

Measuring Blast Movement to Reduce Ore Loss And Dilution

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Abstract

Blasting causes movement of the rock and can be detrimental to the accurate delineation of the ore and waste regions within the resulting muck pile. The consequences can be ore loss and dilution. However, ore loss and dilution can be minimized and significant increases in profit can be realized if the movement can be accurately measured.

Various methods have been used to measure muck pile movement including poly-pipe, chain and sandbags but these have been either inaccurate or impractical. The Julius Kruttschnitt Mineral Research Centre, JKMRC, has developed an electronic blast movement monitor that provides accurate three-dimensional movement vectors following a production blast. From this information, the ore block boundaries in the blasted bench can be adjusted to compensate for the measured movement and then ore recovery can be optimised. Following initial development of the prototype technology, the JKMRC further developed and demonstrated the system in actual production blasts at an open pit gold mine operated by Placer Dome Inc.

This paper presents the movement detection technology, its use in production blasting and the results from field trials. The primary results are summarized below:

- Horizontal movements:
 - Average of 4.7 m (15 ft.) in top flitch (from 46 transmitters)
 - Average of 9.4 m (30 ft.) in bottom flitch (from 22 transmitters)
 - Up to 15.4 m (50 ft.) maximum movement.
- Gathered sufficient information to provide geologists with movement templates, or guidelines, for similar future blasting.
- Total potential costs estimated from the eight monitored blasts:
 - Gold loss: greater than USD 1.5 million.
 - Dilution (processing waste): about USD 0.5 million.
 - Ore loss costs about three times more than dilution.

Introduction

Open-pit metal mines typically mine deposits that are highly heterogeneous with the ore disseminated in pockets of varying grade. An economic cut-off grade is determined for each operation and any material with less mineralisation is designated as waste. A geological model is developed and provides a three-dimensional map of the ore and waste regions. The ore is excavated and hauled to the concentrator while the waste is transported to a suitable dumping location.

Blasting of these blocks is necessary to fragment and loosen the rock mass and provide efficient excavation. However, blasting also causes movement of the rock and this is detrimental to the accurate delineation of the ore and waste regions within the resulting muck pile. The consequences can be ore loss (the ore moves to a region marked as waste and is discarded) and dilution (waste is wrongly categorized as ore and sent to the concentrator). On the other hand, if the movement can be accurately measured, the ore loss and dilution can be minimized and significant savings can be realized. Provided movement within the muckpile can be measured and/or predicted, ore loss and dilution due to blast movement can be controlled. Then, significant increases in profit can be realized. This is particularly important for deposits where the ore has high value and where narrow ore veins are being mined such as in gold operations.

This paper presents a revolutionary new system that can provide accurate three-dimensional movement vectors within about an hour of a blast. From this information, the ore block boundaries can be adjusted to account for the measured movement and then excavation can be optimised. It is also an excellent tool for understanding how blasted rock volumes move in three-dimensional space.

The benefit of the system is to accurately perform post-blast translation of ore blocks, minimising ore loss and dilution. Reduced ore loss results in increased revenue for the same operating cost. Figure 1 shows the value (in Australian dollars) of gold lost for various combinations of movement and grade (50 m (160 ft.) wide ore block; 5 m (16 ft.) high flitch). For example, if there is a 6 m (20 ft.) error between the marked position and the actual location of the ore on a bench, and:

- the block is 4 g/t (0.13 opt), about AUD 300,000 (USD 200,000) is lost;
- the ore grade is 8 g/t (0.26 opt), the loss is over AUD 500,000 (USD 350,000).
- missing the ore boundary by just 1 m (3.3 ft.) could result in up to AUD 100,000 (USD 70,000) lost gold.

State of the Art

A range of different techniques has been used to measure muck pile movement but they have demonstrated mixed success. The methods range from an assortment of passive markers (such as sand bags, chain and poly-pipe) to expensive electronic sensors, but all of these systems suffer from either insufficient accuracy or poor practicality. A common technique used in the Australian gold industry is to drill additional holes within a blast area and insert long lengths of poly-pipe. The blast is then excavated in horizontal layers referred to as “flitches” and the location of the poly-pipes can be monitored in relation to ore locations. The use of passive markers is typically not published in the open literature, but rather is done in an *ad hoc* manner by individuals as required.

