Atlas Iron

Assessment of Blasting at Miralga Creek Project

Preservation of Ghost Bat Habitats Post Mining Activities

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1 Executive Summary

Atlas Iron are seeking approval to mine the Miralga Creek Project, located 130 kilometres (km) south east of Port Hedland in the Pilbara Region, Western Australia. Ghost Bats, a threatened species, occur in the region and have been recorded in caves adjacent to proposed open cut pits in the Miralga East mining area. Several potential habitat caves are located within 150m of the proposed pits, including one possible maternity roost important to the local population of Ghost Bats (cave CMRC-15).

Blast It Global was engaged to assess the predicted effects of blasting on the integrity of nearby identified caves. A computer based model was developed to study potential ground vibration levels and flyrock impact zones in order to be able to determine a safe set of blast parameters for undertaking drill and blast activities at the the Miralga Creek Project.

The modelling determined that 102mm and 115mm diameter drill holes will need to be used to blast mining benches of maximum 5m height when blasting within 100m of the caves so that ground vibration and flyrock impacts can be appropriately controlled to safe levels.

At distances greater than 100m from the cave locations, the model determined that 102mm and 115mm diameter drill holes would be able to be used on 10m bench heights.

A blast monitoring program employing permanent blast monitor locations will be required for all blasting activities conducted within 400m of the caves. Data collected from the monitoring program will need to added to the equations within the computer model on an ongoing basis, so as to be able to improve the accuracy and reliability of predicted outputs and allow systematic refinement of the blast parameter set.

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2 Introduction

Atlas Iron is currently in the process of applying for mining and environmental approvals to mine iron ore from five pits at the Miralga Creek Project located in the Pilbara Region of Western Australia.

Two of the proposed pits at the Miralga East mining location are to be located adjacent to four known natural caves / rock shelters (caves). The caves provide habitat for *Macroderma gigas* (Ghost Bats) which are listed as "vulnerable" under both the Biodiversity Conservation Act 2016 (Western Australia), September 2018 list and the Environment Protection and Biodiversity Conservation Act 1999 (Commonwealth). Three of the caves – CMRC-13, CMRC-14 and CMRC-15 – have previously been recommended for retention.

Atlas Iron has obtained specialist advice that, although Ghost Bats may abandon the caves while mining activities are taking place, the species is likely to return once mining has ended, if the structural integrity of the caves is maintained. Atlas Iron has commissioned Blast It Global to model the effects of blasting on these caves and determine blasting parameters and associated controls/monitoring necessary to maintain the structural integrity of the caves.

This document is a desktop study of the proposed blasting parameters to be used on the Miralga Creek Project. It includes assessment of potential blast vibration and flyrock caused by blasting operations, and the likely effects blasting operations may have on the nearby caves.

3 Literature Review

The literature review focussed on blasting studies conducted to explore the effects of blasting vibration on the stability of rock structures, e.g. caves and rock shelters. Several papers were omitted from the review where they were found not to be relevant to the Miralga Creek Project; This included studies of far-field effects where vibration readings were less than 5.0 mm\s, those where the structures were currently inhabited by bats and hence the vibration limits were designed according to bat comfort levels, and those where preservation of stalactite \ stalagmite structures was the primary focus.

The papers and texts reviewed in the study comprised of:

- Report of Potential Effects of Surface Mine Blasts Upon Bat Hibernaculum (Dept. EPA, 2006);
- Blasting In Proximity to World Heritage Site – A Success Story (Birch, 2012);
- Blasting New Entrance to Carrol Cave (Bowles, 2003);
- Construction Vibrations – Chapter 21 Unlined Opening in Rocks (Dowding, 2000);
- Experimental Techniques to Reduce Blast Vibration Level (Khaled, 2007) ; and

- Reducing the Adverse Effects if Blasting on the Cave Ecosystem Near the Future Exploitation Field Gradusa (Mesec, 2019).

All literature review papers are included in the Reference section of this report.

In all papers, apart from "Construction Vibrations", the blasting programs were required to achieve very conservative limits due to the significance of the structures themselves and/or the inhabitants. None of the documented studies proposed maximum blast vibration level above 20.0 mm/s.

Construction Vibrations (Dowding 2000, pp 335) summarised damage zones in a tunnel collapse test. In this study, a man-made tunnel located adjacent to surface blasting suffered intermittent rock falls at vibration levels of >900 mm/s. The minimum particle velocity found associated with a rock fall was 460 mm/s. The testing was carried out in sandstone and granite geologies. Figure 1 displays the results in the form of a table (Table 21-3 Dowding, 2000) and a diagram (Figure 21-5 Dowding, 2000) depicting the tunnel, blast locations and the measurement zones.

TABLE 21-3 Summary of UET Tests, Sandstone

	Zone			
	1	2	3	4
Scaled distance, $R/W^{1/3}$ (ft/lb)	1.3	2.0	3.3	5.1
Free-field radial strain	0.012	0.004	0.0012	0.0004
Free-field radial particle velocity [ft/sec (m/s)]		40 (12)	13 (4)	3–6 (0.9–1.8)

Source: After Hendron (1977).

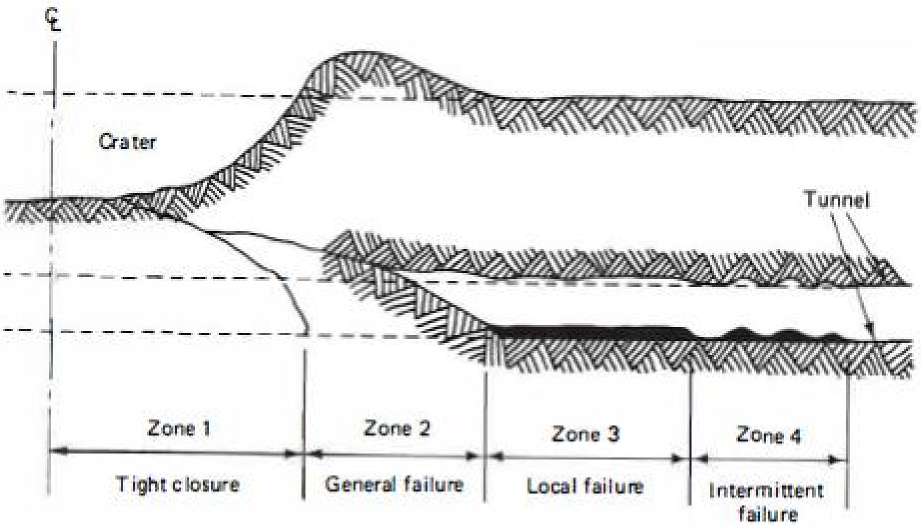


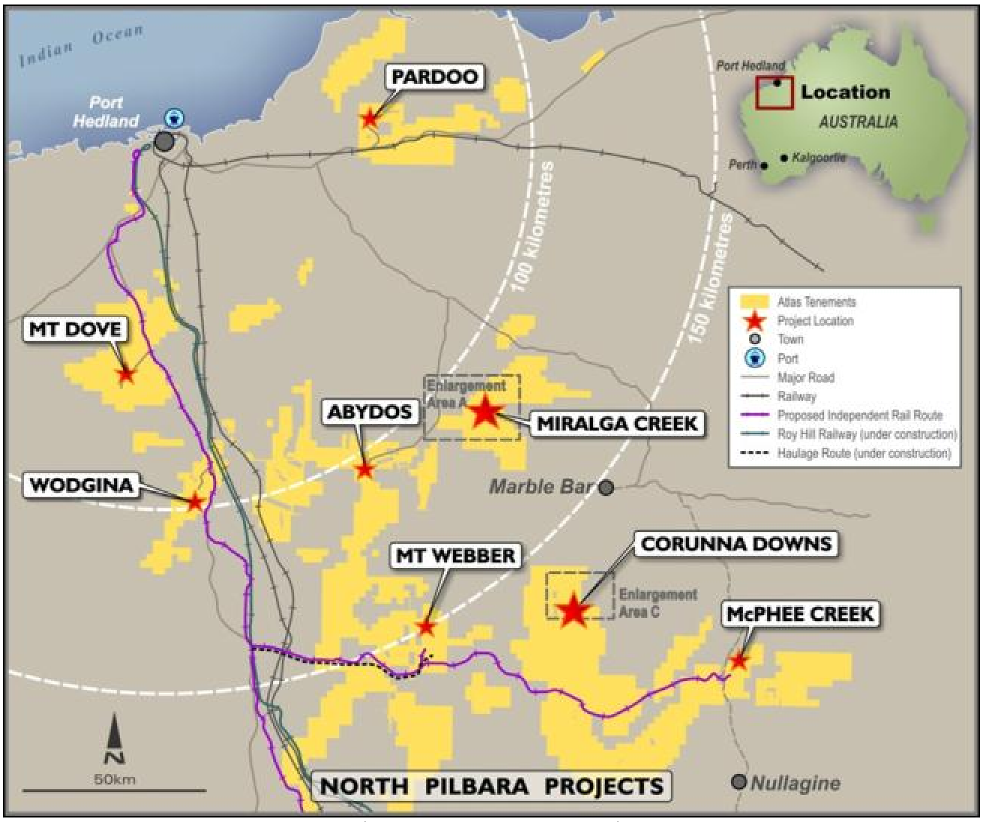
Figure 21-5 Damage zones in tunnel collapse tests. (From Hendron, 1977, p. 256: reprinted by permission of Prentice Hall, Inc., Englewood Cliffs, N.J.)

Figure 1 Effects of blasting within close proximity of a tunnel (Dowding, 2000, pp 335)

4 Miralga Creek Project Location

The Miralga Creek Project is located 130 km South East of Port Hedland, in the Pilbara Region of Western Australia. The Miralga Creek East mining location is part of Atlas Iron's current measured iron ore reserves, with a project focus to be mining in the second half of the 2020 calendar year.

