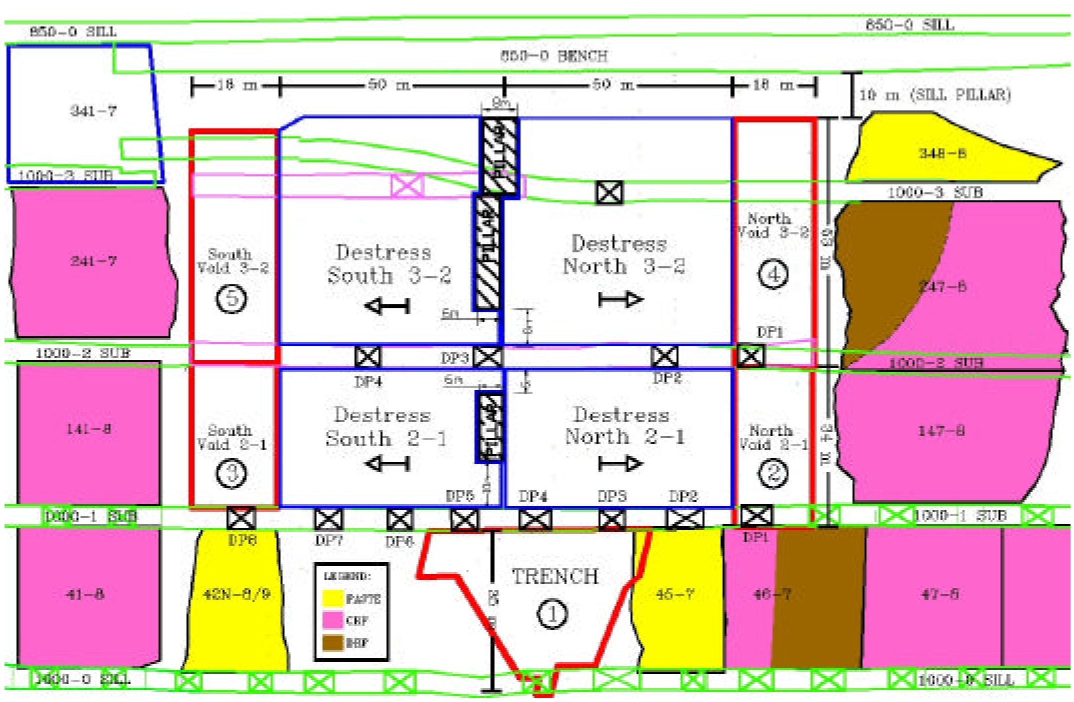

Figure 3. Overall blasting strategy of the NRP destress mass blast.

Once the dimensions of the destress slot and the voids were determined, the quantity of work was estimated for project management purposes. The following blasts were planned as of December 2001:

Table 1: First estimation of project progress and requirement of bulk emulsion.

Blasting blocks	Start Date	Tonnage (metric tonnes)	Meters of drilling	Drill factor (t/m)	Powder factor (kg/t)	Kg of emulsion
Trench	June 15, 2002	18,500	2,055	9.2	1.13	20,843
North Void 1 –2 sub	Aug. 10, 2002	39,990	2,330	17.4	0.49	19,728
South Void 1 – 2 sub	Aug. 12, 2003	39,000	2,500	15.6	0.49	19,227
North Void 2–3 sub+sill	Sept 19, 2002	51,920	3,505	14.8	0.55	28,556
South Void 2 –3 sub+sill	Oct 4, 2002	50,000	3,400	14.7	0.55	27,500
Final destress blast						
North 1-2 sub	Nov. 1, 2002	38,000	3,300	11.5	1.26	45,916
2-3 sub + sill	Oct 21, 2002	61,150	5,245	11.7	1.06	64,727
South 1-2 sub	Nov 20, 2002	38,000	3,300	11.5	1.26	47,842
2-3 sub + sill	Nov 13, 2002	58,000	5,000	11.6	1.06	61,393

2. THE NORTH VOID

As indicated in Table 1, the North Void has two sections: the lower section below 2-sub and the upper section below 3-sub and above 3-sub in the sill. The lower section has to be mined out first and it serves as void for the upper section. Figure 4 shows a side-view of the North Void while Figure 5 and 6 show the plan views on 2-sub and 3-sub respectively.

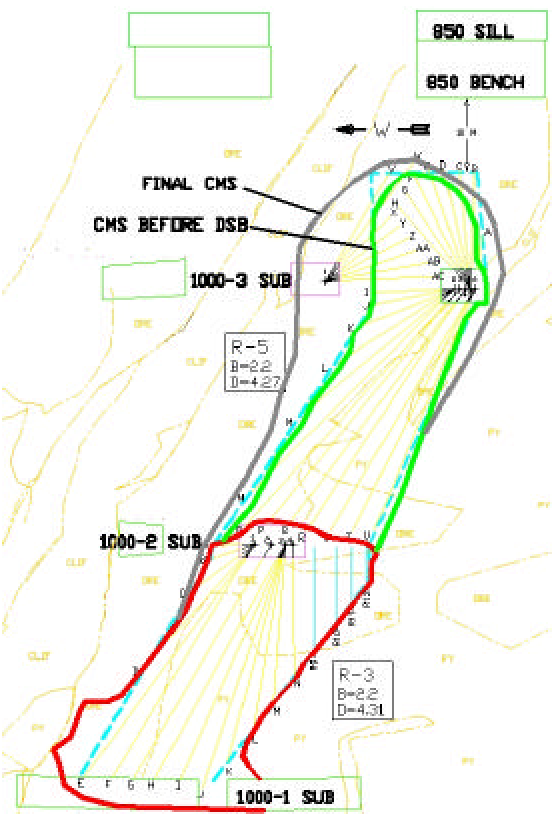

Figure 4. Side-View of North Void, looking north.

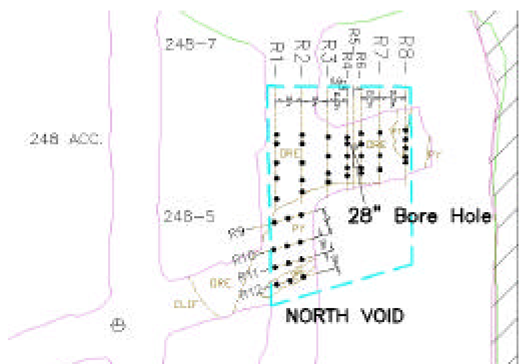

Figure 5. North Void Plan View on 2-sub.