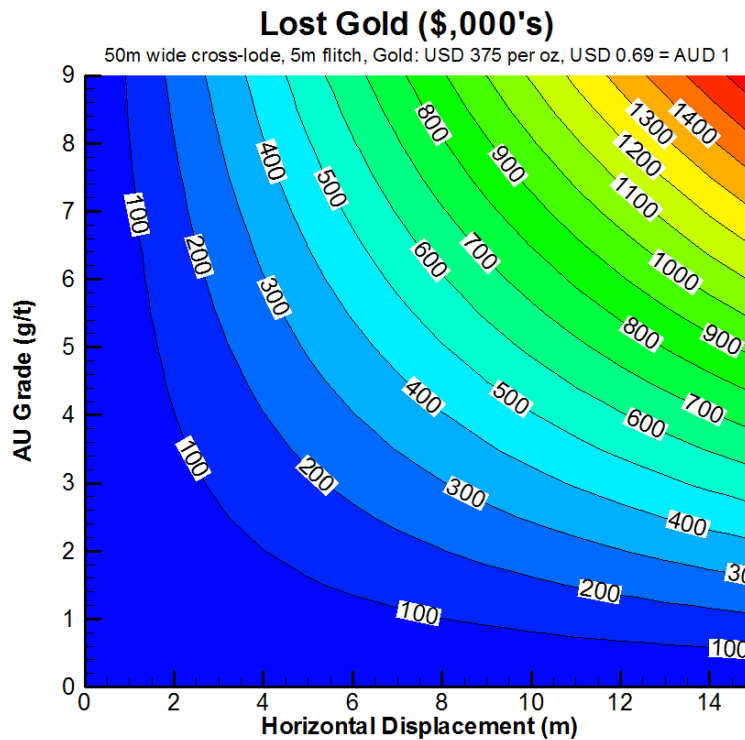


Figure 1 - Contour plot of the value of lost gold (in Australian dollars) for various grade and movement combinations

Gilbride *et al.* (1995) and Taylor (1995) report that the issue of ore dilution due to blast-induced muckpile movement was first examined in 1992 and 1993. Their study demonstrated that theoretical blast-induced ore dilution ranges from less than 10% to almost 100% by weight, depending upon several factors including blast design, free face conditions, rock mass properties and the geological environment and geometry. Gilbride and Taylor also tested and compared two measurement methods at three mines in Nevada. These tests concentrated on the use of *marker bags* (17 blasts) that were surveyed as the shovel uncovered them but the detection of magnetic targets with a *magnetic gradiometer* was also tried. The marker bags were simple, inexpensive and accurate, however typically less than 50% of the bags were located (30% for lower bags) and it took several days before all of the bags were uncovered. The measured three-dimensional movement ranged from 3 m to 7.7 m (10 to 25 ft.). The magnetic gradiometer trial sought to determine overall potential of the technique. The targets were detected at reasonable depths but the disadvantages included:

- Restricted to operations not susceptible to equipment damage from the metallic targets (eg. crusher jamming) or interference with the metals extraction process.
- The target locations are interpreted and in practice may not be visually verified.
- Unlike marker bags, only one magnetic target may be placed in each hole.

Adequate horizontal distance between markers is required to avoid interference. The early magnetic gradiometer research by Gilbride *et al.* was evidently continued and Harris *et al.* (1999 and 2001) report on a system using a caesium vapour gradiometer and a GPS receiver to locate the pre- and post-blast positions of magnet targets distributed through a blast. They report that horizontal rock movement can be measured with an accuracy of ± 1 m (3.3 ft.) and vertical movement to an accuracy of ± 1.2 m (4 ft.), to a depth of 15 m (50 ft.) below the surface.

Description of Blast Movement Monitoring System

The system consists of a 150 mm (6 inch) diameter plastic transmitter located in a dedicated hole within the blast pattern (Figure 2). For the trials presented here, the units were typically located midway between blast holes, about 3 m (10 ft.) from the nearest blast hole, but have been located as close as 1.4 m (4.6 ft.). Typically, 10 to 15 transmitters were deployed in each blast within two hours of blasting (Figure 3). The initial position of the transmitter is determined from the surveyed location of the hole collar and the measured depth. Immediately after the blast, each transmitter is located using a specially developed detector (Figure 4). The location directly above the transmitter, on the surface of the muckpile, is determined directly (i.e. requires no data processing) while the depth is determined from a site signal attenuation calibration. A mark is painted on the muckpile surface at the located position for later surveying using conventional means. Once the initial and final coordinates are known, a calculation is made to determine the horizontal and three-dimensional movement vectors (where the horizontal vector is the projection of the three-dimensional vector onto the x-y plane). Depending upon the availability of mine surveyors, three-dimensional movement vectors for each transmitter can be available within about two hours of blasting.