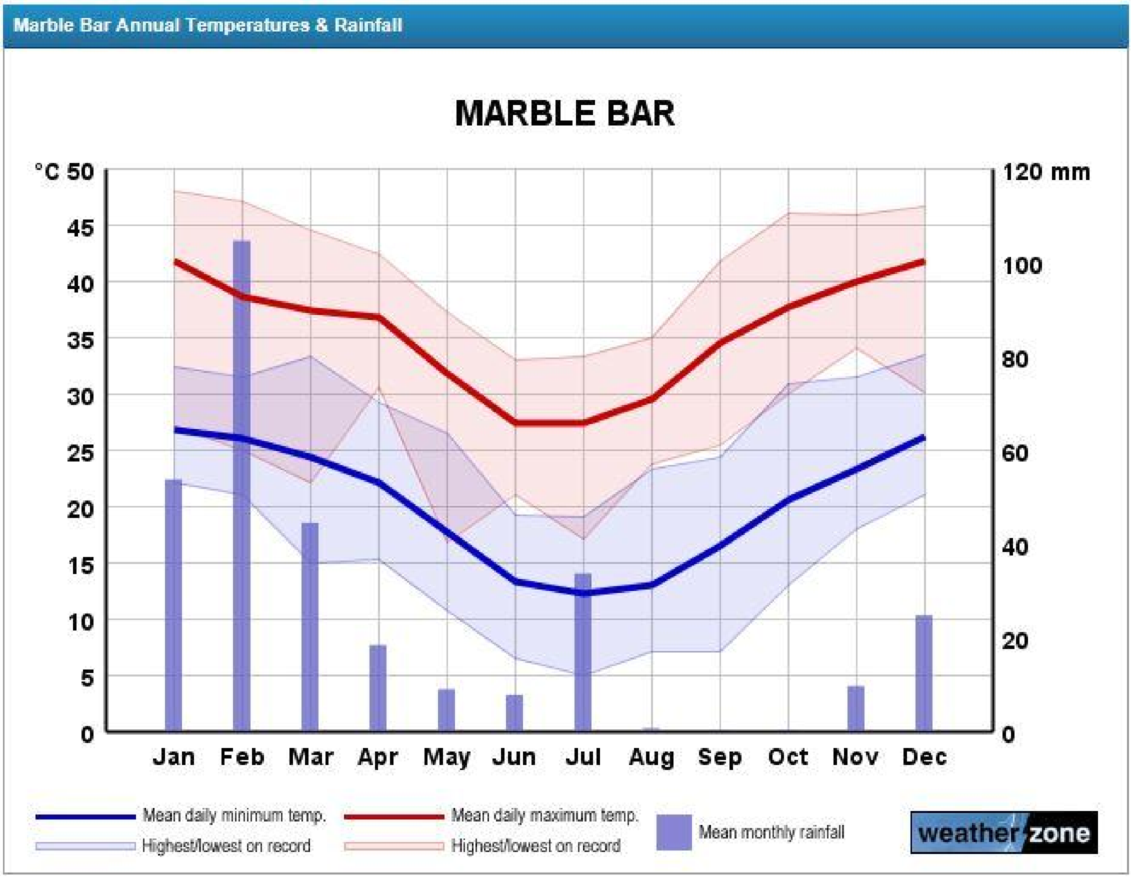
Figure 2 displays the Miralga Creek Project location.



(source: Atlas Iron Website)

Figure 2 Project Location Map

The region experiences a climate that can be described as hot and dry. Most of the rainfall occurs during the cyclone season December to March. Figure 3 displays a summary of Marble Bar's monthly temperature averages.



(source: http://www.farmonlineweather.com.au/climate/)

Figure 3 Marble Bar Annual Climate Summary

Understanding the climatic conditions in the Pilbara Region is important for selecting the correct bulk explosives and controlling post blast fume.

5 Environmental Considerations

The assessment of blasting impacts on the caves at the Miralga Creek project identified the following key environmental considerations;

- Fauna (Ghost Bat);
- Blast vibration;
- Airblast overpressure; and
- Flyrock.

5.1 Ghost Bat

The Ghost Bat (*Macroderma gigas*) formerly occurred over a wide area of the Central, Northern and Southern Regions of Australia, but has declined significantly in the Southern parts of its range over the last 200 years (Armstrong & Anstee, 2000). The species now occurs in only a few highly disjunct sites, across the Northern Regions, confined to the Kimberley and Pilbara in Western Australia (van Dyck & Strahan, 2008). In the Pilbara Region, the species roosts in deep, complex caves beneath bluffs of low rounded hills, which are often composed of Marra Mamba or banded iron formation, granite rock piles and abandoned mines (Armstrong & Anstee, 2000). They roost either individually or in colonies (Churchill, 2008) and move between a number of caves, both seasonally and as dictated by weather changes (van Dyck & Strahan, 2008).

The same geological materials that are associated with forming caves ideal for Ghost Bat habitats are also those which host economic deposits of iron ore resources. The key Ghost Bat habitat at Miralga Creek is cave CMRC-15, which is immediately south of Miralga East pit 2 (Bat Call WA, 2019). Cave CMRC-15 is a potential maternity roost, and specialist advice has previously recommended this cave be retained along with nearby lower-value caves CMRC-13 and CMRC-14, which are located immediately southeast of pit 2 (Bat Call WA, 2020). A fourth cave (CMRC-01, located between pits 2 and 3) is an overhang not considered important for the long-term presence of the Ghost Bat (Bat Call WA, 2019).

Figure 4 displays the caves in relation to the proposed pit 2 and pit 3 at the Miralga Creek East mining area. Appendix 1 displays the cross sectional profile between the closest mining pit and the cave locations.

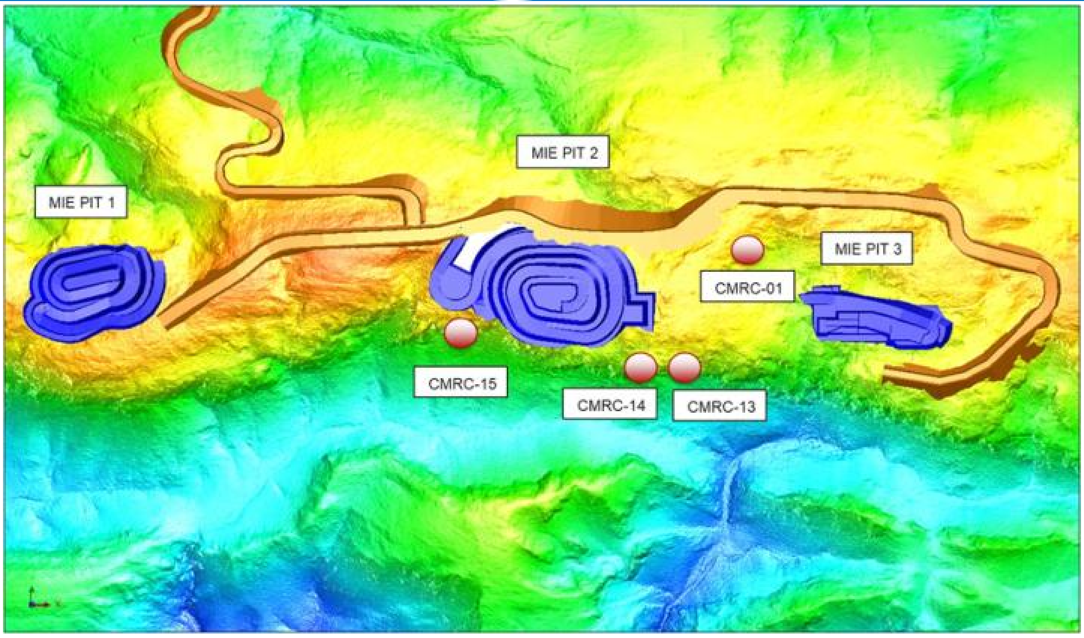


Figure 4 Miralga Creek East mining and cave locations (source: Atlas Iron)

In the past, several mining companies have conducted operations, including blasting activities, within close proximity of protected flora and fauna. Many of these occurred prior to the industry having had stricter requirements enforced in order to better preserve the natural environment. A notable example is that of the Shay Gap Iron Ore operations which blasted within 100m of a series of caves without the requirement to undertake any environmental monitoring. A Ghost Bat colony was known to be present at the commencement of mining. When mining was eventually completed the colony was found to still be present, though relative sizes of before and after populations are unknown.

Key environmental blasting management practices are now focused around minimising airblast overpressure, blast vibration, flyrock, dust from blasting and post detonation fumes (CO and NOx gases). This report will consider the proposed mining distances and the blasting parameters (such as bench heights, hole diameters, explosives usage etc) and assess these against conservative limits for all blasting environmental considerations related to the structural integrity of the identified caves.

5.2 Blast Vibration Criteria

No true measurements or studies conducted on preserving the structural integrity of existing caves in weathered iron ore formations, like those occurring in the Pilbara, have been identified as being externally published or otherwise available in the Public Domain. Available documented studies instead concentrate on blasting to defined blast vibration levels often using very conservative limits. Typically, vibration limits are assigned via assessment of the following criteria:

- Is the cave habituated by native fauna and does the habitation have to remain undisturbed during mining operations?
- Is the cave a cultural heritage site and does the site have to be preserved?
- Geotechnical stability of the cave?
- Cave preservation as a habitat post mining operation?
- Other criteria?

The listed criteria should lead to the setting of appropriate blast vibration limits. In many cases the limits have typically been adopted from those presented in Australian Standard 2187.2 2006 Use of Explosives Appendix J, or other documented literature sources.

However AS 2187.2 is not relevant to any of the above criteria due to two key differences; fauna are not humans and so their comfort response to blasting may be higher or lower, and, the materials (rock) that comprise the caves are not man-made materials with the caves not being engineered above-ground structures. Therefore, in the case of these bat caves, response to blasting vibration may be vastly different from the situations presented in AS 2187.2.

The literature review found several blast vibration limits potentially more relevant to this project. All had been sourced from, or directly cited Hoek & Bray 3rd Ed. 1981, Chapter 11 (pp 271). Though this is now an old text, it still provides a carefully documented set of blast vibration limits for a variety of settings. Today it is typically used by consultants searching for base criteria that can then be measured and validated in the field.

On page 292 of Hoek & Bray there is a reference to Langefors and Kihlstrom, Duuvall and Foegelson who explored the relationship between maximum particle velocity and structural damage, and developed a corresponding table, reproduced below as Table 1.

