The Implications of Blast-Induced Movement to Grade Control

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ABSTRACT

The sole reason for a mine to exist is to extract the finite mineral resource. Accurate grade control is critical to the economics of any mine. If grade control is not optimised, then no matter how good the downstream processes are, the full potential of the operation will not be realised. The detailed implementation of grade control varies but typically consists of sampling and assaying to determine the location of the ore zones. A lot of time, money and effort are spent defining the location of the ore as accurately as possible … but then it is blown up! The effect that blasting has on grade control is rarely adequately accounted for when the rock is excavated because there has never been an accurate and practical method for measuring blast movement.

This paper draws on over six years of research into measuring and understanding blast movement, which started at the Julius Kruttschnitt Mineral Research Centre (JKMRC) of the University of Queensland. The research has made a unique contribution to open pit blasting by helping to develop a practical tool for measuring blast movement, which was then used to improve the understanding of three-dimensional blast movement dynamics. However, these achievements would be of largely academic interest without taking the final step of using this technology and knowledge to account for blast movement by translating the ore polygons in response to the measured movement vectors. This paper provides an overview of blast movement but focuses on one site where blast movement was measured during three separate periods, with significantly different orientation of the mineralisation on each occasion. The theoretical ore loss varied from nine per cent to 24 per cent. The differences are primarily due to the orientation of the ore polygons relative to the direction of movement. The optimum grade control solution is a combination of accurately accounting for blast movement and designing appropriate blasts.

INTRODUCTION

Grade control is an important process for most mining operations since the sole reason for the existence of the mine is to extract the valuable mineral from the ground. As the first step of the beneficiation process, if grade control is not optimised, then no matter how good the downstream processes are the full potential of the operation will not be realised. The detailed implementation of grade control varies between mines but typically consists of sampling and assaying to determine the quantity and location of the mineral and then defining economic, minable ore zones. Considerable research has been done in the field of geology to improve these processes; however, there is a significant event that takes place before the mineral can be excavated and extracted – blasting. Again, considerable research has been done in the area of blast optimisation but this has had a strong emphasis on production, such as fragmentation, diggability, vibration and damage. However, blasting also has a significant impact on grade control due to the movement of the rock, but blast movement, and blast dynamics in general, is not well understood.

It is somewhat surprising that in a mature industry, a critical process such as blast movement would not be understood very well. One could sight various reasons for this lack of awareness but arguably, the main reason was that there was no reliable, accurate and practical method to routinely measure blast movement. There had been isolated investigations by individuals at sites and a handful of researchers with varying success (Gilbride, Taylor and Zhang, 1995; Taylor, Gilbride and Daemen, 1996; Harris, Mousset-Jones and Daemen, 1999, 2001). Most of this work involved *ad-hoc* visual targets such as sand bags, chains, plastic pipe and various other items but none fit the criteria of being reliable, accurate and practical.

This paper is the product of six years of research into quantifying and understanding blast movement and its impact on grade control. It started at the Julius Kruttschnitt Mineral Research Centre of the University of Queensland with the development of an electronic system for measuring blast movement that is both accurate and practical. With support from Barrick Gold Corporation, the author then led a research project to continue development of the system and investigate blast movement dynamics and grade control. This is the first time that it has been practical to collect enough reliable data to conduct detailed measurements of blast movement rather than relying on theory (ie models). The data set currently includes 1500 movement vectors from 28 sites around the world and covers most of the practical range of blasting conditions (eg powder factors from 0.36 kg/m^3 to 1.7 kg/m^3; rock densities up to 3200 kg/m^3; bench heights from 5 m to 15 m and all methods of initiation).

The main objectives of this paper are:

- to provide a basic understanding of blast dynamics that grade control geologists can apply to defining ore polygons after a blast; and
- through the use of a case study, demonstrate that optimum grade control is achieved by an understanding of blast movement, direct measurement of blast movement and appropriate blast design.

BACKGROUND

Blast movement measurement

The benefits of measuring blast movement to reduce ore loss and dilution have been recognised by many people for many years and various methods have been used with limited success. Most use *ad-hoc* visual targets such as pipe, chain, rope and coloured sandbags. The disadvantages of these methods include:

- poor recoveries,
- labour intensive,
- have to be excavated before their position is known, and
- some only provide two-dimensional movement.

Electronic methods promise to alleviate some of the shortcomings of the visual methods, especially the last two items. Again, several techniques have been tested including ground penetrating radar, magnetometery, metal detection and recently, radio-frequency identification (RFID) tags. Most suffer from limited range, which means the targets must be placed close to the surface or indeed, on the surface, which is inherently inaccurate due to movement dynamics as explained in Figure 1.