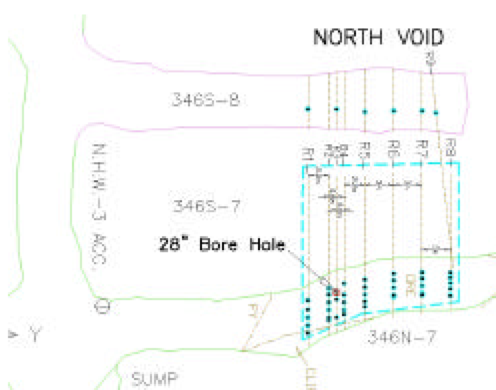

Figure 6. North Void Plan view on 3-sub

In general, the North Void provided about 21,400 m^3 of void to host 23,100 m^3 of ore from the northern portion of the final mass blast. Given the fact that North Void is much thicker in east-west direction than the destress slot, and only 70% of its volume might be useful as void for muck, the overall muck accommodation is still acceptable for the final mass blast.

North Void from 1 to 2 sub:

A total of 3 blasts were required. All those blasts were fired using regular shock-tube detonators (LP's). While mucking the first two blast, some CRF (Cemented Rock Fill) was observed in the muck pile from the extreme north side of the stope. It was then decided not to blast the last row of holes on the north side (Ring #8). Through out the mucking of North Void on 1-sub after the final blast, there was not any sign of CRF dilution again in the muck.

North Void from 2 to 3 sub and sill pillar:

In theory, the whole upper section of the North Void could be blasted in just one shot. However, the risk is high. By taking two smaller blasts in the drop raise to bring it up close to the 3-sub, the total delay time required in the final blast can be greatly reduced and so is the risk of misfires. Thus, a total of 3 blasts were taken to mine out the upper section of the North Void. The first 2 blasts (2 x 40ft) were designed to take out the slot raise around a 28" borehole using regular shock-tube detonators (LP's). After the two blasts, most of the holes in regular rings stayed open and at full length. Because the final blast has both down-hole and the up-holes drilled from a H/W drift, the down-hole drop raise as well as the regular rings must be completed before firing the up-holes. Therefore, the firing speed is relatively slow at the beginning for the drop raise as well as the gradual expansion from the drop raise with down-holes, followed by faster initiation with regular rings. The first 7 holes in the drop raise had 200 ms between each other to blast off the 10 m plug. Then the first 5 full-length holes (30 m) had 200 to 500 ms delays between each hole. In the first 4 seconds only 15 holes were fired and the other 140 holes took only 3 seconds. This type of initiation with slow-start and fast-ending calls for detonators with high precision and long delay timing which can only be achieved with ectronic detonators. In total, the final blast used 337 I-kon detonators and 2 loggers for a total time of 6825ms (6.8sec), see Figure 7 for vibration monitoring results from 0 ms to 5100 ms where every delay is recognizable. The monitoring results indicate that the electronic detonators are extremely accurate and blast went as expected. Indeed, CMS scan after mucking showed that the ore was broken almost exactly to the designed limits – see the CMS line before DSB (destress slot blast) in Figure 4.

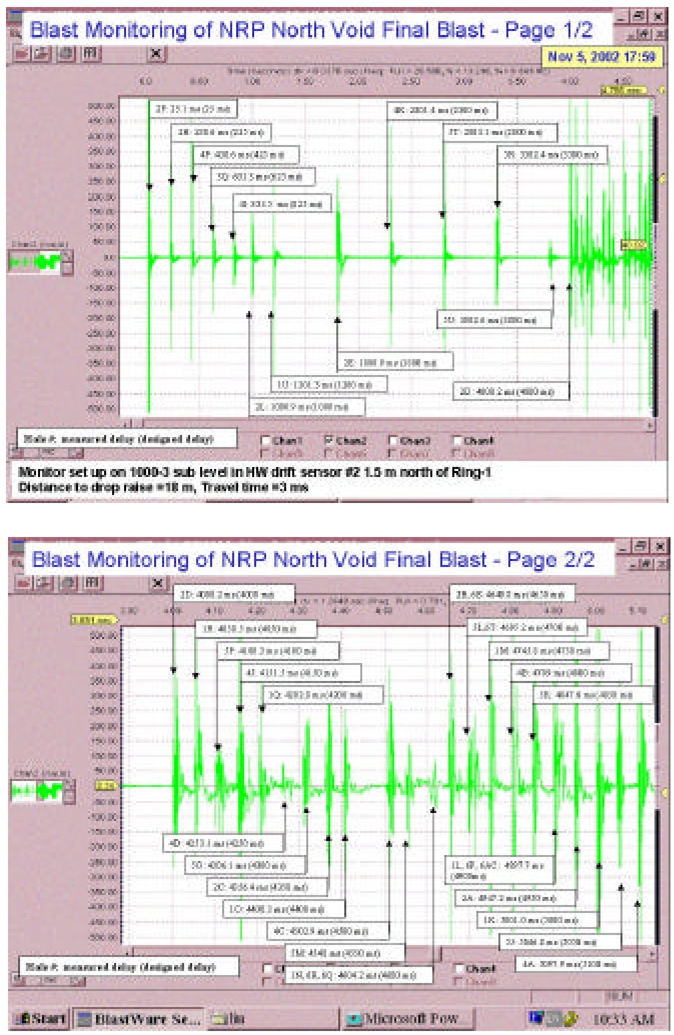

Figure 7. Vibration monitoring results of North Void final blast (top for 0 – 4000 ms, bottom for 4000 – 5100 ms).

In order to provide a safe working environment after the blast on 2-sub and 3-sub, shotcrete arch-and-pillars were erected after having loaded the blastholes. Figure 8 shows the pictures of the shoctcrete pillars on 3-sub before and after the final North Void blast. The blastholes for the final mass blast must also be protected. This is why the shotcrete pillar are on located on the H/W (right) side.

Figure 8. Shotcrete arch and pillars before (left) and after (right) the North Void final blast.

After the North Void final blast, a mucking procedure was followed. Due to the caving of cemented rock fill on 1-sub, the muck was kept in the stope to support the side-wall on the north. However, the high grade ore can be oxidized if the muck pile stayed still for over one week. Therefore, mucking was slow but continuous after the blast and intensive mucking only started after all the drilling of the final mass blast was completed.