Particle Velocity (in\sec)	Particle Velocity (mm/s)	Damage
2	51	Limit below which risk of damage or structures, even old buildings, is very slight (less than 5%)
5	127	Minor damage, cracking of plaster, serious complaints.
12	305	Rockfalls in unlined tunnels.
25	635	Onset of cracking of rock
100	2540	Breakage of rock

Table 1 Hoek & Bray threshold blast vibration limits (Source: Hoek & Bray 1981)

Using the values in Table 1, Geotechnical consultants have applied the criteria associated with a blast vibration limit where the risk to structures was very slight, 51 mm/s. To ensure that there was a lower probability of litigation from the client(s) or damage to company reputation, this value was often further reduced to just 25 mm/s for sensitive sites that were classified as culturally significant. This criterion is still being used in the Pilbara Region today by a host of other multinational mining companies.

Atlas Iron's criteria for preservation of caves CMRC-13, CMRC-14 and CMRC-15 at the Miralga Creek Project is the caves remain viable as diurnal roosts for Ghost Bats in the future, once mining has finished. This defined criterion would allow for minor rockfalls out of the roofs and walls of the caves, but not damage that would lead to changes in the caves' internal microclimates. This suggests a level of 305 mm/s from Table 1 could be adopted. However it must be noted that the structures are already showing natural deterioration due to weathering processes, e.g. CMRC-15 cave's pre-mining survey indicates the presence of "debris on the floors from the walls and roof of the cave". The cave survey also notes that a geological fault is visible in the wall of this cave, which is heavily weathered. Taking this into account, it could be argued that the value of 127 mm/s be assigned as an appropriate vibration limit.

After a careful review of the available literature and evaluation of the site's specific conditions, this report recommends the following blasting criteria be applied:

- Blast Vibration < 100 mm/s at the closest cave to any specific blast;
- Design all blast to achieve < 85 mm/s;
- If blasts exceed the 100 mm/s blast vibration limit all blasting should cease until the cause of the blast exceedance is identified and steps implemented to prevent a reoccurrence. A cave inspection would be required.

Further supporting evidence for the blast vibration limits is documented in Section 8 of this report.

5.3 Blast Airblast Criteria

Airblast overpressure will not be a criterion for preservation of the structural integrity as rocks of these geological types will not be structurally affected by airblast. It will be assumed that the caves will not be inhabited by Ghost Bats. In any event, the entries to the caves are not aligned in orientations that would allow direct airblast pressure pulse injection; thus internally induced pressures will be somewhat reduced inside the caves.

5.4 Flyrock Criteria

Any flyrock must be limited in size and adequately controlled. Flyrock of a moderately small size, for example < 3kg, would be expected to have minimal impact on structural stability of the four caves. Larger sized rock must not land within the zones near the cave entrances.

A Blast Exclusion Zone (BEZ) will need to be defined for each blast evacuation area. A well planned BEZ will have several radii, depending on the objects being protected; for example, a typical BEZ may adopt 500 m for personnel, 200 m for mobile plant and 100m for fixed infrastructure. For the Miralga Creek project, an appropriate BEZ for the caves would be 50m.

6 Regulations and Standards

To evaluate the impacts of the proposed blasting activities to the sensitive sites, the relevant Australian Standards and legislation will be used, where applicable:

- Dangerous Goods Safety (Explosives) Regulations 2007 (DGS 2007);
- Australian Standards 2187.2 – 2006 Explosives – Storage and use Part 2: Use of explosives (Appendix J, Table J (4.5)A);
- Environmental Protection (Noise) Regulations 1997;

No Standards or Regulations have blasting limits for native fauna, flora or the natural environment. The prescribed blasting criteria will form part of the site's Blast Management Plan (BMP), which is required under the DGS 2007.

7 Cave Surveys

Geotechnical surveys and spatial surveys have been conducted of all four caves with summary information provided to Blast It Global. Reports were supplied highlighting joints, rocks, or blocks that may be susceptible to spalling by ground pressure, caused by blasting activities.

Land Surveys conducted a survey on the 19th November 2019 collecting spatial data points that were then meshed to create a 3D surface. This technique enables visualisation of the void size, and measurement of void dimensions.

The Land Surveys survey provided a 3D pdf file of each cave and a summary of each cave's dimensions. The specific dimensions of each cave are documented in Table 2 and the corresponding layouts are illustrated in Figures 5 to 8.

ID	L1 (m)	W1 (m)	W2 (m)	W3 (m)	H
CMRC-01	8.77	12.7	8.5	4.25	2
CMRC-13	5.12	7.06	7.11	NA	2.5
CMRC-14	4.37	2.57	2.82	NA	2.6
CMRC-15	15.98	8.52	16.49	9.93	4.5

Source: Land Survey Bat cave preso.pptx
Survey conducted using AMG coordinate system.

Table 2 Miralga Creek Project surveyed cave(s) dimensions

Figure 5 CMRC-01 measured dimensions reference locations (Land Survey 2019)

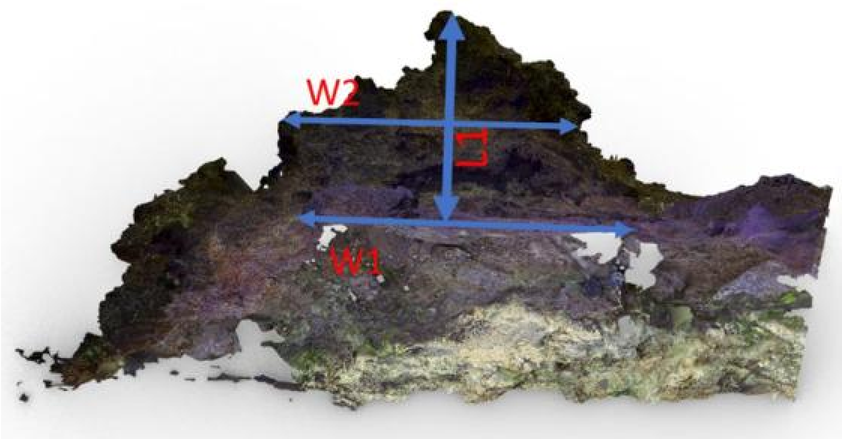


Figure 6 CMRC-13 measured dimensions reference locations (Land Survey 2019)

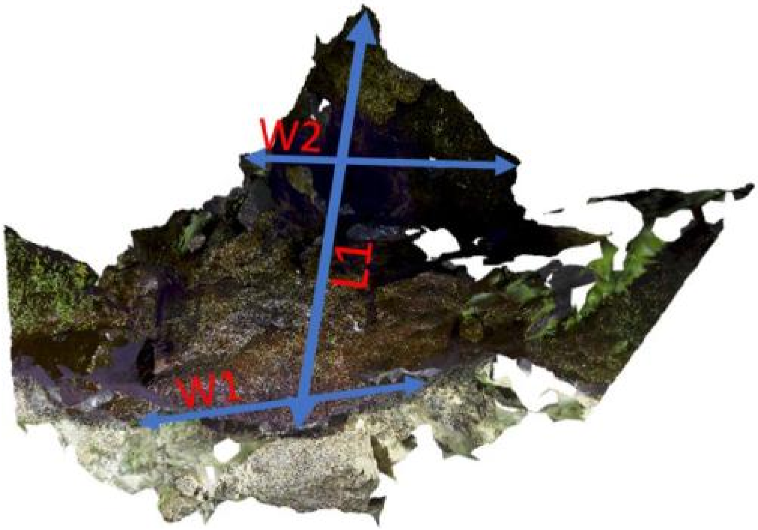


Figure 7 CMRC-14 measured dimensions reference locations (Land Survey 2019)

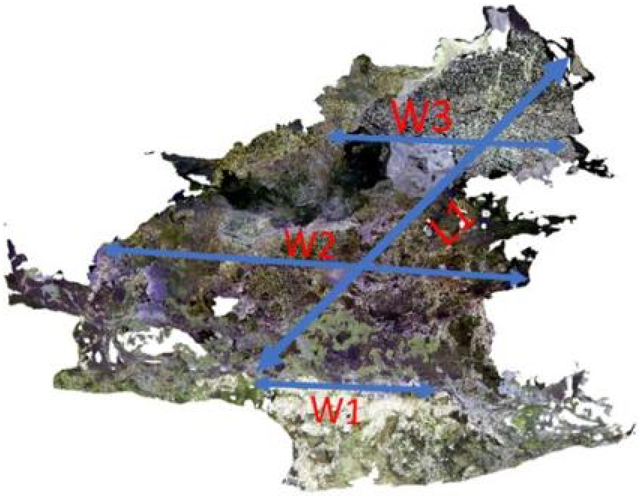


Figure 8 CMRC-15 measured dimensions reference locations (Land Survey 2019)

PSM conducted a geotechnical evaluation of the four caves on 14th to the 16th November 2019. Each cave was inspected with photo evidence and comments on the specific geological concerns within each cave documented. Cave CMRC-15 was the largest cave by volume and displayed the most potential for localised structural failures, e.g. of loose boulders and rocks.

Figure 9 displays a photo from the PSM Geotechnical survey report. The key potential hazard is hanging boulders that may drop to the floor of the cave, if blasting induces sufficient displacement at the boulder-roof interface. The top left hand photo of Figure 9 displays naturally accumulated rock debris on the floor of the cave. The rock debris are a result of the natural weathering processes.