Description of Blast Movement Monitor system

The Blast Movement Monitor (BMM®) system was developed and patented by the University of Queensland and commercialised under licence by Blast Movement Technologies. The complete system is explained below:

- The Activator is a remote control that switches each transmitter on and programs it as required.

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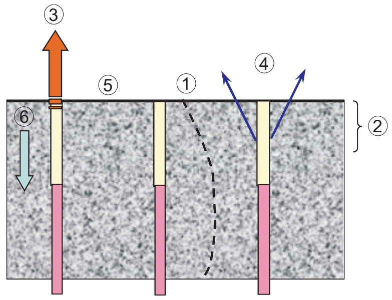

1. Vertical profile – Horizontal displacement is minimum at the surface.
2. Movement close to the surface is more variable than at depth – extra degree of freedom.
3. Anything placed in the stemming could get ejected! Even if not ejected, unlikely to be representative of bulk movement.
4. Cratering can launch near-surface objects, similar to stemming ejection!
5. An object on the surface can be lifted by the shockwave; the rock moves forward; and the object lands close to its original location.
6. Power Trough – surface drops down into 'void' left by lower bench moving forward.

FIG 1 - Cross-section illustration of why near-surface movement is not useful for grade control purposes.

- A number of BMM®s are then installed in dedicated drill holes within the blast and surveyed.
- A special detector is used to locate each BMM® after the blast and determine its depth.
- The dedicated software calculates the three-dimension movement vector of each BMM®. The data is archived in a database for future reference.
- Ore boundaries can be redefined within one to two hours of the blast to reflect the measured movement so that the material can be transported to the correct location.

BLAST MOVEMENT DYNAMICS

Mechanisms

There are several basic concepts that must be kept in mind to understand blast dynamics that will ultimately help to define post-blast ore polygons and optimise blast design. The explosive is a source of energy that is distributed in space and time – it is not a point source. Individual holes are linear sources, typically in the lower half of the bench and initiation usually starts at the bottom. At the scale of the whole blast, holes release their energy at discrete times. The basic physics involved are:

- Upon detonation, each discrete element of the explosive exerts a force equally in all directions on the adjacent rock. The rocks with least resistance will begin to move. These rocks in turn act on neighbouring rocks, which results in bulk movement of the rock mass.
- The rock moves in the direction of the path of least resistance. This is approximately perpendicular to the initiation timing contours.
- The rock at the top of the bench is not directly pushed by the explosive but instead is either indirectly moved by collisions from other rocks or dragged along by the friction from the moving rocks below. The further a rock is above the explosive column, the less energy it will receive and therefore the less distance it will move. Hence, the D-shaped vertical profile with greater movement in the mid-to-lower level of the bench. The movement reduces near the floor due to friction from the unbroken floor.

Movement in various regions of a blast

A blast consists of a number of regions or zones where movement is different due to the different dynamics in each. The main ones are the front, the back and close to the centreline of initiation. Each of these extend for about two to three hole spacings and the remainder is termed the body of the blast.

Body

The body of the blast is everywhere that is not influenced by any edge affects and the movement in this region is regarded as normal or typical for that particular blast. Horizontal displacement is directly related to powder factor and has been measured up to 40 m in the body of the blast (ie not face throw). The characteristics of the movement in the body of a blast are:

- The horizontal displacement changes with depth as per the characteristic D-shaped profile.
- The direction is approximately perpendicular to the timing contours.
- The inclination is positive (upward). It is close to horizontal at the bottom of the bench and increases progressively through the bench. This increasing inclination is illustrated in Figure 2 and Figure 3 where the points 3 and 4 represent body movement (also see Figure 4).

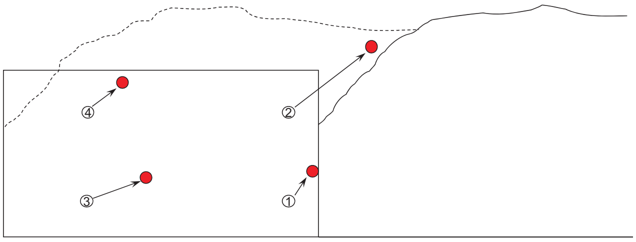

FIG 2 - Cross-section illustration of movement close to the front for a buffered blast.

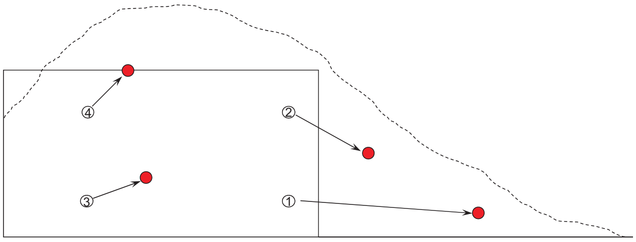

FIG 3 - Cross-section illustration of movement close to the front for a free-faced blast.