3. THE SOUTH VOID

The South Void was designed to provide 20,700 m^3 void. The volume of ore to fill it from the final mass blast is estimated about 20,300 m^3. The South Void is measured 16m X 18m on plan view and 86 m high covering from 1-sub to the sill above 3-sub. Similar to the North Void, the lower section between 1-sub and 2-sub was blasted out first, followed by the upper section from 3-sub. Figure 9, 10 and 11 show the shape and dimensions of the South Void for side-view, plan view on 2-sub and plan view on 3-sub respectively.

South Void from 1 to 2 sub:
A total of 4 blasts were required for the 39,000 tonnes of ore. All those blasts were fired using regular shock-tube detonators (LP's). Due to the high stress levels, hole cleaning with a drill was required after every blast for some holes. The final blast had to be revised two times because of holes being plugged. After the final blast, the top did not break to the floor on 2-sub. Back analysis concluded that some holes were not loaded with proper collar of explosives. The small unbroken bench was later blasted by holes drilled from the access on north side. CMS scan after the small blast indicated that the overall volume of the South Void was achieved.

South Void from 2 to 3 sub and sill pillar:
Due to the stressed ground conditions, it was preferable to take as less blasts as possible in order to maintain the safe access on the 3-sub. After careful design, only two blasts were carried out to complete the upper section of the South Void. The slot raise with a 42-inch borehole was openned up in just one blast to bring up 80ft using regular shock-tube detonators (LP's). After the first blast, the floor was lifted around the drop raise on 3 sub due to 2 ft - 3 ft of cuttings on the floor and 5 blastholes had to be cleaned with a drill.

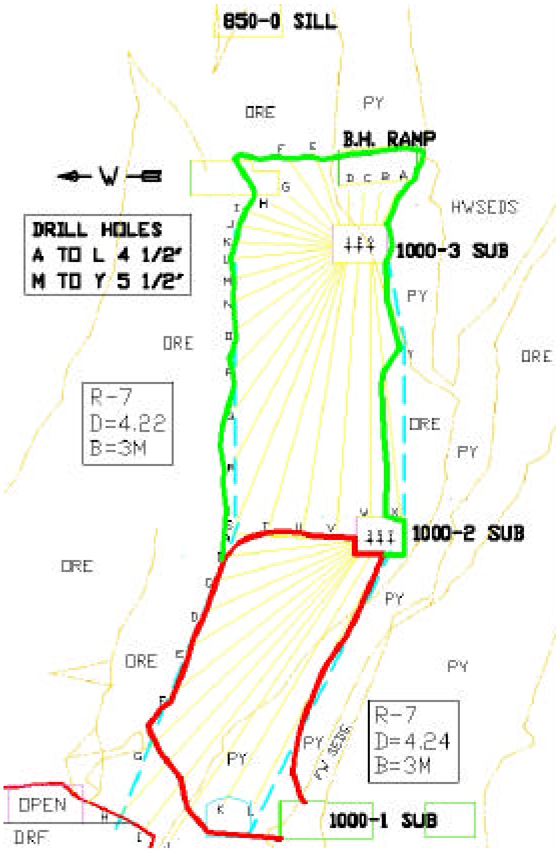

Figure 9. Side-View of North Void, looking north.

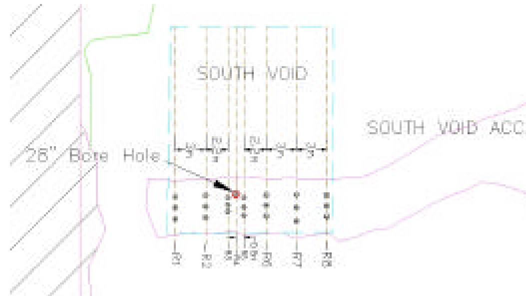

Figure 10. South Void Plan View on 2-sub.

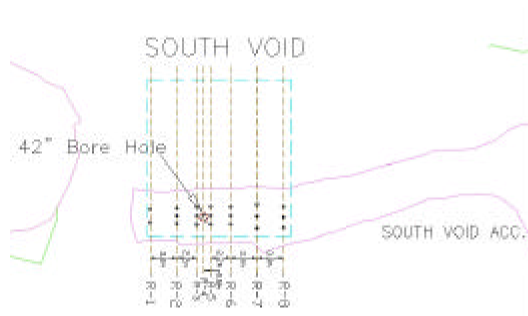

Figure 11. South Void Plan View on 3-sub.

The South Void final blast was also initiated with I-kon detonators for the similar reasons as the North Void final blast. Again, slow initiation was required for the drop raise area on the 3-sub. Once the opening is enlarged big enough, initiation was speeding up to take regular ring holes. It should be noted that there is no inverse drop raise for the up-holes. Instead, the ring holes are fanned up. Thus initiation sequence was to gradually slash the down-holes, moving up to side-holes and finally the up-holes. In total, 292 I-Kon detonators were consumed in the blast, for a total delay time of 7550ms (7.55 seconds). The CMS survey demonstrated that the blast was successful, see the thick green line on top in Figure 9. However, vibration monitoring results indicate that there were 3 blastholes did not show any vibration traces, likely blown out by nearby blastholes. Nevertheless, subsequent blastholes were all initiated well as indicated by the vibration monitoring.

The South Void final blast was fired on November 16, 2002. It was actually ready on November 15. The regular blasting line from surface to the station on 850 m Level had a current leakage on the I-kon Blaster and the blast had to be delayed to the next day. Following this incident, it was decided to investigate the possibility of using communication wires which were installed for the underground seismic system. The direct line would insure a much cleaner and more direct communication between the I-kon Blaster on surface and the Loggers underground.

In order to protect the drift back at the boundary with the South Void on 3-sub, a shotcrete arch was installed at the access before the South Void was blasted. Figure 12 shows the shotcrete arch between the South Void final blast that was already connected with I-kon detonators and the collar of blastholes for the final destress mass blast. To maintain the access to these blastholes, each hole was plugged with a "balloon" that is inflated by compressed air and then stuffed with burlap. At the boundary with the South Void on 2-sub, a shotcrete wall was erected to protect the blastholes of the final mass blast, see Figure 13.

Figure 12. Shotcrete arch on 3-sub at the boundary with the South Void.

Figure 13. Shotcrete wall on 2-sub to protect the blastholes.