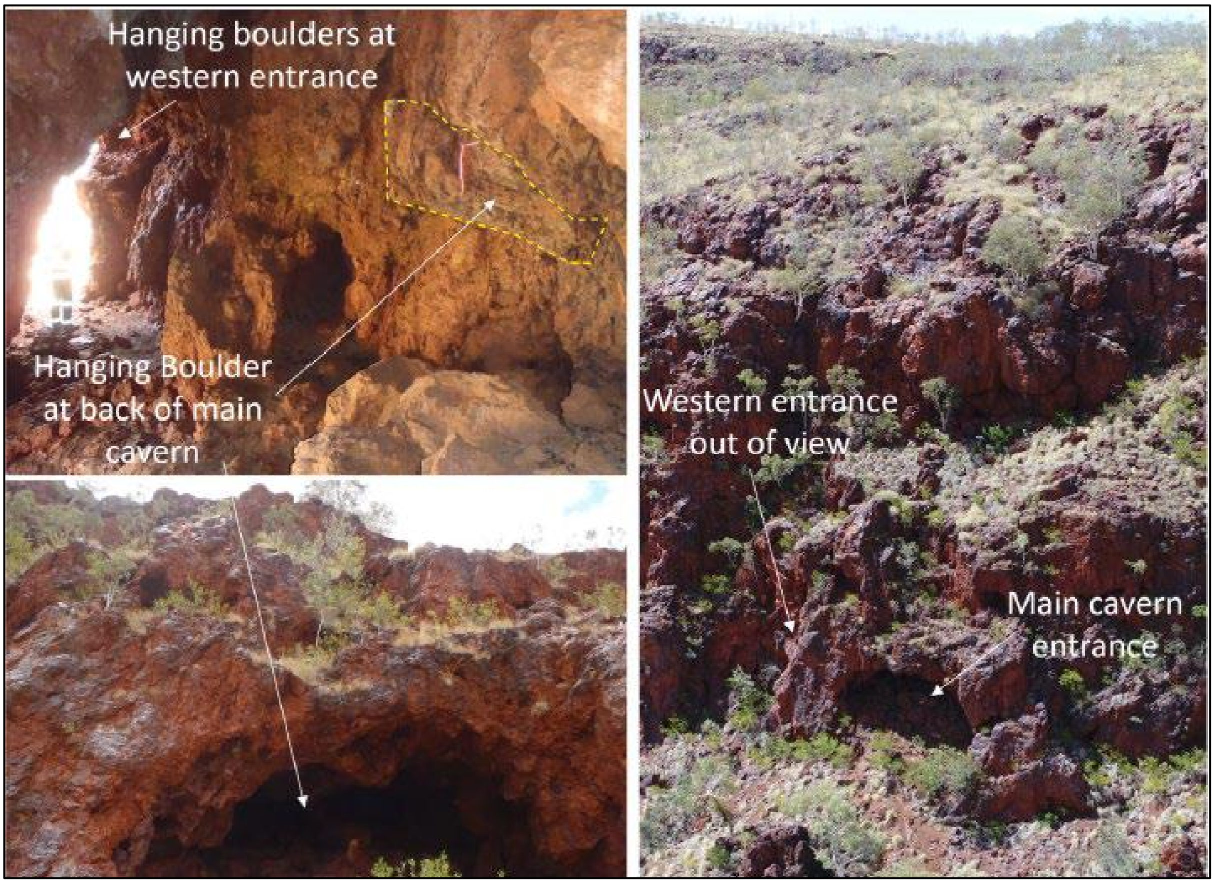


Figure 9 CMRC-15 potential failure locations (PSM 2019)

The spatial and geotechnical surveys are an important source of information to record the condition of the caves prior to any blasting. This can be used in combination with defining potential areas of failure that may be accelerated by blasting and mining activities proposed by Atlas Iron's Miralga Creek Project. Post-blast surveys will be able to record any changes in the caves' condition.

8 Failure Modes

Rock failure when blasting is caused by several mechanisms relating to the explosive's detonation process. For typical bulk products used in the mining industry each kilogram of explosives generates over 1000 litres of gas. When this gas is generated in a confined blast hole it will promptly initiate compression failure in the rock immediately around the explosives. The compression failure is a result of the explosive gas pressure being far greater than the compressive strength of the rock. This is typically known as the crush zone in the annulus around a blast hole. The diagram in Figure 10 depicts this crush zone. Typically the crush zone (grey) is one to three times the blast hole diameter (blue), dependant on rock type, explosives type and degree of confinement.

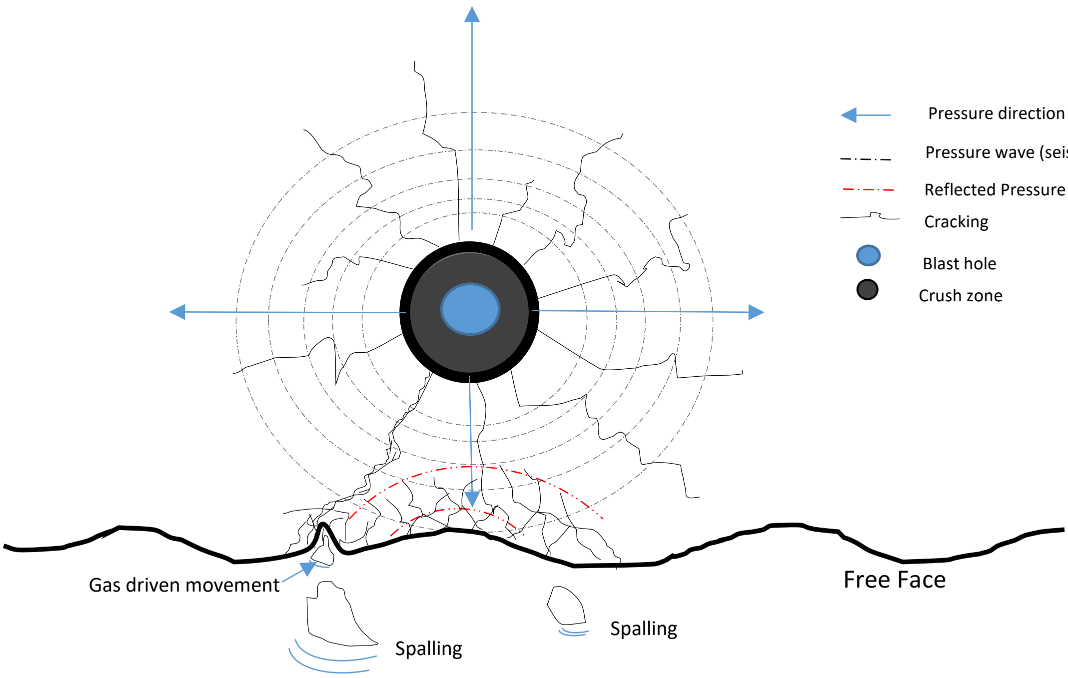


Figure 10 Cross section annotation of blast hole detonation with breakage modes

Post compressional breakage occurs along planes via Primary wave and Shear wave driven cracks. The Primary wave compresses the rock while the Shear wave applies fracturing under tension. Tensional fracturing will occur at much lower pressures than compressional breakage. Wave refection then adds additional fracturing, breaking the rock in tension, identified as red broken lines in Figure 10.

Rock breakage also occurs via the spalling mechanism. This occurs when the pressure waves (p wave, s wave or Rayleigh waves) reflect against a surface and cause flexing (displacement) of the surface. This flexing causes rocks that are not strongly connected to the face to be projected forward when the cohesion strength affixing them to the surface is overcome. This is the mechanism that will be the most probable cause of failure within the caves of the Miralga Creek Project.

The final breakage mechanism is gas movement of the fragments of rock that have been fractured. The explosive gasses move along the fractures causing block movement towards a free face. This movement also creates rock on rock fragmentation.

The minimum separation distance from any blast location to a cave is 23m. This is the distance from cave CMRC-15 to Pit 2. This is a significant distance to the inside cavern face when considering an 89mm, 102mm or 115 mm blast hole. Figure 11 displays a free face blast mid-way through detonation, with blocks that have been displaced via the spalling mechanism from adjacent rock faces.

Figure 11 Quarry with 10 m bench height demonstrating spalling adjacent to a blast firing (Slate Quarry)

Figure 11 shows spalling on the adjacent face occurring at a distance up to approximately 10m from the blast. The pressure pulse moving along the face creates enough displacement to overcome the cohesion of the natural joints to allow the block to move. The charge weight per delay was approximately 70 kg in the blast featured in Figure 11.

The example displayed in Figure 11 is a simplified (“worst case”) scenario as typically the joint set is not parallel to the face angle. This site produces slate tiles and has adjusted the angle of the face to match the geology in order to maximise their recovery of saleable material. In more complex geological situations, the magnitude of the displacement must be great enough to break the joint cohesion and also orientated in the direction that the block of rock will slide out from/to.

To understand the technical requirements of block displacement, e.g. blocks of rocks being dislodged out of a cave's walls and roof by blast induced displacement, an understanding of the conditions required to enable block movement is required, which includes:

- Cohesion between the block fragments and the main rock mass;
- The block size;
- The wavelength of the pressure pulse;
- The displacement caused by the blast vibration on the block.

Typically, mining companies and their consultants tend to consider only blast vibration levels, which is only one component of displacement process. Using wave motion mathematics, Equation 1 Displacement displays the equation and definition of the variables that contribute to the displacement magnitude.

$$Displacement\ (s) = \frac{Vibration\ (v)}{2\ \pi\ Frequency}$$

Where:

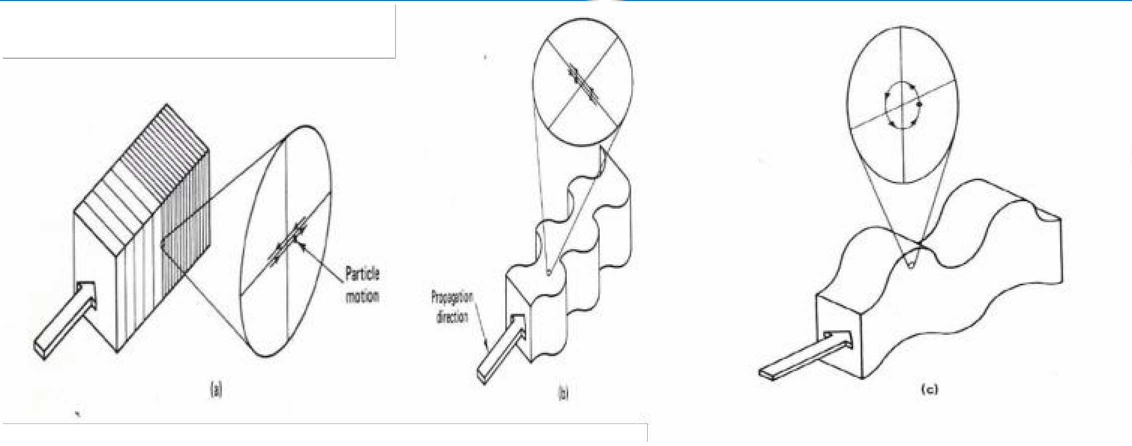
Vibration	Peak component vibration velocity (mm/s)
Frequency	Frequency at which the peak component blast vibration occurs (Hz)

Equation 1 Displacement

Displacement caused by blasting as displayed in Equation 1 Displacement, is a function of the peak component velocity and the frequency at which the peak velocity occurred. This relationship is explored and defined in mathematic text and also in the paper 'Fallacies in Blast Vibration Analysis' (Spathis 2001).