Front

The front edge is defined as the boundary adjacent to the ignition point in the direction of movement – it could be a buffered or clean face. Figure 2 and Figure 3 illustrate the conceptual movement vectors for buffered and free-face blasts respectively. Points 3 and 4 represent typical movement of the body of the blast in the upper and lower bench.

For a buffered blast (Figure 2), the movement at position 1 is less than the corresponding body movement at 3. The 3D distance is less, but the inclination is greater as it moves towards the free surface. The vertical displacement is likely to be greater, depending on the depth. At position 2, the movement is greater than the corresponding body movement at 4 because of the partial free-face provided by the power trough.

For a free-faced blast (Figure 3), the movement in the body and the back are essentially the same as for a buffered blast but the front face movement is different. Provided there is sufficient energy to move the face burden, movement at position 1 is considerably greater than the corresponding body movement at position 3 and potentially downward (depends on the initial height). The movement at position 2 is almost certainly downward as it falls behind the lower bench and the distance is likely to be greater than the corresponding body movement at 4.

Back

The back of the blast is defined as the edge(s) opposite to the direction of movement, typically characterised after the blast by a vertical face along the back edge where the surface of the muck pile is below bench height – referred to as the power (or energy) trough. One of the most satisfying achievements from the research is the quantification of the dynamics that form the power trough. Figure 4 is a diagram to help with the explanation and the numbers of the following points relate to the corresponding numbers in the diagram.

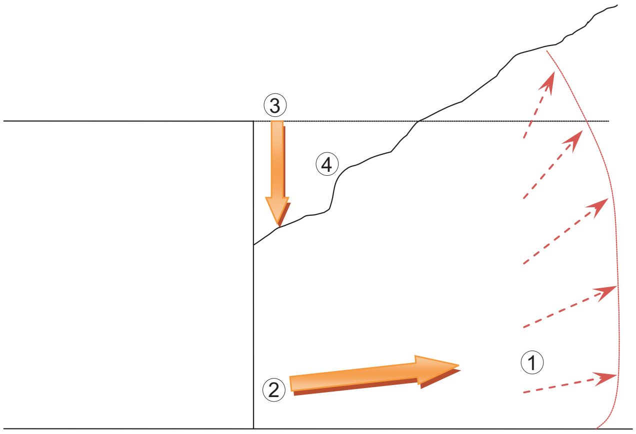

FIG 4 - Diagram of the dynamics that form a power trough.

1. The movement follows the D-shaped profile throughout most of the muck pile until a few rows before the back edge where the dynamics begins to change. In the front and body regions, the upper bench moves forward and upward.
2. When the explosive in the last row detonates, it pushes the rock forward the same as for the body region, but …
3. There is no rock moving forward from behind the last row to move and support the upper bench at 3 and this rock drops down into the void.
4. The surface of the muck pile in the power trough is the original bench surface that has literally tilted up and the back edge dropped down.

Centreline

The typical muck pile from a V-initiated blast is characterised by a ridge along the centreline of the initiation. A good blast with appropriate burden and spacing and energy containment will result in consistent bulk movement of the rock mass. To help with understanding certain aspects of the dynamics, the rock can be considered to behave like a fluid once it is in motion. The movement is forward and upward and perhaps the most important finding is that material does not cross the centreline. The vertical movement is greater in the upper part of the bench than in the body of the blast, forming the characteristic elevated ridge along the centreline. This is due to the greater confinement promoting vertical movement together with the lower bench moving towards the centreline. Note that the extra elevation of the muck pile in this region compared to the body of the blast is not just due to swell, there is also significant migration of material which actually increases the volume in this region.

The movement close to the centreline is more variable than in the body of the blast due to the random collisions of rocks. The more acute the angle of movement, the more variable the movement to the point of being almost random. Figure 5 shows two V-initiated patterns from the same bench. The movement vector between the pre- and post-blast BMM location can be compared to the timing contours, which theory suggests should be approximately perpendicular. The pattern on the left has