For the muck from the South Void, the plan was to keep the muck to fill #19 ore-pass just before the final mass blast. By early January 2003, there were still over 25,000 t of muck to be taken out and the muck-pile already became hard to muck due to sulphide oxidation, although there was not yet any SO_2 emission. To avoid further development of a steep muck-pile, it was decided to clean out the muck before the start of loading the final mass.

4. The Trench

The trench is located just below the destress mass blast, see Figure 3, and it was developed before the North Void and South Void. This excavation has two purposes:

- It diverts the stress below 1-sub to protect of the access drifts going to the main ore-body on the west.
- It serves as addition void for the final destress mass blast.

In the calculation of voids, North Void and South Void are supposed to provide enough volume for the final mass blast. However, the final mass blast is a very narrow and long slot. Muck movement speeds are greatly reduced due to wall frictions and premature settlement of muck on the foot-wall. Therefore, muck pile accumulation starts earlier and progresses faster than a normal bench blast. The void volume in front of the free-face keeps reducing as the mass blast progresses from the edge to the centre. At a certain point the dynamic void can be reduced to zero and the blast "freezes". This phenomenon may happen on 1-sub where the mucking level is located with solid floor. To avoid the potential freeze of the mass blast, it is preferable to have additional voids below the mass blast. This is the main purpose of the trench from a blasting standpoint.

However the trench contains mainly low grade ore that has hardly any economic value. For the amount of extra work, the excavation is the smaller the better. From risk management point of view, on the other hand, the void is the bigger the better. The theoretical depth of the trench should be about 11 m below 1-sub to provide the required void. Stress modelling showed that a 15 m trench would be sufficient to reduce the level of stress in the access drift on the west of the destress slot. Therefore it was decided to develop a roughly V-shape of trench: 50 m long on 1-sub, 16 m long on the sill and only 5 m width. After the final blast of the Trench, the control of mucking on the 1000 m Sill level produced a trench of about 11 m deep over 25 m long and 15 m deep just below the access drift, see Figure 14 for the plan view on 1-sub and Figure 15 for the longitudinal.

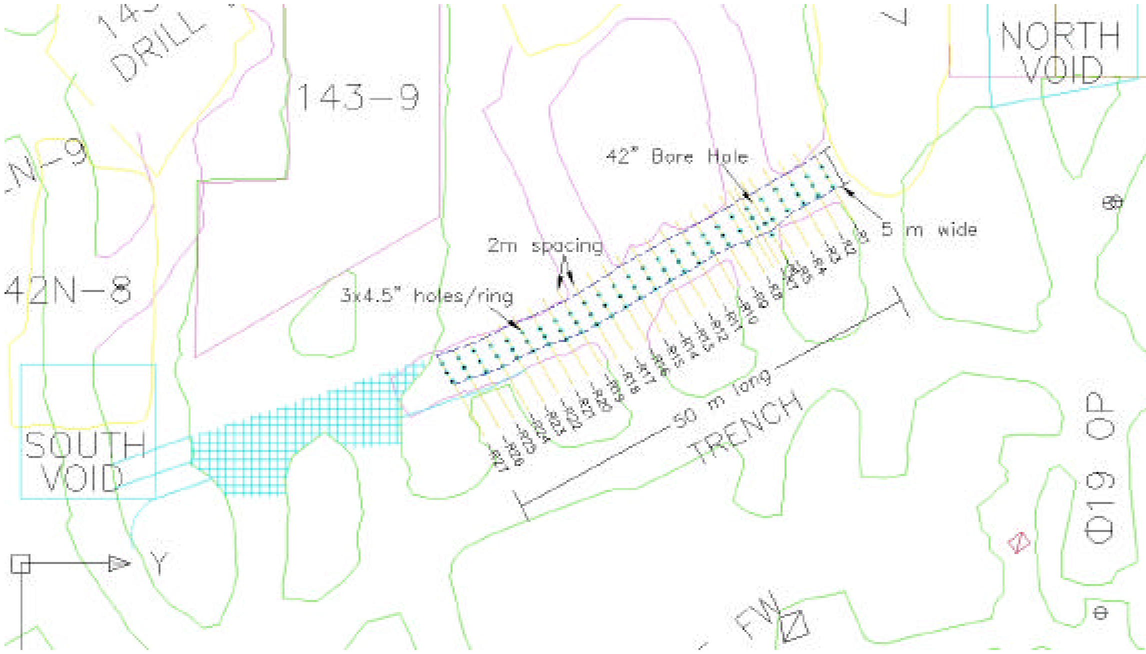

Figure 14. Plan view of the trench on 1-sub.