If we consider a blast vibration control limit of 25 mm\s the blast can create displacements from 0.04 mm at 100 Hz to 1.0 mm at 10 Hz. This clearly displays the shortcomings of common industry approaches towards blast vibration control having no defined frequency components in attempting to prevent structural damage at heritage sites.

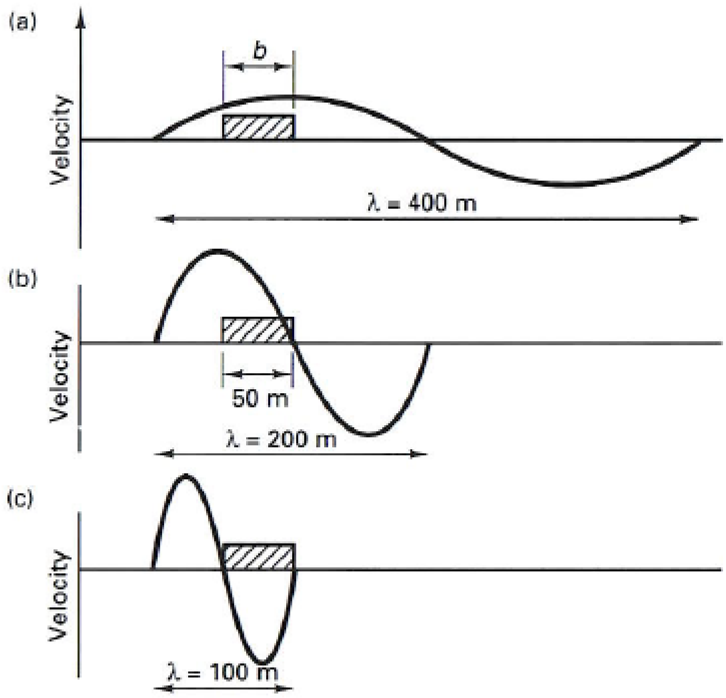
Consideration of the block size is important on larger surfaces as particle motion occurs in a wave, e.g. a surface Rayleigh wave is displayed in Figure 12.



(a) Primary Wave Monition (b) Shear Wave motion (c) Rayleigh Wave Motion

Figure 12 Wave motion (Dowding 2000 pp22)

The requirement to understand wave speed, wave frequency and determine the wavelength is displayed in Figure 13.



Smaller phase difference produces more coherent motion and thus is more appropriate for pseudostatic analysis; examples include 50-m-long block excited by motion with propagation velocity of 700 mis and frequencies of 1.75, 3.5, and 7 Hz: (a) if.,= 45°./ = 1.75 Hz; (b) if.,= 90°,f = 3.5 Hz; (c) if.,= 180°,/ = 7 Hz.

Figure 13 Wave motion and block size (Dowding 2000 pp287)

Case 9(a) in Figure 13 shows that a wave causing displacement to a block must be of at least 8 times the length of block dimension in to propagate movement in a single direction.

With an understanding of the multiple variables that contribute to blast displacement in combination with block size, it can be seen that adopting a limit on a single variable only (in this case a vibration limit) is a blunt approach that oversimplifies the physics. However, it is an over-conservative approach. This is evident if a first principle analysis is undertaken, which would likely support less stringent limits still with appropriate safety margins.

9 Technical Evaluation

Blast vibration and flyrock are assessed using industry recognised equations, which are based on assuming site attenuation constants and inputs of the proposed blast parameters, including separation distances. Fume and dust evaluations are experienced based, using industry knowledge of explosive application techniques.

Using the site's geological domains and proposed mining techniques, blast parameters will be selected and used to evaluate the potential of alternate blast parameters to comply with suggested environmental blasting limits, as outlined in Section 5 Environmental Blasting Concerns.

9.1 Geological Setting

The local geological setting comprises of hematite iron ores with varying degrees of natural weathering. The caves are located within the faces of outcropping ridges consisting of highly weathered banded iron formations and cherts. Weathering occurs naturally through rainfall events, temperature variations (heating and cooling of the rock) and chemical alteration. The effects of weathering are continuous and eventually the caves will collapse when the cave structure can no longer be supported by the surrounding rock.

The effects of weathering can be accelerated by natural events like earthquakes and flooding, and man-made events like blasting and mining. Figure 14 is an example of a weathered and jointed rock mass, similar to the geological conditions at the Miralga Creek Project.

Figure 14 Example of weathered banded iron formations

The natural structure of banded iron formations and cherts, being heavily jointed, provide the ideal setting for small localised failures and loose rocks dropping out of the walls and roofs of the caves.

9.2 Proposed Blast Parameters

Blast parameters are linked to the rock properties, bench heights, mining methods and crushing and processing requirements. The proposed blast parameters will assume a maximum target particle size of 1.0 m for both ore and waste material and will use an estimated powder factor based on the author's extensive experience in blasting these rock types. The mining operations department will be assumed to use a 100T to 250T sized backhoe excavator for excavation of the muck pile.

The proposed mining method may utilise the following blast parameters or similar alternatives:

Pattern Scenario:	A	B	C	D	E
Bench Height (m):	5	5	5	10	10
Blast Hole Diameter (mm):	89	102	115	102	115
Burden (m)	2.7	3.0	3.2	3.0	3.2
Spacing (m)	3.2	3.4	3.6	3.4	3.6
Stemming Length (m):	1.8	2.0	2.3	2.0	2.3
Subdrill (m):	0.4	0.5	0.5	0.5	0.5
Explosives Type (m):	ANFO	ANFO	ANFO	ANFO	ANFO
Explosives Density (gcm^{-3}):	0.82	0.82	0.82	0.82	0.82
Explosives Charge per Blast Hole (kg):	18.4	23.5	27.3	43.9	57.0
Powder Factor (kgm^{-3})	0.43	0.46	0.47	0.51	0.56
Initiation System (1):	Non electric	Non electric	Non electric	Non electric	Non electric
Alternate Initiation (2)	Electronic	Electronic	Electronic	Electronic	Electronic
Maximum Instantaneous Charge (kg) (1):	36.8	47.0	54.6	87.8	114.0
No of blast holes per delay (1)	2	2	2	2	2
Maximum Instantaneous Charge (kg) (2):	18.4	23.5	27.3	43.9	57.0
No of blast holes per delay (2)	1	1	1	1	1

Table 3 Modelled Blast Parameter

The blast parameters documented in Table 3 can be considered an average set of blast parameters, and if implemented correctly will produce the required fragmentation when used by experienced drill and blast designers.

Explosive chemistry is an important factor to consider when selecting an explosive supplier and determining the most economical solution. ANFO will be best suited to the site's geology and environmental sensitivities, as long as the blast holes are not wet and the general ground conditions are not saturated.

In the past, explosive suppliers have supplied Ammonium Nitrate Emulsion (ANE) based bulk explosives for use in wet and dewatered blast holes. There are a wide range of products available, with varying energy and formulations. The chief variation is the proportion of water in the emulsion which can potentially range from 16% to 25% by weight. Increasing the water content decreases the explosives' energy and lowers the sensitivity of the blended bulk explosives.

The geological conditions at the proposed Miralga Creek Project will provide average confinement and therefore, providing the hole diameter is at least 102mm, the bulk explosives should reliably and effectively detonate at densities up to 1.1 gcm^{-3} (average in hole density). In overburden sedimentary materials, bulk explosives with densities over 1.1 gcm^{-3} will commonly produce noxious post blast fume, indicating poor detonation conditions (low ground confinement). Other causes of fume can arise when the product has been desensitised by water (for example ANFO loaded into wet holes). Where the ground geology is causing post blast fume, and water is not the reason, the density of the explosives must be reduced in order to increase the sensitivity of the explosives. This technique is called impedance matching.

Sometimes the blast designer may attempt to increase the explosives' density in order to achieve the desired overall blast powder factor. Using a density that is too high for the ground conditions is a known cause of excessive post blast fume and poor fragmentation results.

Prior to selecting the set of blast parameters to begin blasting at a site, all the required inputs must be considered, which includes all the mechanisms of fragmentation. The required outputs can then be assessed e.g. required environmental results, fragmentation, muckpile heave and costs, using comprehensive and effective methodology.

9.3 Blast Vibration Evaluation

Ground vibration is caused by the detonation of explosives in the ground. For the evaluation of the blast induced ground vibration at the proposed Miralga Creek Project's sensitive sites, industry recognised equations will be used. AS2187.2-2006 recommends the use of the following equation to predict blast vibration levels:

$$PPV = K\left(\frac{R}{\sqrt{Q}}\right)^{B}$$

Where:

PPV	= Peak Particle Velocity (mm/s)
R	= Distance from blast to sensitive receiver (m)
Q	= Charge weight detonating within given time window (8ms for this assessment)
K	= K intercept of line
B	= Slope of the line (slope is negative)

Equation 2 Blast vibration prediction equation

The initial pit development which will include blasting operations may be located, at the closest distance, 23 metres from cave CMRC-15 . Separation distance between the cave CMRC-15 and the proposed Pit 2 is displayed in Figure 15.

The K factor for the prediction of vibration will use a value of 400 for the 50th percentile probability and a value of **800** for the 95th percentile probability. The author's experience would suggest that a K value of **400**, and use of 50th percentiles be acceptable based on previous work conducted at Koodaideri mines site (Martin 2014).