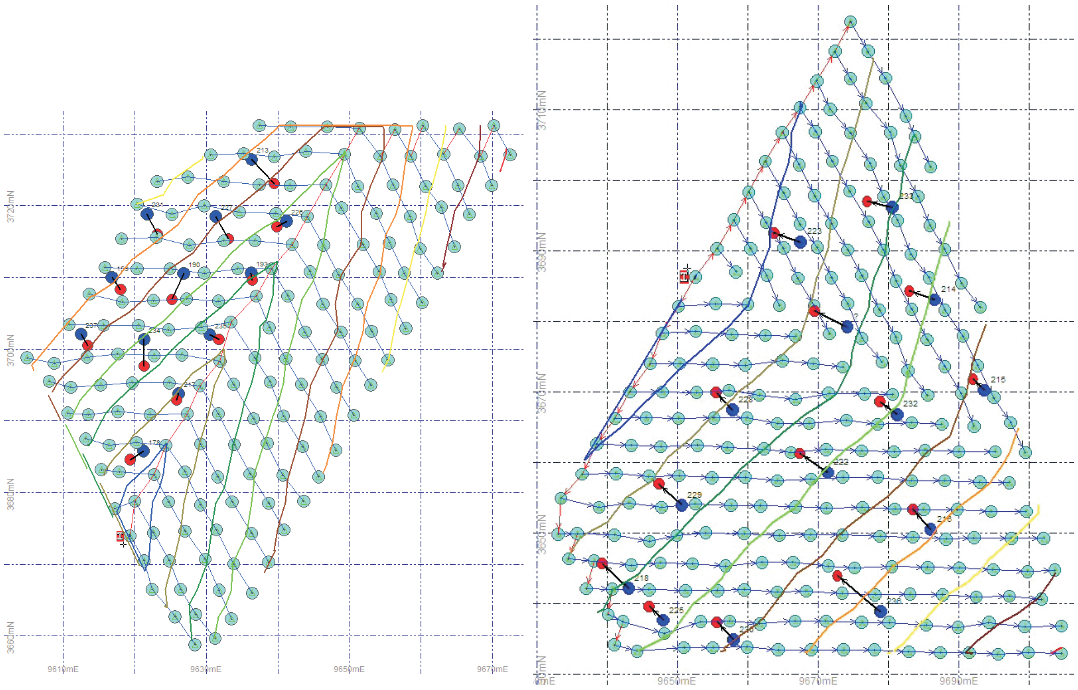

FIG 5 - Comparison of the movement from two adjacent V-initiated blasts.

timing contours at an acute angle to the centreline and the movement is chaotic close to the centreline. Compare this to the blast on the right that has a flat V and the movement is consistent throughout. The surface profiles of the muck piles were as expected – the first one steep and the second one flatter. The second blast is much easier to accurately account for blast movement and therefore would result in less ore loss and dilution, regardless of monitoring. The details of this project can be seen in Adam and Thornton (2004).

ACCOUNTING FOR BLAST MOVEMENT IN GRADE CONTROL

The research has made a unique contribution to open pit blasting by helping to develop a practical tool for measuring blast movement then using it to improve understanding of blast dynamics. However, these achievements would be of largely academic interest without taking the final step of using this technology and knowledge to account for blast movement as part of the grade control process. Grade control is critical to the economics of most mines and considerable resources are expended to produce the best estimate of economic and minable ore polygons. There is much uncertainty associated with grade control but the one thing that is certain is that the rock (and ore) will move when it is blasted and therefore grade control is not optimised unless this movement is taken into consideration when defining the post-blast ore polygons. This is not an onerous task – typically less than half a man-day spread between drill and blast, grade control and survey is required but the potential benefits are orders of magnitude greater than the cost (Taylor and Firth, 2003; Thornton, Sprott and Brunton, 2005). There are also intangible flow-on benefits due to broadening the awareness of the problem and improved communication between geology and engineering disciplines.

The magnitude of movement is proportional to the energy applied to the rock mass. The average horizontal displacement for all measurements to date is about 4.3 m but displacements greater than 10 m are reasonably common. The movement at any particular location is primarily determined by the blasting objectives and rock mass. For example, if the rock mass is hard and massive and the goal is fine fragmentation for Mine to Mill® considerations then a lot is energy is required, which will result in correspondingly large displacement. There is little that can be done to reduce displacement for a given set of circumstances although blast design decisions can help to control blast movement and make the grade control more accurate. In those operations where ore and waste materials cannot be identified, either visually or by associated rock mass structure, the only way to account for blast-induced movement is to measure it.

Ore loss occurs when it is misclassified as waste and sent to the waste dump. Similarly, dilution occurs when waste is designated as ore and sent to the concentrator. Therefore if ore polygons are excavated in their original location, ore loss occurs forward of the leading ore/waste boundaries and dilution occurs at the trailing boundaries. There are a number of diagrams in the case study below that show these zones.