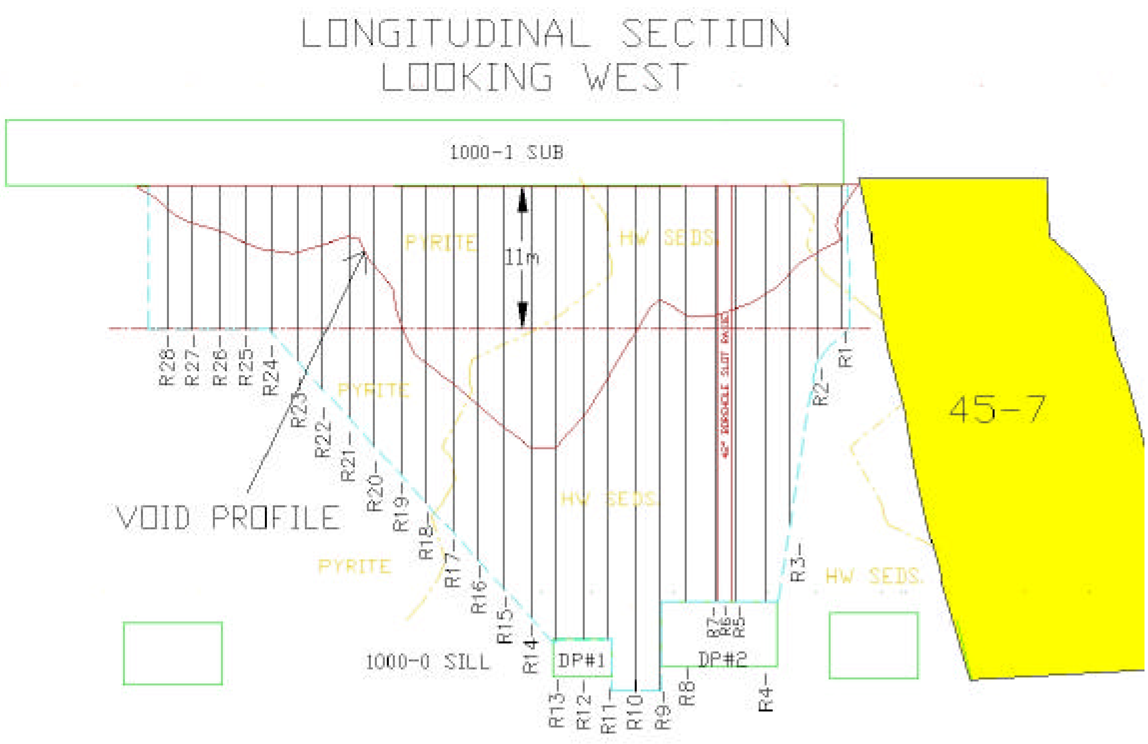

Figure 15. The trench blasthole rings and the final contour.

5. THE FINAL DESTRESS MASS BLAST

To a large extend, the NRP destress mass blast adopted the key blasting parameters from the WOZ mass blast: The blastholes are maintained at 5.5-inch diameter, with a pattern of 2 m burden and 2.5 m spacing and the firing speed is kept at 100 ms per ring. The final mass blast was divided into 4 sections, see Figure 16:

- Destress North 2 – 1 sub
- Destress North 3 – 2 sub
- Destress South 2 – 1 sub, and
- Destress South 3 – 2 sub.

Each section has its own free face towards the voids, see Figure 16. In principle, the lower section (e.g. Destress North 2-1 sub) should be fired before the upper section (e.g. Destress North 3-2 sub), and on the 3-sub the down-holes should be fired before the up-holes in order to best utilize the voids.

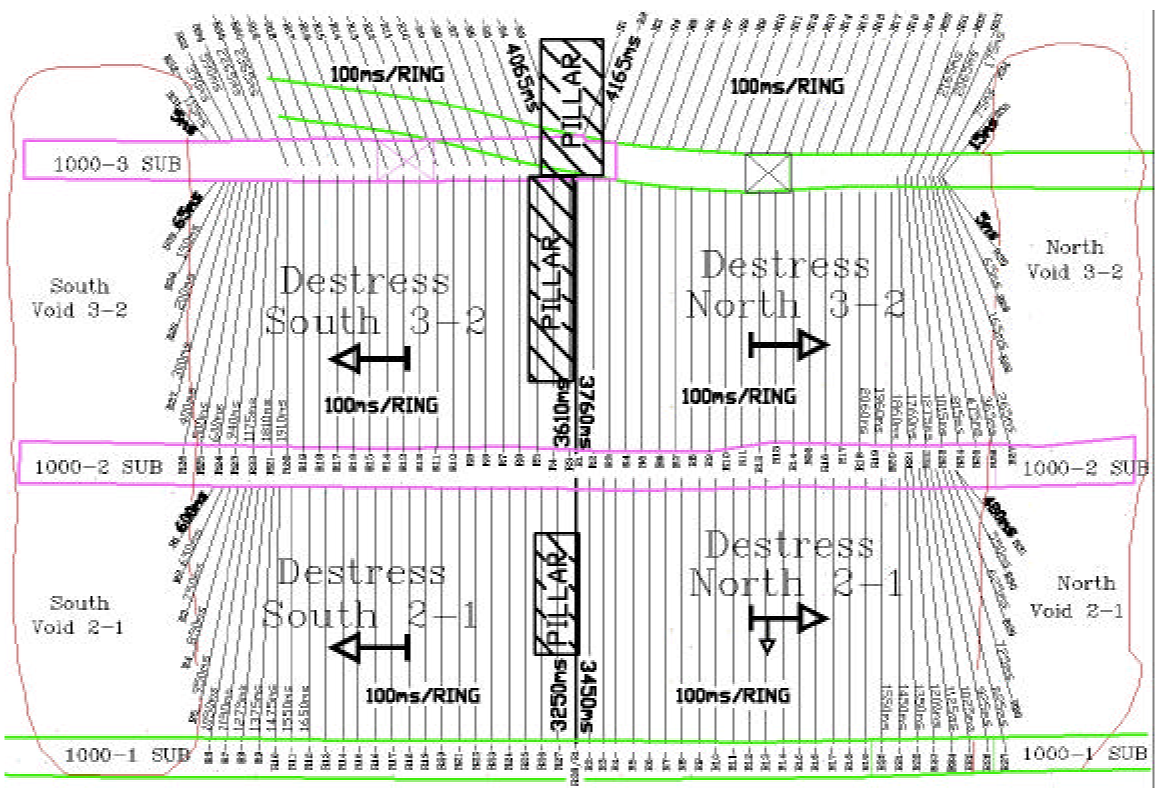

Figure 16. Longitudinal of NRP destress mass blast.

The crushing pillars

The pillars in the middle of the NRP mass blast zone are designed to reduce the hydraulic radius of the H/W of the blasted void. With an area of 140 m long by 86 m high after the mass blast, the H/W, although in ore, will inevitably fall down. The H/W inclination is about 70-degrees on the north side and almost vertical on the south side. The pillar in the middle reduces the length by half along the strike. Thus the level of potential caving is reduced or delayed. The pillar can not be too big to carry or transmit stresses, nor it can be too small to be ineffective in supporting the H/W. Pillar width/thickness ratio should be around 1.0 to make it crushed by stress but still maintained in place to hold up the H/W. The width of the pillar was designed for 6 m. The location of the pillars is roughly in the middle. But due to the fact that the trench void is located slightly towards the north side, the pillars should be left slightly towards the south from the center line. It should be noted that the pillars were cut out for 8 m to 10 m above the 2-sub and 3-sub. The reason is to avoid stress concentrations in the haulage drift and its intersection with draw-points on the F/W side. Indeed, after the destress mass blast, high intensity of seismic activities have been observed in the pillars for about 2 weeks, indicating that the stress was working on the pillars to crush them. The F/W access drifts were safe for mucking.