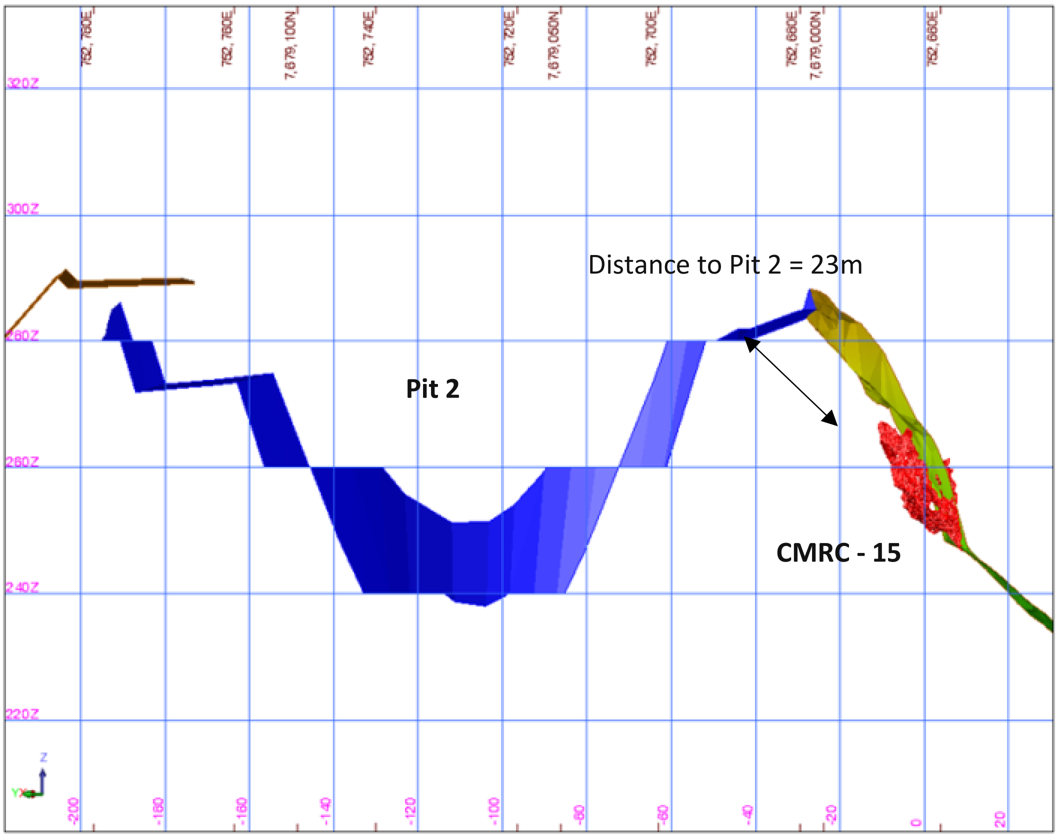


Figure 15 Separation distance between Stage 2 Pit and CMRC-15 cave

Table 4 displays the 50th percentile and Table 5 the 95th percentile prediction of expected blast vibration for each blast parameter scenario at a given distance, using a non-electric initiation system.

Scenario	Distance (m) 23	50	100	150	200	300	400
A	47.4	13.7	4.5	0.1	1.5	0.8	0.5
B	57.7	16.6	5.5	0.1	1.8	0.9	0.6
C	65.0	18.8	6.2	0.1	2.0	1.1	0.7
D	95.1	27.4	9.1	0.1	3.0	1.6	1.0
E	117.2	33.8	11.2	0.1	3.7	1.9	1.2

Table 4 Predicted blast vibration results (mm/s) 50th Percentile (non-electric initiation)

Scenario	Distance (m) 23	50	100	150	200	300	400
A	94.8	27.4	9.0	0.1	3.0	1.6	1.0
B	115.3	33.3	11.0	0.1	3.6	1.9	1.2
C	130.0	37.5	12.4	0.2	4.1	2.1	1.3
D	190.2	54.9	18.1	0.2	6.0	3.1	2.0
E	234.3	67.6	22.3	0.3	7.4	3.8	2.4

Table 5 Predicted blast vibration results (mm/s) 95th Percentile (non-electric initiation)

Table 4 and Table 5 were calculated on the basis of **two holes** firing at any one time (commonly referred to as '2 holes per delay') within a typically sized blast. This is the concept known as the Maximum Instantaneous Charge (MIC). Maximum instantaneous charge is defined as the combined charge weight firing within a given time frame, with the industry standard being an 8 ms firing window for holes of this type. To achieve the MIC generated from only two holes, the blast designer would need to limit the size of the blast **and** carefully choose an initiation sequence using appropriate delay numbers.

The results displayed in Table 2 identify that for the closest separation distance between blasting and a cave, 23m, only a pattern based on 89mm blast holes with a 5 m bench height (Scenario A in Table 3) would suitably ensure compliance with the required 100 mm/s maximum vibration level.

There are ways of firing blasts with a reasonable number of holes and achieving an MIC based on firing **just one hole** per delay. The most common methods of achieving this are to either; fire long narrow blasts with the number of rows being limited (normally 10 rows or less, preferably 5 rows) or to use electronic detonators.

Table 6 repeats the modelling, this time employing an initiation sequence designed to achieve single hole firing.

	Distance (m)						
Scenario	**23**	**50**	**100**	**1500**	**200**	**300**	**400**
A	54.5	15.7	5.2	0.1	1.7	0.9	0.6
B	66.2	19.1	6.3	0.1	2.1	1.1	0.7
C	74.7	21.6	7.1	0.1	2.3	1.2	0.8
D	109.2	31.5	10.4	0.1	3.4	1.8	1.1
E	134.6	67.6	22.3	0.3	7.4	3.8	2.4

Table 6 Predicted blast vibration results (mm/s) 95 Percentile- Single Hole Firing

Based on the results displayed in Table 6, the applicable scenarios are now A, B and C, thus showing that 115mm diameter blast holes could be used under these conditions (Note that the bench height is still limited to 5 m). However, it is recommended that the first blast conducted at the site in close proximity should still utilise a 102mm blast hole to confirm the blast vibration transmission assumptions made in this analysis.

Figure 16 displays the MIC (kg) at a given distance to comply with the 100 mm/s vibration limit for the four caves.

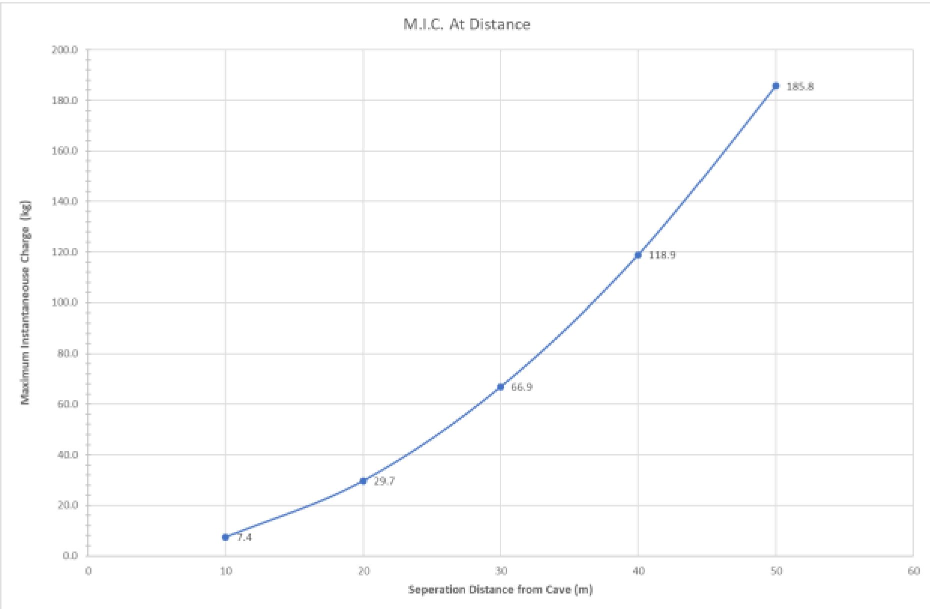


Figure 16 Maximum Instantaneous Charge at Distance to Achieve 100 mm/s Blast Vibration Limit (K = 800)

Concerns will be raised over the blast vibration limit of 100 mm/s to ensure that the structural integrity of all of the caves are maintained in the long term. Without a comprehensive geotechnical survey of the workings, informed general vibration limits can only be applied with regards to structural integrity e.g. limiting rockfall events.

As a comparison, the literature review suggests that new fractures start to form in softer rock (low strength) types at approximately 250 mm/s and in high strength rock types new fractures start to form at +1000 mm/s. Rock that already has fractures and is only sitting in place by confinement of the surrounding rock may start to move and spall at lower levels.

9.4 Blast Fume Evaluation

Blasting of rock using conventional bulk explosives can generate toxic fume (gasses) and dust. Correct bulk explosives selection is a key control for reducing or eliminating post blast fume. In addition to water (steam, vapour), Nitrogen and Carbon Dioxide, post blast fume can also contain toxic gases such as Carbon Monoxide (CO) and the various Nitrogen Oxides (represented as NO_X). This is a concern where caves may be inhabited by native fauna. The Blast Management Plan must address the production of post blast fume and any toxic gases that may be poisonous to humans and fauna at elevated levels.

Carbon Monoxide is an odourless and colourless gas that can inhibit oxygen supply to cells, causing dizziness, headaches, nausea and loss of co-ordination. At higher concentrations it can lead to collapse and death in minutes.

CO can be formed during the blasting process when the bulk explosives fail to detonate completely or at a sufficiently high order. Sometimes this is caused by poor loading practices, inappropriate blast design or failure to adapt the blasting to the specific geological issues present. As an example; Heavy ANFO's and Ammonium Nitrate Emulsion (ANE) \ Ammonium Nitrate Suspension (ANS) (Watergels) have been recorded as generating excessive CO in low confinement geology (softer ground types). Bulk explosives product formulation however is also a major source of CO; Over-fuelled bulk explosives can generate excessive amounts of CO gas due to there being insufficient Oxygen available to be able to fully produce CO_2. An Oxygen balanced bulk explosive (5.7% Fuel to 94.3% Oxidiser by weight ratio) with maximum sensitivity and an appropriate density should be selected when loading within 500m of the roosting habitat entry points. If ground conditions are wet, a low water content ANE or a Watergel must be used to ensure that the detonation conditions are optimal as possible. Excess water content in the emulsion is undesirable for mitigating production of CO.