Figure 2 – Expanded view of plastic “transmitter” ball

To assess the accuracy of the system, several transmitters have been recovered in the field and their positions surveyed. A comparison between the estimated location and the surveyed location provides a measure of the accuracy of the system. The error is estimated to be between ± 0.1 m (0.3 ft.) and ± 0.5 m (1.6 ft.) depending upon the depth (error increases with depth).



Figure 3 - Installation of blast movement monitor (white cylinder at hole collar)



Figure 4 - Locating the transmitters on a freshly blasted muck pile

Methodology

Ore Block Translation

As described above, once the initial and final coordinates are known, it is a simple calculation to determine the horizontal and three-dimensional movement vectors. Determining ore movement vectors is only the first step to reducing ore loss and dilution. The next step is to translate the original location of the ore blocks to their post-blast location. There are two ways of achieving this:

- (A) Use vectors that have been measured for the particular blast and use a distance weighted average (or other suitable method) to determine the movement vector at each vertex of the polygon defining the ore block, or
- (B) Estimate average movement vectors for various regions of the blast from data and experience obtained from similar blasts and then translate the ore block by these vectors (a blast movement template).

Although direct measurements exist for each of the blasts presented in this report, they have not been used for direct ore block translation. The procedure used here was to take the average measured direction for the blast (either side of the V if appropriate) and combine this with the average distance derived from all measurements (within a fitch). This approach was used for the following reasons:

- One of the objectives of the tests was to use the results to provide guidelines (a movement template) for estimating movement vectors, alleviating the necessity to continually monitor future blasts. Therefore, the analysis presented here is equivalent to what mine operations would likely do in the future.
- There is a direct relationship between the movement distance and depth (refer to Figure 8). That is, horizontal movement increases as the depth increases (until at least 7 m (23 ft.)) and it is not valid to use a movement vector from say, 2 m (6.5 ft.) deep to translate the bottom fitch.

Loss and Dilution Defined

Loss occurs when ore is misclassified as waste, for whatever reason, and sent to the waste dump. Similarly, dilution occurs when waste is sent to the processing plant. Figure 5 is a simplified sketch of where loss and dilution occurs when an ore block moves during blasting but is mined from the original location. The large rectangle represents the effective blast boundary and the small circles within the rectangle are the blast holes. The original location of the ore block is depicted by the solid shaded rectangle. A thick arrow indicates the direction of movement, and in this case it is perpendicular to the ore block. The dashed lines represent the location of the ore block after being moved by the blast. Ore loss is the material within the post-blast boundary but not within the pre-blast boundary (diagonal hatching). Dilution is the material within the pre-blast boundary but not within the post-blast boundary (horizontal dashed hatching). In practical terms, if the ore block was marked in its original location and excavated, then the area designated as dilution is actually waste and is sent to the processing plant. Similarly, the area that is designated waste but is actually ore would be mined as waste and dumped.

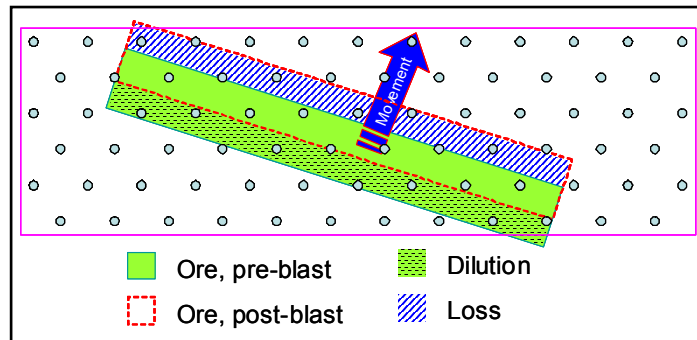


Figure 5 - Illustration of how loss and dilution occurs due to ore block movement

Affect of the Blast Boundary

The rock mass does not move outside the “effective” blast boundary. That is, the blasted material shears away from the boundary. Therefore, if an ore block intersects a blast boundary, then only the portion of the polygon within the blast boundary is translated (Figure 6 (a)). Finally, the loss and dilution regions are marked (Figure 6 (b)). If the ore that moves beyond the blast boundary is still within an ore block, it is not considered to be lost since it is expected that it would be mined with the ore block of the adjacent blast.