Firing sequence:

Based on the experience from the WOZ and blast simulation work with Orica (Liu, Ellis and Chung, 2003), the firing sequence is roughly as following:

- Firing speed is 100 ms/ring: center to center between rings;
- In each ring, the center hole is fired first, followed by the HW hole 25 ms later and the FW hole 50 ms later; FW hole should be fired last in each ring to achieve a better lifting effect.
- In general, the firing fronts across the 3 sub-levels should have a V-shape: North side and South side firing simultaneously; 2 –1 sub should have 2 rings fired in advance of the 3 – 2 sub; and 3 – 2 sub should have 4 rings in advance of the uppers above 3-sub.
- Due to the fanned rings on 3-sub and 2-sub towards the voids, the front holes on 3-sub had to be fired first in order to have a desired V-shape firing front in respect to the 2-sub. This is why the whole mass blast starts on the 3-sub with 5 ms and 480 ms on the 2-sub on the North. Similarly, a delay of 600 ms was given on the South side on the 2-sub, see Figure 16 for the firing sequence.
- The 2-sub finishes at 3450 ms, 3-sub at 3760 ms and the uppers at 4165 ms.

The use of i-kon electronic detonators:

For the NRP destress mass blast, the I-kon detonators were fired from a dedicated line taken from the mine-wide seismic monitoring system. The issue of using a seismic-sensor line as a firing line for the I-kon electronic detonators was thoroughly discussed with the safety and mine department. After running tests on the line with “dummy” detonators and minor modifications to the blasting room on surface everything was approved. Firing with the seismic-sensor communication wires was successfully tested in a real situation on January 6th, 2003 with the stope 3/493-2/3 where90,000 tonnes were blasted in 8 seconds.

In the NRP destress mass blast, a total 1,558 units of I-kon detonators were consumed together with 210,400 kg of emulsion explosive for the 202,209 tonnes of ore. The number of I-kon detonators used in this blast is close to the maximum capacity of 1,600 with the I-kon system. There were 8 loggers being placed on the 2-sub access drift, about 150 m away from the mass blast. There were 2 holes drilled from 3-sub to 2-sub to pass the blasting wires through. From the loggers on 2-sub to the surface blasting room, the seismic-sensor line provide a clear and no-leakage communication and the blast was successfully initiated at 17:50 on February 7, 2003.

Blast Monitoring:

There were 15 high-frequency OYO geophones installed on 3-sub and 2-sub on the foot-wall side of the NRP mass blast. Four blast monitors were used. Figure 17 shows the location of geophones and blast monitors on 2-sub and 3-sub. The 15 sensors covered the whole blast area, from north to south and from 2-sub to 3-sub. To analyze the vibration traces, one need to look into a specific channel for a certain blasting areas. Figure 18 shows the typical vibration traces: one from each of the blasting quadrants. Note that the whole blast lasted 4165 ms and the long-holes (>15 m) were all gone by 3760 ms. In general, the blast went very well. All the detonators seemed to have functioned as planned.