The most obvious member of the Nitrous Oxides (NOx) is Nitrogen Dioxide (NO_2); a readily visible brown gas at high levels, changing to red, orange and then yellow at lower concentrations. NO_2 is an acrid smelling gas with an irritating sharp odour at 1-5 ppm. It is an eye, skin and respiratory tract irritant and can cause pulmonary oedema, pneumonitis, bronchitis, bronchiolitis and emphysema.

As with CO, NO_2 can be formed when the bulk explosives fail to detonate properly, so appropriate care must be taken with loading practices, blast design and matching products to the geology. Product formulations that are under-fuelled can lead to excessive generation of NO_2 as the excess amount of Oxygen results in the generation of NO_x rather than N_2 as products of the detonation reactions.

Because NO_2 is highly visible and smells bad whereas CO is invisible and odourless there can be a penchant to adjust the oxygen balance of the bulk explosives formulations so they are more fuel rich: thus reducing the likelihood of generating NO_x even when the ground or loading conditions are sub-optimal, thereby getting rid of the obvious fume issue. This must be avoided. To best control toxic fume levels an oxygen balanced bulk explosive should be selected that has a loading density suitable for the geological conditions such that maximum product sensitivity is delivered, and optimal detonation occurs. Most rock masses display no improvement in fragmentation when increasing the bulk explosives density past 1.1 gcm^{-3}, despite the apparent increase in Powder factor. Therefore, to promote the best bulk explosive detonation conditions, a density of 1.1 gcm^{-3} or less should be selected to reduce the potential of toxic gasses in the blast fume cloud.

Figure 8 displays an example of post detonating fume (NOx) at a mine site.

Figure 17 Example of a Post Blast Fume Event (NOx)

9.5 Blast Dust Evaluation

The prediction of post blast dust and controlling the generation of post blast dust has proven a very difficult task. Applying water, misting the blast, applying membranes and chemical retardants have all been tried with minimal benefits. A proven method of control, which is used by many blasting operations located near residential areas, is to monitor weather conditions and only fire the blast when the prevailing winds are blowing away from sensitive structure. This will also assist in restricting any post blast gasses moving toward the roosting habitat entry points. Figure 18 displays an example of a post blast dust event.

Figure 18 Example of Post Blast Dusts

9.6 Blast Flyrock Evaluation

Australian Standard 2187.2-2006 Appendix E highlights considerations for blast designers to minimise the generation of flyrock. Section E2.1 - Contributing Factors, outlines the key blasting parameters that must be considered when addressing controls to minimise the effects of flyrock and developing a safe and productive Blast Exclusion Zone (BEZ).

Many industry experts have developed site prediction methodologies for determining a safe BEZ to protect quarry personnel, equipment, infrastructure and the public. The causes of flyrock have been well studied and documented. The three main mechanisms are rifling, cratering and face bursting. The equations shown in Figure 19 (Richards & Moore) address these three mechanisms of flyrock generation and will be used to determine the safe blast exclusion distances.

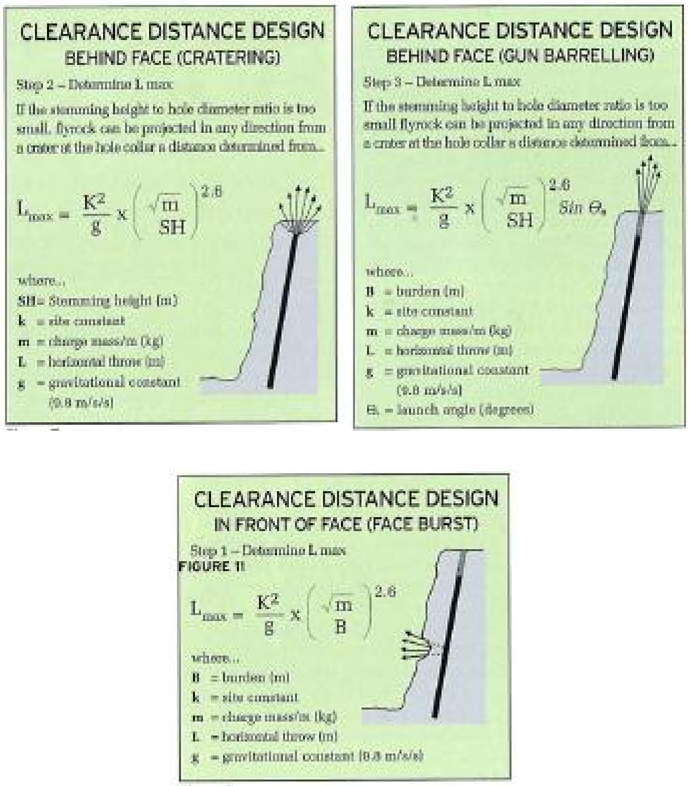


Figure 19 (Richards & Moore) Flyrock Equations

The above equations include a site constant “K”, which requires calibration to site conditions to improve the accuracy of the factor of safety calculation, and in some cases, improve productivity by ensuring good energy confinement. This can be achieved by measuring actual blast parameters and recording the maximum fly rock projection distance from each blast on site, thus ensuring specificity to the site’s drill and blast parameters and geology.

Industry standard K values are from 13 in soft rock, to 27 in hard rocks such as Granite. In this case the absence of any site data suggests that a conservative value of 27 should be adopted initially for “K” to maximise the factor of safety.

The cratering mechanism can be eliminated by ensuring that the correct stemming length is used in relation to the blast hole diameter. Flyrock caused through a cratering scenario is typically associated with poor blast design. The empirical rule that determines the correct stemming length is documented in Equation 3, and also depicted in Figure 20.

$$SD = D/W^{0.333}$$

Where:

SD	= Scaled Depth (m/∛kg)
W	= Charge weight contained in 10 hole diameters (kg)
D	= Distance from point of interest (m)

Equation 3: Scaled Depth of Burial equation

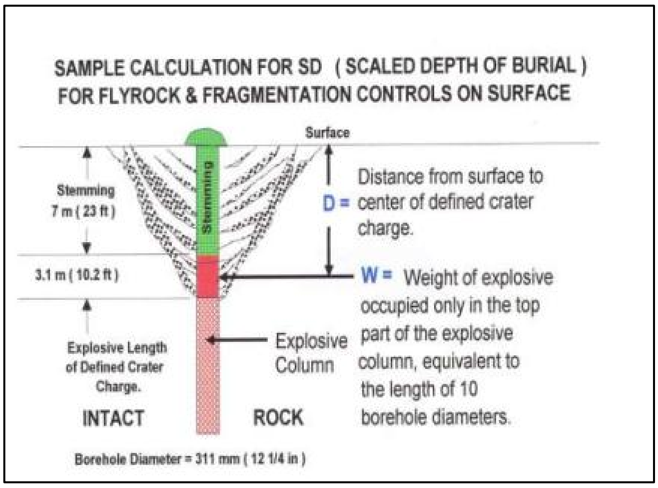


Figure 20 Scale Depth of Burial Dimensions Defined (Chiappetta)

To determine the trajectory of the flyrock, a launch velocity must be calculated using Equation 4:

$$V_0 = \sqrt{\frac{L_{\max} g}{Sin 2\theta}}$$

Where:

θ	= Flyrock launch angle
L_{max}	= maximum flyrock range
V_0	= Launch velocity (ms^{-1})
g	= gravitational constant (9.81 ms^{-2})

Equation 4: Launch velocity

The above equations and techniques were used to determine the safe blast exclusion zone and maximum theoretical flyrock throw distances.

Table 7 lists the blast parameters that have been used to predict the expected blast vibration and airblast overpressure levels in the previous sections of this report, along with the maximum calculated flyrock distances and Scaled Depth of Burial (SDoB). The worst case scenarios were modelled using the equations documented in the in this section of this report. A flyrock constant (K) of 22 was used in all calculations, based on experience in similar rock mass where the flyrock constant were validated. Where the SDoB is greater than 1.3 the “Maximum Horizontal Distance Crater” value was not used.

Pattern Scenario:	A	B	C	D	E
Bench Height (m)	5	5	5	10	10
Hole Diameter (mm)	89	102	115	102	115
Face Burden (m)	3.0	3.5	3.8	3.5	3.8
Burden (m)	2.7	3.0	3.2	3.0	3.2
Spacing (m)	3.2	3.4	3.6	3.4	3.6
Stemming (m)	1.8	2.0	2.3	2.0	2.3
Subdrill (m)	0.4	0.5	0.5	0.5	0.5
Explosive Density (g/cm3)	0.82	0.82	0.82	0.82	0.82
Charge Weight (kg)	18.4	23.5	27.3	43.9	57.0
Max Horizontal Distance Face Burst (m)	29	23	25	23	25
Max Horizontal Distance Cratering (m)	84	96	92	96	92
Max Horizontal Distance Stem Ejection (m)	45	48	46	48	46
SDoB	**1.36**	**1.30**	**1.34**	**1.32**	**1.34**

Table 7: Calculated Worse Case Flyrock Projection Distances (Rock Density = 2.7 gcm^{-3})

A graphical plot of the expected flyrock trajectories is displayed in Appendix 2

. All of the parameter's scenarios comply with a "no flyrock within 50m of the caves" design prerequisite. This will also require a restriction on free face firing be applied for all blasts facing towards a cave e.g. cave CMRC-01. Such blasts must be fired 'choked'; that means fired into broken muck of a least 10 m thickness across the entire front row of the blast. Note that the designs are based on achieving a SDoB factor greater than 1.3 which would support no to minimal cratering type flyrock.

Due to the location of CMRC-13, CMRC-14 and CMRC-15 being positioned over a vertical face, flyrock presents a very low risk to these three sites.

9.7 Initiation Systems Evaluation

Blast vibration control within 100m of the caves would require the use of an electronic initiation system or a non-electric system, depending on the blasting contractor's skill sets. Prior to commencing full scale production blasting it would be suggested that a seed hole firing program be planned and fired to evaluate actual site blast vibration attenuation constants. Determination of the blast vibration constants will enable the selection of the most economic initiation system for reliably controlling blast vibration.

An electronic initiation system should allow the users to control blast vibration with greater ease and flexibility, although both systems can be used to control vibration by experienced blasting professionals. If a scientifically determined blast vibration equation cannot be developed with a high confidence level (for example too much scatter and variation in the observed data points), then it would be suggested that when blasting within 50m of the caves that electronic detonators are used.