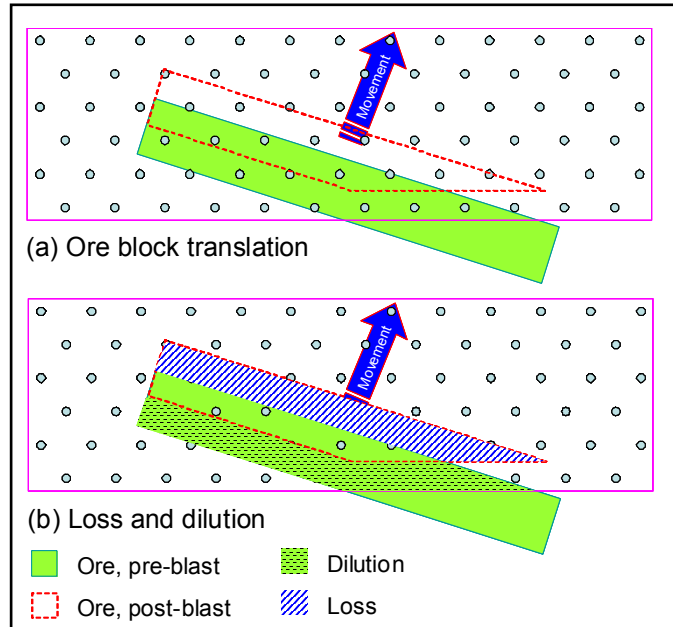


Figure 6 - Movement only occurs within the blast boundary

Fieldwork Results

The following fieldwork results are from an open pit gold mine operated by Placer Dome Inc. The blast pattern parameters at the mine during the study are summarised in Table 1. The powder factor is relatively high at 0.43 kg/t (0.86 lb/ton) but this is due to a dominant cemented conglomerate ore that is traditionally difficult to break. The pattern was tightened in an effort to aid on-going fragmentation problems and is now 5.5 m x 6.5 m (18 ft. x 21 ft.) with 229 mm (9 inch) diameter holes. Also, the sub-drill was increased and the stemming height decreased during the improvement process. Unfortunately, higher powder factors often translate into increased ore movement. The solution of using more explosive energy to improve fragmentation has aggravated the accurate delineation of ore and waste regions within the resulting muck piles at this operation.

Table 1 – Summary of blast pattern

Burden, m (ft.)	5.5 (18)
Spacing, m (ft.)	6.5 (21)
Hole Diameter, mm (in.)	229 (9)
Sub-drill, m (ft.)	1.8 (6)
Stemming Height, m (ft.)	4 (13)
Staggered	Yes
Explosive Length, m (ft.)	7.8 (25)
Explosive Density, S.G.	1.25
Explosive Weight, kg (lbs)	400 (881)
Powder Factor, kg/t (lb/ton)	0.43 (0.86)

Detection of Transmitters

The total number of transmitters installed in 12 blasts was 81, with 68 of these detected (84%). It is suspected that the majority of those “lost” ended up too deep to be detected as evidenced by the greater loss from the bottom flitch (Table 2). This was particularly true for the blasts that were smaller and more confined and resulted in greater heave. Also, a couple of transmitters were probably thrown over the pit edge.

Table 2 – Summary of transmitter detection

	Top Flitch	Bottom Flitch	Total
Number	51	30	81
Detected	46	22	68
Percent	90%	73%	84%

Movement Vectors

The average horizontal movement from the bottom flitch was approximately twice as great as the top flitch, 9.3 m and 4.7 m respectively (Table 3). This is expected since most of the explosive charge is within the bottom flitch and the explosive’s energy, and hence its influence on the surrounding rock mass, reduces very rapidly with increasing distance from it. Figure 7 is a histogram of horizontal movement from all tests separated by top and bottom flitch. Different movement from various regions in the blast (front, back, edge and body) causes the multi-modal nature of the histograms.