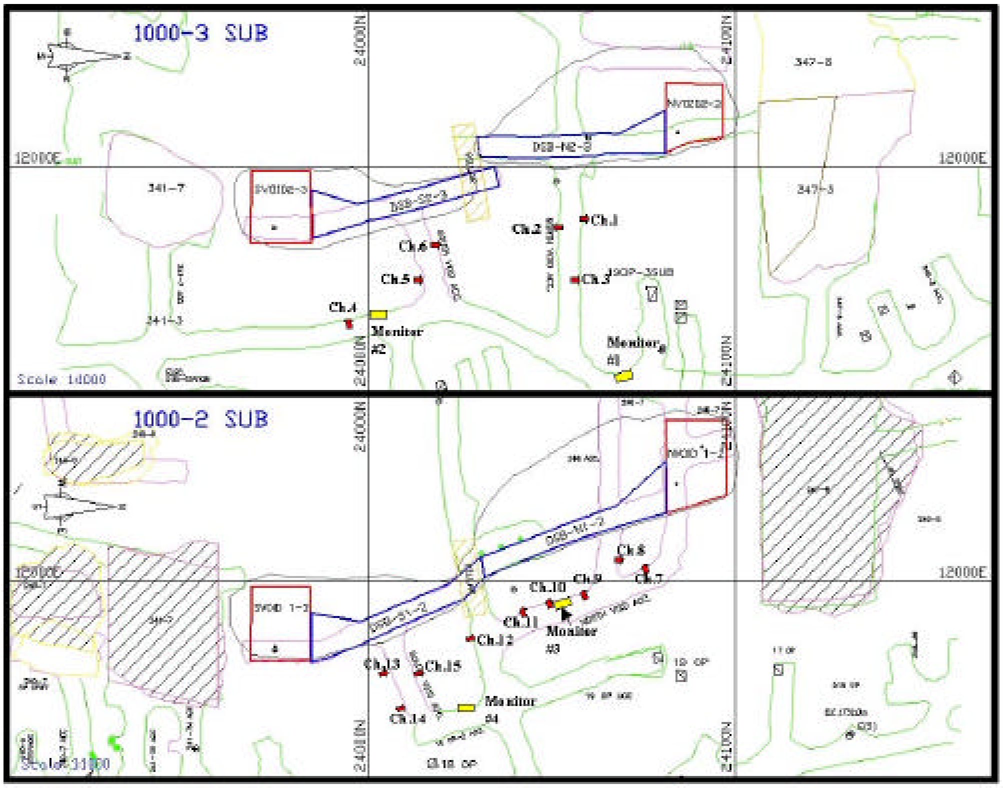

Figure 17: The location geophones and blast monitors

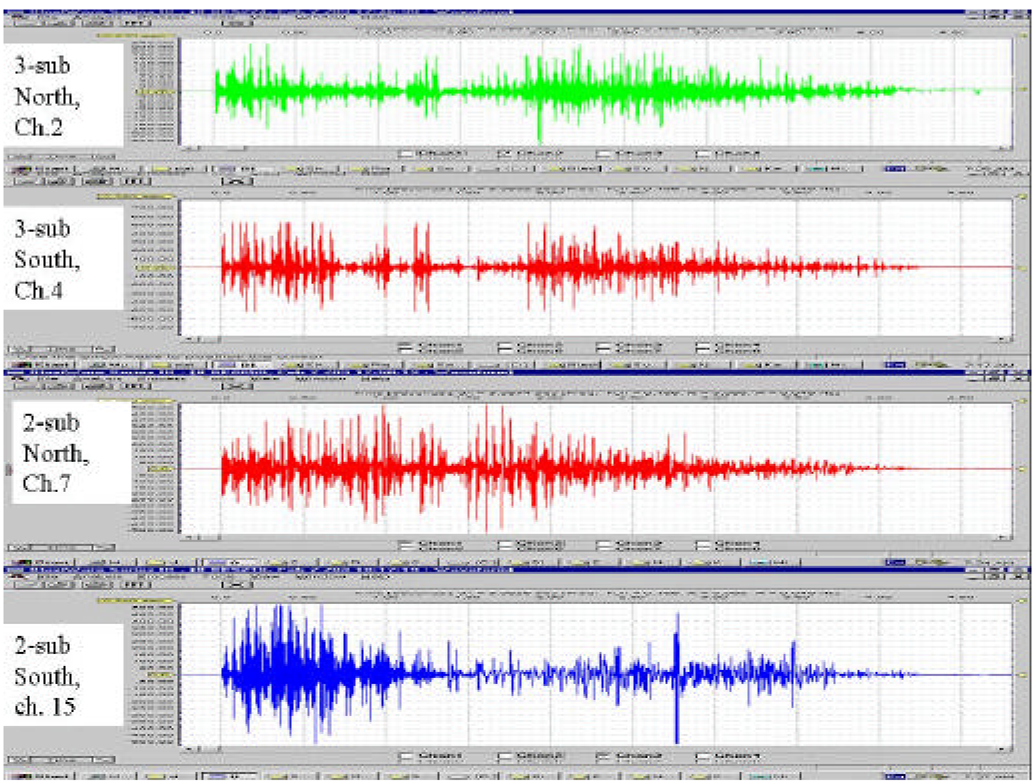

Figure 18. Some typical blast vibration traces.

6. MUCKING STRATEGY

Geological information indicated that there were some pyrrhotite veins in the NRP mass blast zone. Geological department made some contours for several veins. Based on Brunswick experience with the reactive sulphide material, the muck should be taken out as soon as possible to avoid caking and steep muck pile build-up, and in the worst scenario, SO_2 emissions. It was, therefore, necessary to understand where the pyrrhotite contents are located in the muck pile after blast so that a mucking strategy can be established. Part of the blast simulation with Orica's DMC_Blast simulation (Chung, Liu and Preece, 2003) was to locate the pyrrhotite areas in the muck pile.

With the crushing pillars in the middle of the mass blast zone, the south side and north side can be treated separately. The procedure of analyzing the muck location is to build grids in the blasting blocks for simulation, and then superimpose the pyrrhotite contours in the grids to locate the pyrrhotite in the muck pile. Figure 19 shows the procedure of locating the grid of ore before and after blasting. For the same simulation, two outputs were made: one with vertical layers and another with horizontal layers. The grid is matched with the contour of pyrrhotite before the blast, and then following the same contour on the grid after the blast to track down the pyrrhotite. Figure 20 shows the final contour of pyrrhotite in NRP mass blast zone in respect to different draw-points.

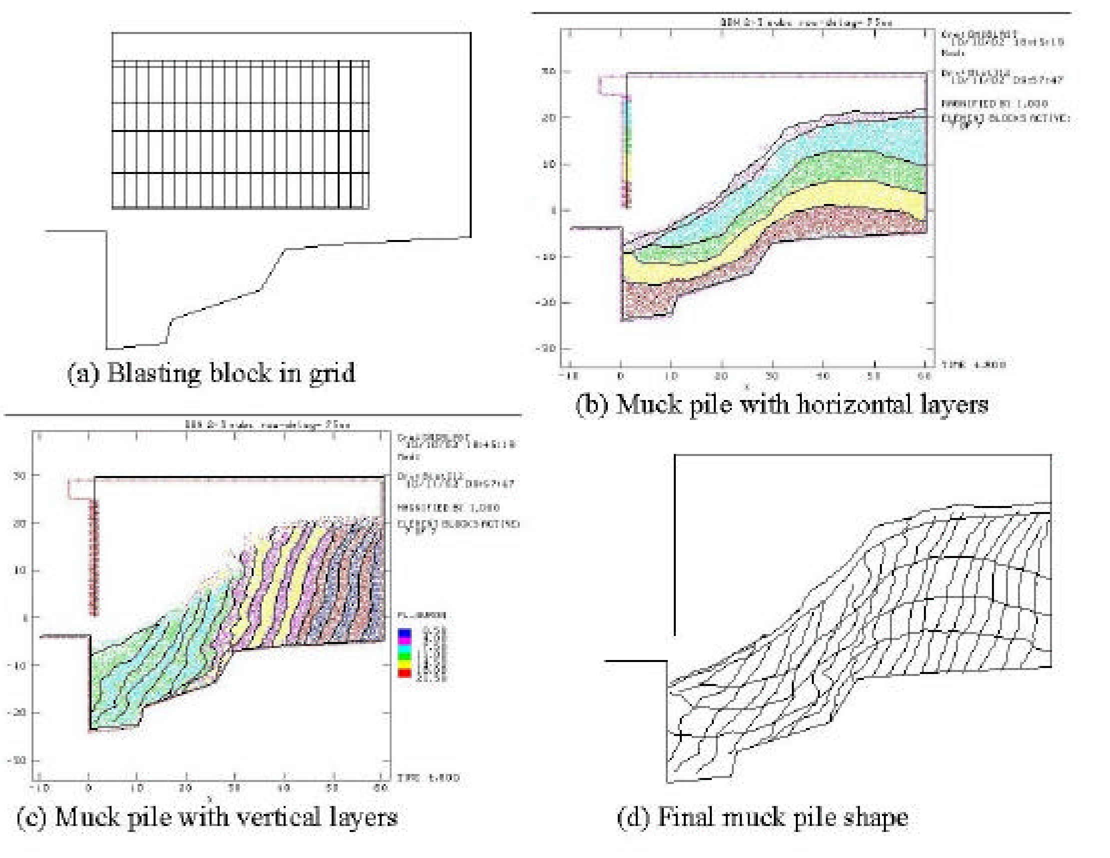

Figure 19. The procedure of locating ore grid before and after blasting.