The mineralisation has a significant influence on the cost of ore loss and dilution and there is no control over it. For example, the shape, grade or dip cannot be changed and these parameters will determine the continuum between favourable and unfavourable mineralisation conditions. The geometry that presents the greatest challenge for accurate grade control are when there are small, isolated ore polygons or long narrow ore polygons and of course high grades magnify the errors (and rewards improvement). The consequence for small, isolated ore polygons is large percentage of ore loss and dilution but perhaps relatively small absolute ore loss and dilution (depending on grade). Conversely, for long, narrow ore polygons, any error of determining a post-blast ore boundary is multiplied by the length of the boundary. The percentage of ore loss and dilution may be small or large depending on the aspect ratio of the polygon and the movement but the there is potentially large absolute ore loss and dilution. Large ore polygons will result in a relatively small percentage of ore loss and dilution but the absolute value could be large. The most favourable condition is contiguous ore polygons because if ore moves into ore then it will eventually be sent to the mill although there could be net present value (NPV) implications from high-grade ore being stockpiled as low grade. Examples of each of these conditions can be seen in the following case study.

Case study

This case study is from a gold mine that dates back to the early research of the blast movement monitor. Blasting was conducted on 10 m benches that were mined in two passes (split-benching or flitch mining). Grade control was done on 5 m composites. Blast movement monitoring projects were done on three separate occasions between August 2003 and December 2005 and purely by chance, the mineralisation regime was significantly different on each occasion. The ore loss and dilution analysis is based on mining the preblast ore polygons since that was the practice during this period. The analysis is theoretical and assumes the grade control and excavation is perfect. In reality, there are errors in all aspects of the grade control procedures but the relative differences are relevant.

The strike of the main orebody was approximately north-south so blasting was aligned in this direction. There were also cross-structures present from a separate mineralisation event and historically these zones resulted in poorer reconciliation. The blast movement project in August 2003 was planned to monitor an entire bench of the stage 2 cut-back where the ore was contained in cross-structures on the fringe of the main orebody that had resulted in poor reconciliation on previous benches. The blast movement monitors were installed at various depths to investigate the movement throughout the bench. Figure 6 is a graph of horizontal displacement against installed depth for all measurements during the August 2003 and April 2005 projects. The dashed curve is a hand-drawn estimate of the average profile based on this data plus knowledge gained from the entire research effort.

The theoretical percentages of ore loss and the mineralisation conditions for the three projects are summarised in Table 1. The powder factor decreased from about 1.01 kg/m^3 in August 2003 to about 0.95 kg/m^3 for the projects in April and December 2005. This would decrease the movement by a relatively small amount but does not account for the large changes in the ore loss. The fact that the April 2005 and December 2005 projects used the same powder factor yet ore loss for in December was double the April value indicates that the mineralisation conditions are the dominant cause of the variation.

In each case the ore loss of the top flitch is less than the bottom flitch because the displacement is approximately half (only the bottom flitch diagrams are shown). The least favourable mineralisation conditions were present during the August 2003 project and Figure 7 is a diagram of the ore loss and dilution for about half of the bench. The average ore loss for the whole bench was 19 per cent and it can be seen that there is potential to send entire ore polygons to the waste dump. A complete summary of this project can be found in Thornton, Sprott and Brunton (2005). April 2005 had the most favourable conditions since the main orebody was being mined and so the ore polygons are predominantly large and contiguous (Figure 8) and the average ore loss is nine per cent. In December 2005, mining was again in the main orebody but cross-structures were (unexpectedly) present (Figure 9) with the average ore loss being 18 per cent. The combination of isolated cross-structures and contiguous ore

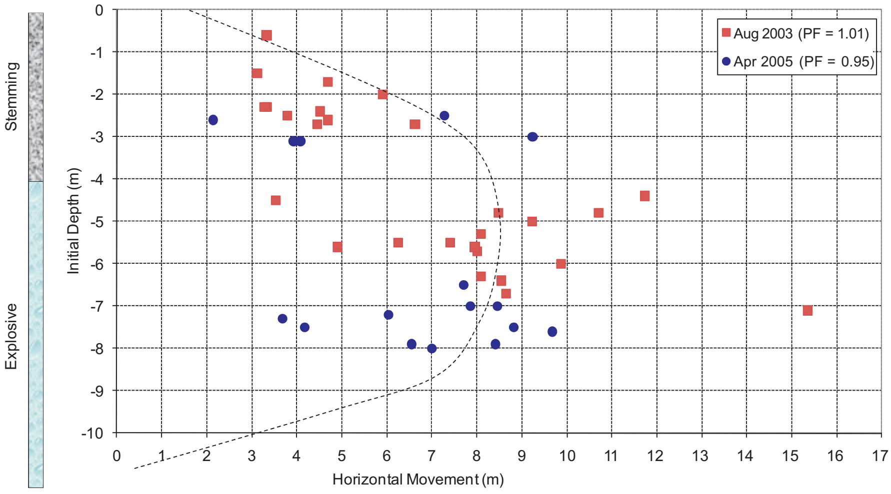

FIG 6 - Measured horizontal displacement versus initial depth.

TABLE 1

Summary of ore loss and dilution analysis from the three projects.