Table 3 - Summary of horizontal movement from all “reliable” results

	Horizontal Movement (m)	
	Top Flitch	Bottom Flitch
Mean	4.7	9.3
Maximum	11.7	15.4
Minimum	1.0	4.9

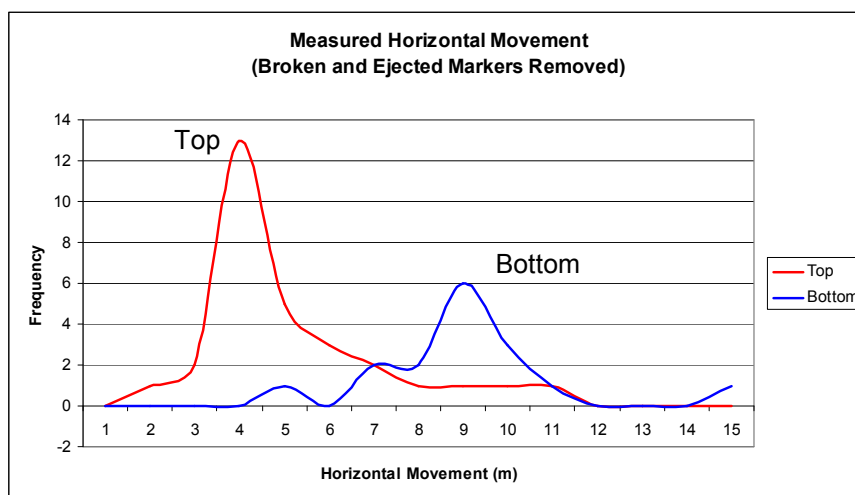


Figure 7 - Histogram of horizontal movement from both flitches

Figure 8 is a graph of horizontal movement plotted against the initial depth of the transmitter. Although there is quite a lot of scatter in this data, there is clearly a direct relationship, with movement increasing with depth. The data has been subdivided into four regions (body, edge, front and back). For example, the pit edge seems to have a significant influence on the movement distance and direction on the top flitch but little influence on the bottom flitch. This is not surprising since the “edge burden” is much greater at the bottom of the bench than at the top. Secondly, near the back row, movement in the bottom flitch is greater than average but less in the top flitch. In fact, the minimum horizontal movement for the entire blast occurs at the back near the surface while the maximum movement occurs deep at the back. This result confirms high-speed video evidence gathered by the researchers from another mine that showed the surface at the back of the blast drop straight down into the power trough.