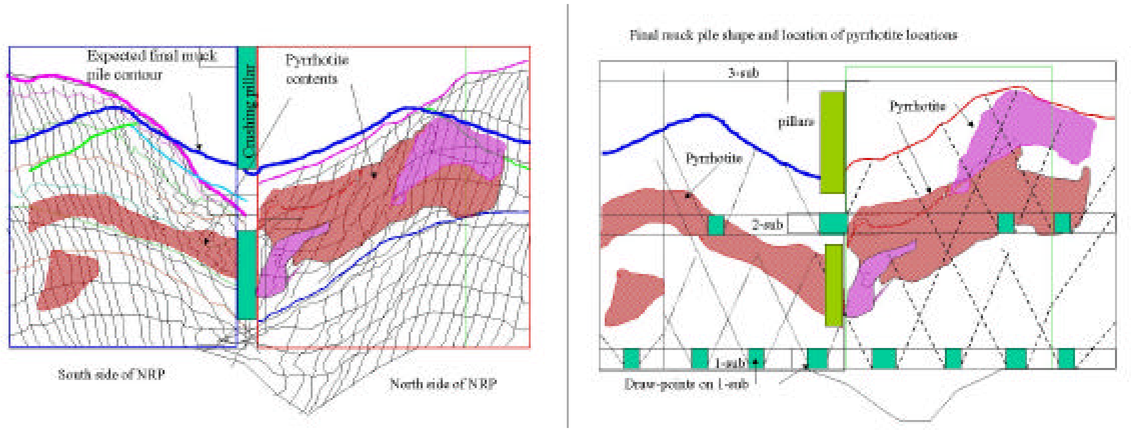

Figure 20. The final contour of pyrrhotite in the muck-pile after the final mass blast: Left: with ore grid; Right: with draw-points.

Mucking started immediately after the final destress mass blast on 1-sub from both north side and south side. Throughout the mucking process, there were signs of heating and no SO_2 gas was detected, which indicates that the mucking strategy worked well in controlling the pyrrhotite self-heating process. However, after a couple of weeks of mucking, both south void and north void draw-points reported some big boulders which were not supposed to be from the mass blast. Fortunately, the muck was all ore in spite of big boulders. It was not until CMS scans were conducted on 3-sub when serious caving was confirmed happening on the H/W side. By the time mucking was completed in early September 2003, a total of 437,000 of ore was mucked out, while the original designed tonnage of the mass blast was only 202,000 tonnes.

Figure 21 shows the typical rings of the mass blast: for the South, Middle and North respectively. It shows that the middle with pillar had less caving from the H/W, indicating that pillars functioned well in supporting the H/W

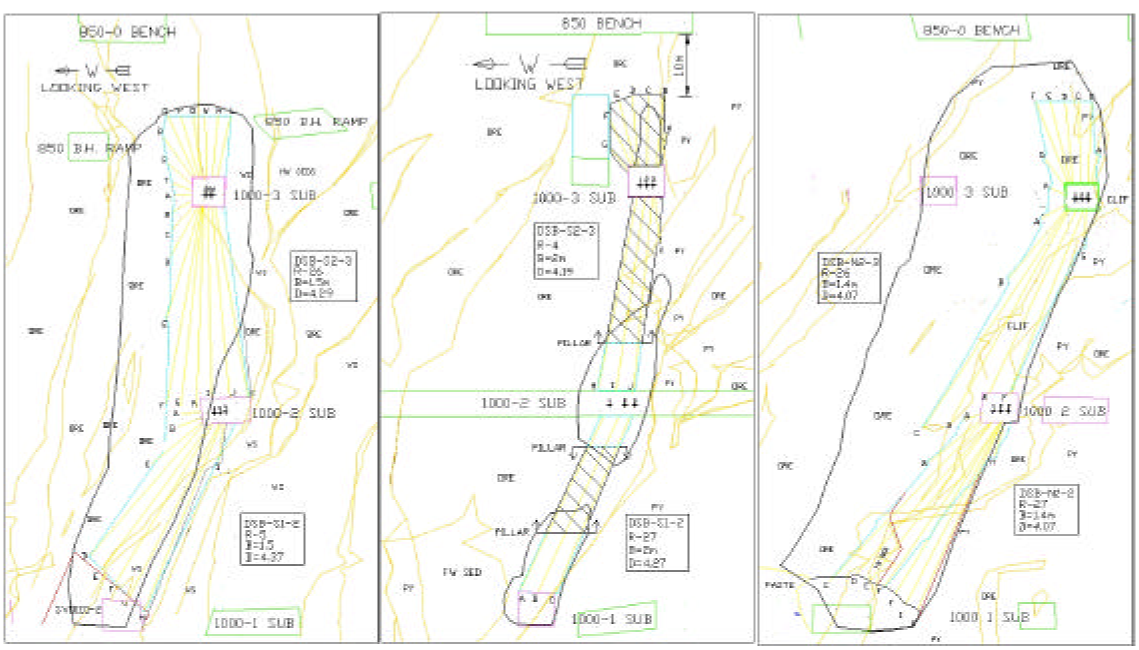

Figure 21. Final contour of the mass blast zone: from left to right: South, Middle and North.

7. CONCLUSIONS

The NRP destress mass blast is the second one of its kind at Brunswick Mine to deal with highly stressed regional pillars, the first one the west ore zone completed in July 2001. The objective of destressing the NRP was achieved following the blast. The engineering of the project was well planned in respect to different aspects from geomechanics to drilling and blasting and to mucking strategy. The schedule of the project has reasonably followed the plan with some production-related delays. The H/W caving however was greater than expected. Nevertheless, it was all ore that was mucked out, more than double of the planned tonnage from the mass blast. Paste backfill started in September when the stopes were all clean of muck. The following dates mark the progress of the NRP mass blast project:

- February 10 ,2002 Mined out the H/W stope 45S-9 and backfill:
- April 15, 2002 Mined out 42N-8/9 stope below South Void:
- July 15, 2002 Blasted 1000-1 sub trench
- August 3, 2002 Blasted North Void on 2-sub:
- August 20, 2003 Blasted South void on 2 sub
- November 5, 2002 Blasted North void on 3 sub
- November 15, 2002 Blasted South void on 3 sub
- February 7, 2003 Initiated the Final Mass Blast
- September 10, 2003 Mucking completed and paste-fill started.

The NRP destress mass blast proved again that large-scale mass blasting can be used as an effective way of releasing major pillars from stress concentrations. This technique is particularly important towards the end of mine-life when regional pillars or crown pillars must be extracted. These mass blast case histories did not only cut off the stresses but also produced a source of ore that provided some direct return on the investment.

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