Project date	Mineralisation conditions	Powder factor (kg/m^3)	Ore loss percentage		
			Top	Bottom	Average
August 2003	Cross-structures	1.01	17%	21%	**19%**
April 2005	Main ore, large and contiguous	0.95	6%	14%	**9%**
December 2005	Main ore and cross-structures	0.95	12%	25%	**18%**

FIG 7 - Loss and dilution for the bottom flitch of blast 260-31, August 2003.

blocks resulted in the gold loss being less than August 2003 but greater than April 2005. The situation in 2003 represents a worst case and April 2003 is probably close to the best case in terms of ore block orientation. Therefore, the actual percentage of ore loss depends on the proportion of favourable and unfavourable mineralisation. At this site, the theoretical ore loss will fluctuate between nine per cent and 19 per cent but since the main orebody represents most of the ore, the overall ore loss will be towards the lower figure and these are theoretical so the actual achievable value is likely to be a little less.

Prior to 2006, adjusting ore polygons to account for blast movement was only done if there was a visual contact between the ore and waste. As discussed above, the blast movement was resulting in a large amount of ore loss and dilution so clearly the

FIG 8 - Loss and dilution for the bottom flitch of all monitored blasts, April 2005.

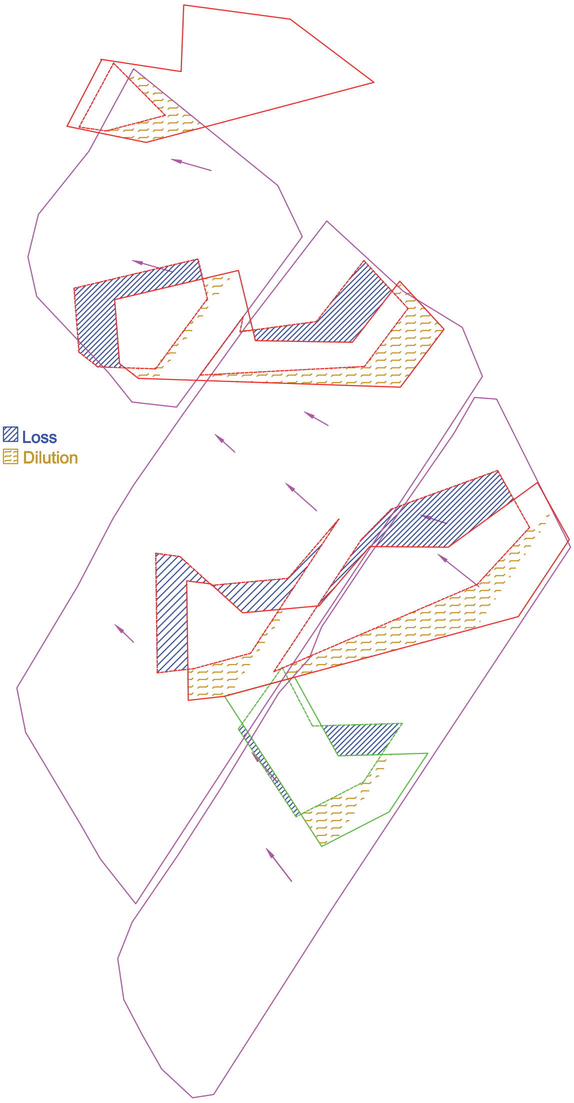

FIG 9 - Diagram showing areas of ore loss and dilution for bottom flitch ore, December 2005.

site was unaware of this and it is a valuable lesson to understand why. The mine had done some measurements with polypipe and concluded that the movement of the top flitch was about 2 m. Few reliable measurements were obtained for the bottom flitch, which is common for this method. The geologists thought the top of the blast moves more than bottom so concluded that blast movement was not an issue. However, polypipe measures the surface movement and Figure 6 shows that indeed the surface displacement is about 2 m. However, the average horizontal displacement of the mid-bench is approximately 8.5 m (maximum 15.4 m). Therefore, the measurement method provided misleading data, which when combined with an incorrect assumption of muck pile dynamics, led to a false sense of security.

The site began routinely monitoring all ore blasts to translate ore polygons according to the measured movement vectors when the BMM System became available for self-use in December 2005.

Other blast movement considerations

Direction of movement

Optimum grade control depends on many factors but in terms of the influence of blasting, the most important are measuring the movement and appropriate blast design. A blast design is constrained by many factors and grade control is just one of the many considerations. The objective is to minimise any errors by moving the rock as consistently as possible and in the optimum direction. For certain mineralisation, the movement direction is critical. For example, the direction of movement should be aligned with the long axis of important ore polygons to minimise any errors associated with defining post-blast ore boundaries.