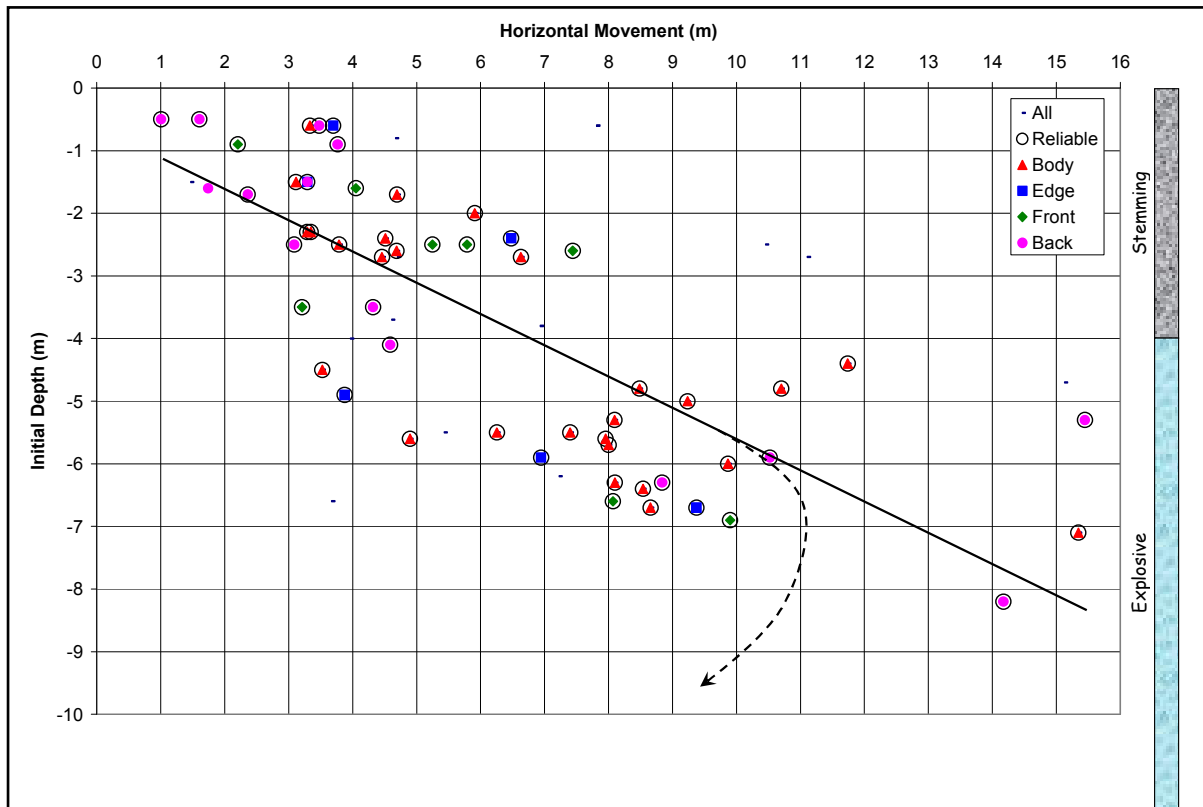


Figure 8 - Graph of horizontal movement versus initial depth

Figure 9 shows the plan of a typical blast pattern where the blast holes are the small circles with the surface delays between them. The initiation timing contours are the wavy lines. Arrows linking the initial and final locations of the blast movement monitors indicate the movement vectors. The direction of movement is typically perpendicular to the local timing contour as expected from blasting theory.

Figure 10 shows the movement of a high-grade ore block within the bottom flitch of one of the monitored blasts (refer to Figure 6 for a complete explanation of the diagram). If the ore will be mined from its original location, approximately 50% of the ore block would be lost or about 1200 oz. There were cases where narrow ore blocks were orientated perpendicular to the direction of movement resulting in potentially complete loss of the ore if it was mined in its original location.

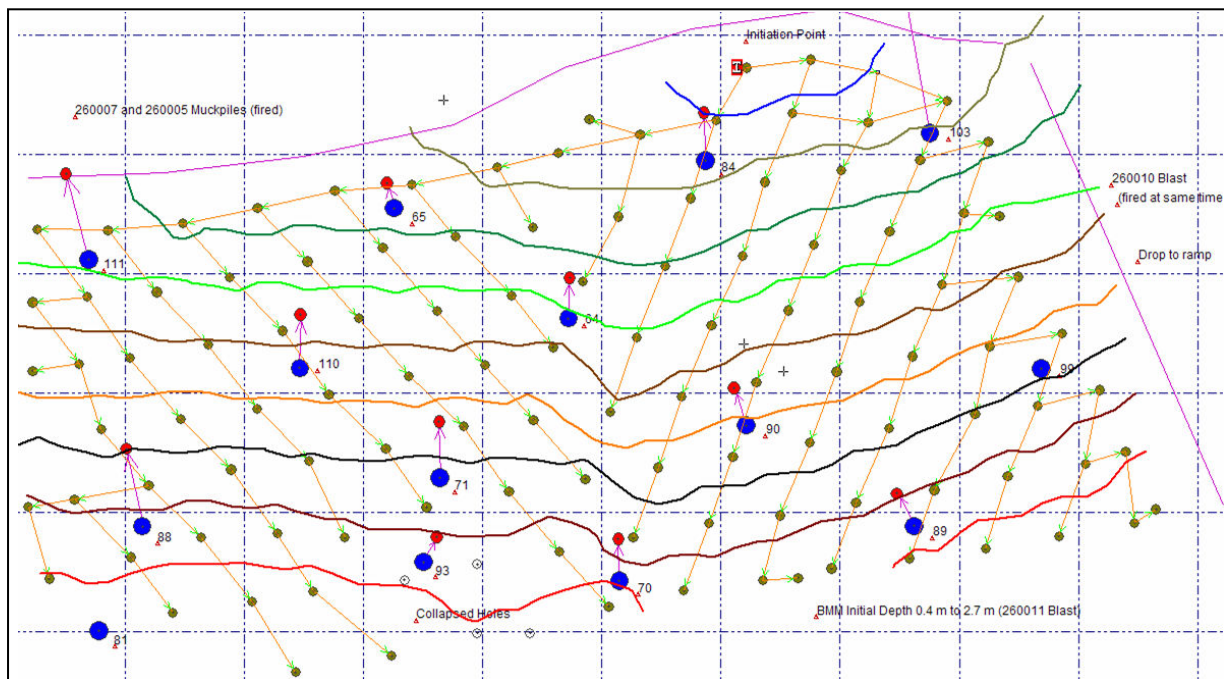


Figure 9 – Plan of blast pattern with timing contours and horizontal movement vectors.