Figure 10 illustrates that movement in the direction of the long axis of an ore block will minimise ore loss (and dilution). The movement vector (blue arrow) is the same length in the three cases but at 0°, 45° and 90° to the rectangular ore block. Therefore, for a given amount of movement, the error is proportional to the length of the boundary in the direction of movement. This is relevant even if blast movement is being measured since every measurement has some error associated with it.

Initiation sequence

Each hole in a blast is initiated in a predetermined sequence to control the release of energy and the three common initiation

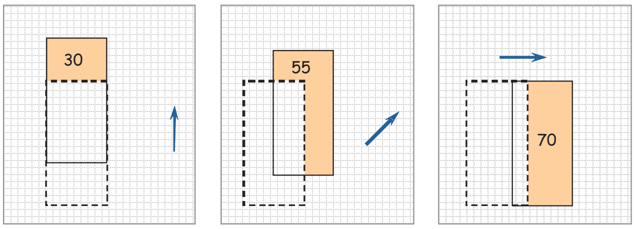

FIG 10 - Illustration of the impact that movement direction relative to the ore has on ore loss.

sequences are usually referred to as *echelon*, *V* and *centre-lift* (also called drop-cut or diamond). It is beyond the scope of this paper to explain the differences or when each may be used but the echelon is the best for grade control because it results in the most consistent movement and therefore the least error.

The author has visited several sites that routinely initiate ore blasts as a V or centre-lift in the belief that this is beneficial for grade control because it is commonly believed the rock moves predominantly upward with this initiation and/or the ore can be separated from the waste. However, the results of this research have led to the conclusion that this practice is detrimental to accurate grade control because:

- The area two to three rows either side of the centreline has chaotic movement and the greater movement of the lower bench means waste will move under ore (or vice versa), therefore creating vertical dilution.
- Blast movement is highly variable in this zone and the displacement has a greater impact than the direction since it is typically ±50 per cent of the mean. The variable horizontal movement will result in the boundary of the ore randomly deviating by several metres.
- The centreline can't follow a boundary if it is not straight.
- The precision that the centreline will align with the ore boundary is no better than half of the burden or spacing.

Vertical displacement

It is important to understand and measure the vertical movement in some regions of the blast because it affects the extent that the ore boundary is distorted in section, which will create vertical dilution and for single-pass excavation, there is little that can be done to accurately account for this. Therefore, when designing patterns, it is prudent to minimise the occurrence of ore boundaries close to the back edge or any centrelines of the initiation timing. If grade control is done by sampling blastholes then by the time the ore polygons are known it is probably not feasible to alter the pattern although the bench above or adjacent patterns can be used as a guide during the planning phase. However, there is considerable flexibility with the location of the point of initiation of V and centre-initiated blasts and this will have an impact on the accuracy of subsequent grade control.

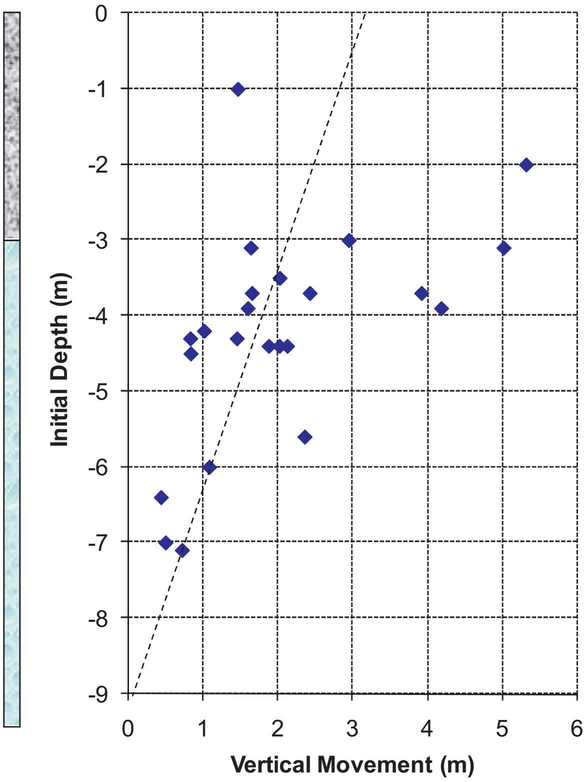

FIG 11 - Relationship between initial depth and vertical movement.

For sites that mine in multiple passes, the vertical movement will have reconciliation implications. In the power trough region, the upper bench ore will be mined with the lower bench (Figure 4) and general muck pile heave defines the level of the sub-benches after the blast. For example, Figure 11 is the relationship between depth and vertical movement from a site in Australia. The dashed lines on the graph are estimated linear relationships. The bench height is 9 m and grade control is done on 3 m intervals. Prior to the movement project, they mined the heave then three 3 m passes. A total of four passes with the first two allocated to the top flitch for grade control purposes. This seems to be common practice because the author has witnessed the same practice at other sites.