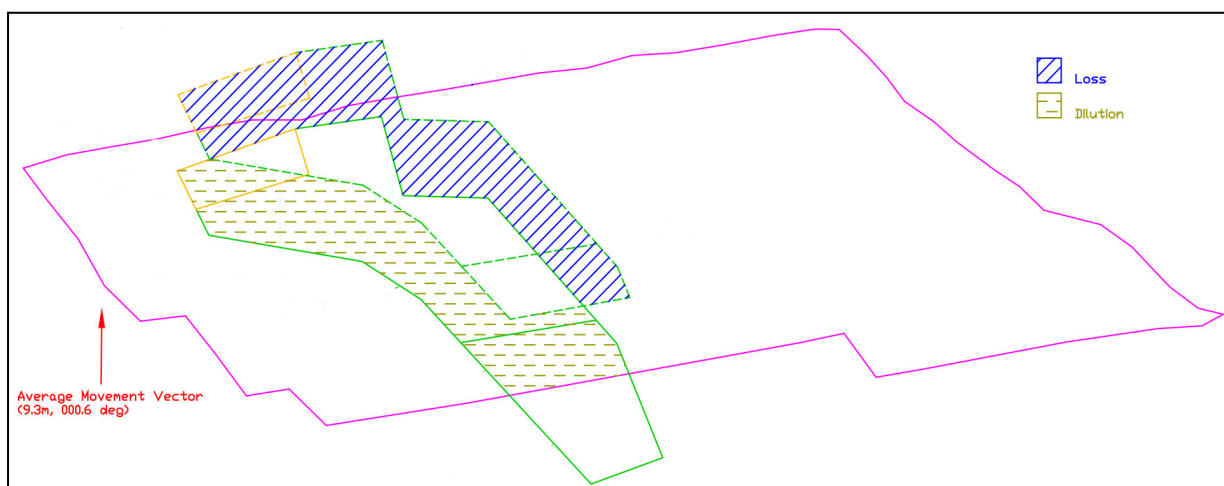


Figure 10 – An actual ore block translation (bottom flitch, potentially 1200 oz of gold lost).

Conclusions

The objective of the fieldwork was to develop a movement template for the current blast pattern to be applied to future similar blasts. The direction of movement was typically perpendicular to the initiation timing contours, confirming what is expected from theory. The average ore movement in the top flitch was 4.7 m (15 ft.) and the average for the bottom flitch was 9.3 m (30 ft.) with the maximum measured horizontal movement of 15.4 m (50 ft.). The ore blocks in the respective flitches were translated by these amounts to estimate the cost of ore loss and dilution for the monitored blasts. The potential value of gold lost from the eight ore blasts monitored was estimated to be above USD 1.5 million while the cost of dilution (processing waste) was about USD 0.5 million. Ore loss costs about three times more than dilution.

The movement through a blast was generally consistent in terms of direction and distance with some exceptions that could usually be explained. The measurements demonstrate that movement distance increases as depth increases (at least to a depth of 7 m (23 ft.)) and is upward, except where a power trough forms and the top of the bench drops down into the void left after the bottom moves forward. There is evidence that the pit edge “attracts” material from the top of the bench but this effect reduces with depth. This is due to the reduced burden at the top of the bench along the edge. The consistency and predictability at which movement was measured is very encouraging and will enable more accurate models in the future.

System Advantages

Compared to existing methods for measuring blast movement, the system described here has the following advantages:

- Low impact to the operation (little interference with blasting operations).
- Availability of results soon after blasting and before excavation commences.
- Accurate three-dimensional movement vectors.
- High survivability and detection rates.
- Relatively low cost (i.e. disposable).

Future Work

Based on the positive results of the new ore movement transmitters, research is continuing in this critical area of blast engineering and ore control. There are certain aspects of the system that have not been fully quantified and there are other improvements that will make the system more practical for routine mine use. Research topics to be investigated will likely include:

- Extending the battery life from eight hours to several months.
- Reducing the diameter of the transmitters to fit in holes less than 100 mm (4 inch) diameter.
- Improving the survival rate of transmitter electronics and case.
- Developing unique identification for each transmitter to permit multiple units per hole.
- Improving transmission through greater than 10 m (33 ft.) of rock.
- Developing models and software to link with ore block modelling packages.

References

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