By measuring three-dimensional movement, it was possible to determine the average post-blast elevation of each flitch. Figure 12

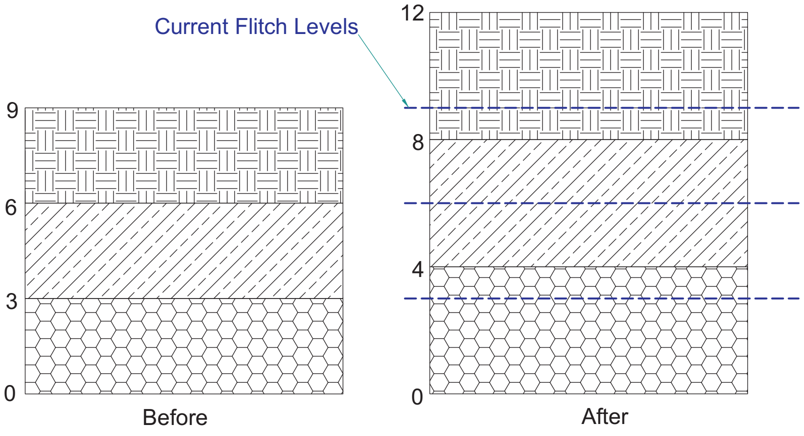

FIG 12 - Illustration of the average measured level of post-blast flitches compared with premonitoring practice.

is an illustration that compares the old mining horizons (blue dashed lines) with the actual locations of the three sub-benches.

The interface between the first and second flitch (initial depth = -3 m) moves between 1.9 m and 2.7 m vertically. The average for a typical pattern is closer to 2 m which is a convenient number to use. The lower interface (-6 m) moves a little more than 1 m vertically, but similarly, 1 m is a convenient operational number. It can be seen that each flitch swells from 3 m thick to about 4 m thick. The blue lines in the 'after' diagram show the old practice of removing the heave followed by three 3 m passes clearly mixes all of the flitches and this has reconciliation implications. The recommended mining sequence, which was implemented, was for three passes of 4 m each. For simplicity, the first pass will mine to a level of 1 m below the original bench level (heave plus 1 m), followed by two 4 m passes.

CONCLUSIONS

The primary motivation for developing the blast movement monitoring system was for a grade control tool to reduce ore loss and dilution. However, it has enabled a new insight into blast dynamics that is useful in its own right but will also lead to improved grade control by interpolating between measured vectors and by enabling improved blast designs. A summary of the main finding is as follows:

- In the body of the blast, the lower bench moves more than the upper bench. The profile is D-shaped, increasing with depth through the stemming column, reaching a maximum near the top of the explosive column and stays reasonably constant until close to the bottom of the hole where it decreases.
- Movement in the body of the pattern is similar for free-faced and buffered blasts. Buffering does not prevent movement. The main differences occur close to the front edge:
  - For a free-faced blast, the bottom half of the bench moves considerably more than the equivalent body movement and more than the top. The upper bench moves forward but falls in behind the lower bench.
  - For a buffered front face, material in the lower bench and close to the front moves less than the equivalent body movement and it moves more steeply upward as it pushes up towards the unconfined surface. Depending on the depth of the power trough of the adjacent blast, the upper bench is likely to move further forward than the equivalent body movement as it is pushed up onto the adjacent muck pile.
- At the back of the blast, the dynamics of the lower bench is the same as for the body of the blast but the top of the bench drops downward into the void left by the lower bench since no material is coming from behind to support and move the upper bench. This creates the power trough along the back edges.
- The case study provides several valuable lessons:
  - it is important to accurately account for blast movement because the potential benefits are to increase mineral output by many per cent;
  - the orientation of the ore polygons relative to the direction of movement has a significant impact on ore loss and dilution; and
  - inappropriate measurements and lack of knowledge about blast dynamics led to incorrect assumptions, which was detrimental to grade control.
- The sequence of initiation affects the movement, which in turn affects the accuracy of grade control. The best method is the echelon and benches should be planned to maximise the number of echelon-initiated patterns. Movement close to any centrelines of surface timing is more variable than in the body, often to the point of being chaotic. There is often flexibility with the location of the point of initiation for V and centre-initiated patterns. The location and orientation of ore polygons should be considered to optimise grade control.
- Understanding and measuring vertical movement can be important for optimising grade control, especially for sites that mine benches in several passes. At the front and back of the pattern, material can move down to lower sub-benches and the overall swell determines the post-blast mining levels.

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- the many sites that have conducted blast movement projects, all of which have contributed to the blast movement knowledge by providing many varied conditions that would have been impossible from a single entity.

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