9.8 Environmental Blast Monitoring

Due to the difficulties of access to cave sites situated on the lower regions of the escarpment it is recommended that representative monitoring locations are installed on top of the escarpment. A key criterion is that a permanent blast vibration monitoring block (buried concrete, plastic or metal cube or cylinder for bolting on the blast monitor's geophone) is located as close to the cave(s) as possible (ideally within 10 m) and positioned between the cave(s) and the proposed blasting locations. If not located at the cave entry then a surveyor must use the surveyed location of the cave void to determine the closest blast monitoring location to the cave. This requirement applies to cave CMRC-13, CMRC-14 and CMRC-15.

Monitoring of the blast for both airblast overpressure and blast vibration must be conducted for all blasting events conducted within 400 m of a cave site. A minimum of two monitors should be acquired for the project and they should be moved as required so that the two closest caves to any given blast are monitored. Figures 21 and 22 display an example of a blast monitor set up with a permanent monitoring block. This block allows the blast monitor to be quickly and reliably attached (coupled to the ground) on the day of the blast and then removed afterwards. Other more expensive permanent blast monitor installations can be established that use remote dial in communications to download data and notify of blast events and exceedances. Dial in remote monitoring requires at least a 3G mobile signal at the monitor location to be able to remotely recover the data.

Figure 21 Blast Monitor - Day Use Installation with Permanent Mounting Block

Figure 22 Blast Monitor - Microphone and Geophone Installation

All personnel using and installing blast monitoring equipment, and the blast designers and shotfirers in charge, must have undertaken industry training for blast monitoring to ensure sufficient competency to undertake the requirements of this specific blasting scenario.

10 Recommendations

Based on the results of the ground vibration and flyrock modelling for blasting at the Miralga Creek Project, the following recommendations are suggested:

- Select conservative blast parameters, similar to the parameters that have been modelled in this report (Table 3), so as to be compliant with blast vibration limits until measurement, verification and confidence of/in expected blast results have been established;
- Select suitable explosives that have a low probability of producing toxic post blast fume events;
- Establish controls in the Blast Management Plan for blasting when wind conditions will drive post blast dust and potential fume towards cave entry point(s), if human access is required post blast;
- Permanent blast monitoring stations should be established at close proximity to caves requiring structural preservation. The monitor must record ground vibration for all nearby blasts (< 400m). The resultant data plus blast parameters should be used to develop site prediction equations;
- Initial site blasting should commence a minimum of 100m from all the cave locations until the site prediction equations are established with a reasonable level of confidence;
- Establish a periodical inspection of the caves for potential damage to validate that the blast vibration limits are suitable for purpose;
- Ensure that caves are inspected post blast after any >85 mm/s blast vibration event. If damage occurs an investigation must be conducted with root causes established (for example deficiencies in QA\QC, inappropriate blast design or the setting of too high a blast vibration limit). Re-establish controls and\or lower blast vibration limits;
- If insufficient blast vibration expertise available at site, ensure external training of all monitoring personnel, Shotfirers, Supervisors and Drill and Blast Designers. Minimum qualification of Monitor and Control the effects of blasting in the environment RIIBLA402D National Unit of Competency;
- All blasting practices should adhere to documented procedures and design standards to ensure above average confinement of the explosive's charges; and

By implementing the recommendations, Atlas Iron will achieve industry best practice to ensure blasting environmental compliance at the identified caves CMRC-13, CMRC-14 and CMRC-15.

11 Conclusion

Drill and blast activities can be conducted, using the blast parameters modelled in this report, to within close proximity of the four caves without resulting in significant vibration, damage to or collapse of the caves, nor adverse impacts from blast fume or dust. This applies to blasting up to the closest planned point; within 23m of the CMRC-15 cave.

To ensure compliance of the blast results with reference to the site's suggested blasting limits, the following conditions should be implemented:

a) The recommendations in this report are followed; and
b) Best practice blasting processes and procedures are implemented and adhered to.

By implementing the recommendations, Atlas Iron will achieve industry best practice to ensure blasting environmental compliance at the identified caves CMRC-13, CMRC-14 and CMRC-15 and ensure sustainable mining practices.

12 References

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13 Appendices

Appendix 1 Miralga Creek Project cross section profile from closest mining location

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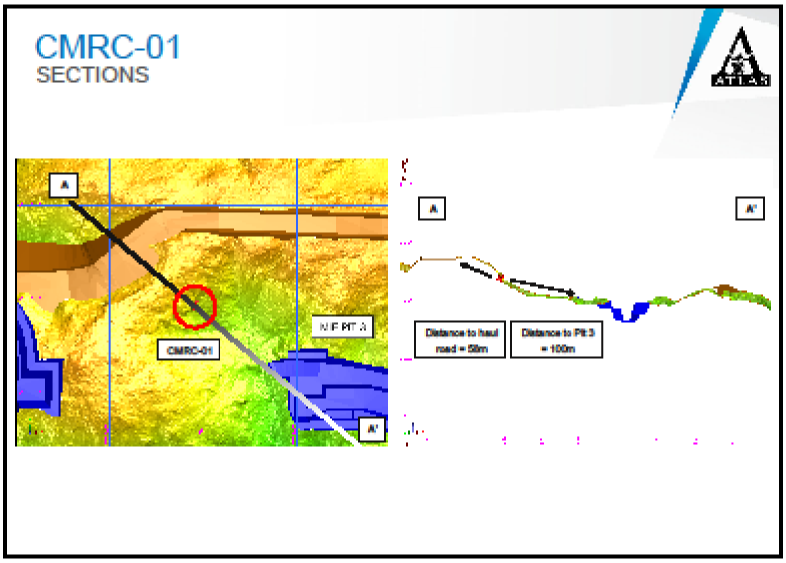

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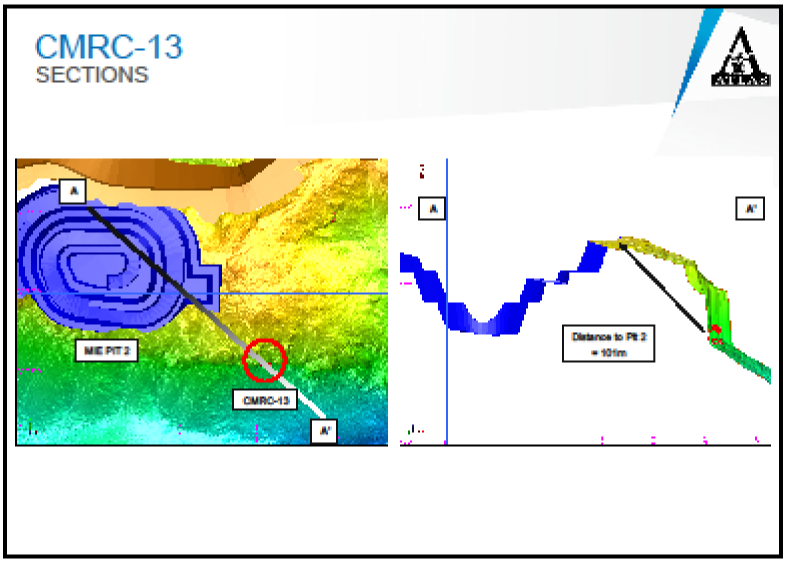

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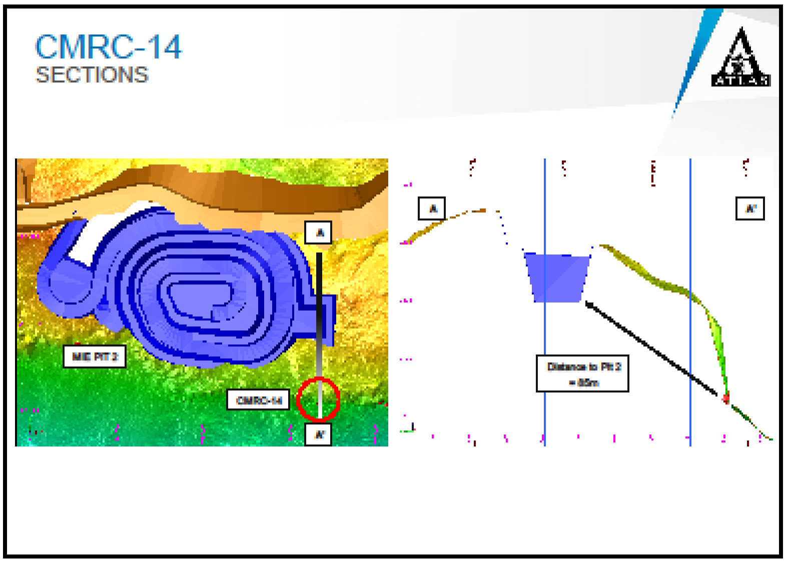

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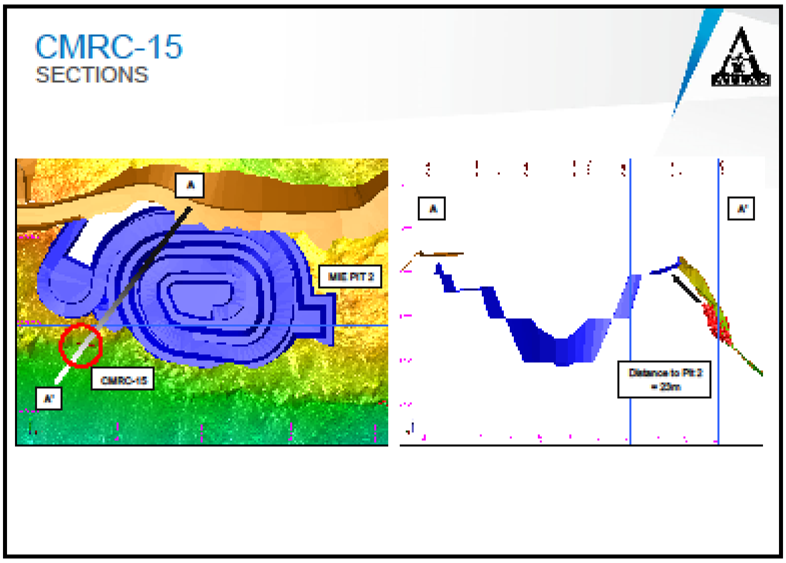

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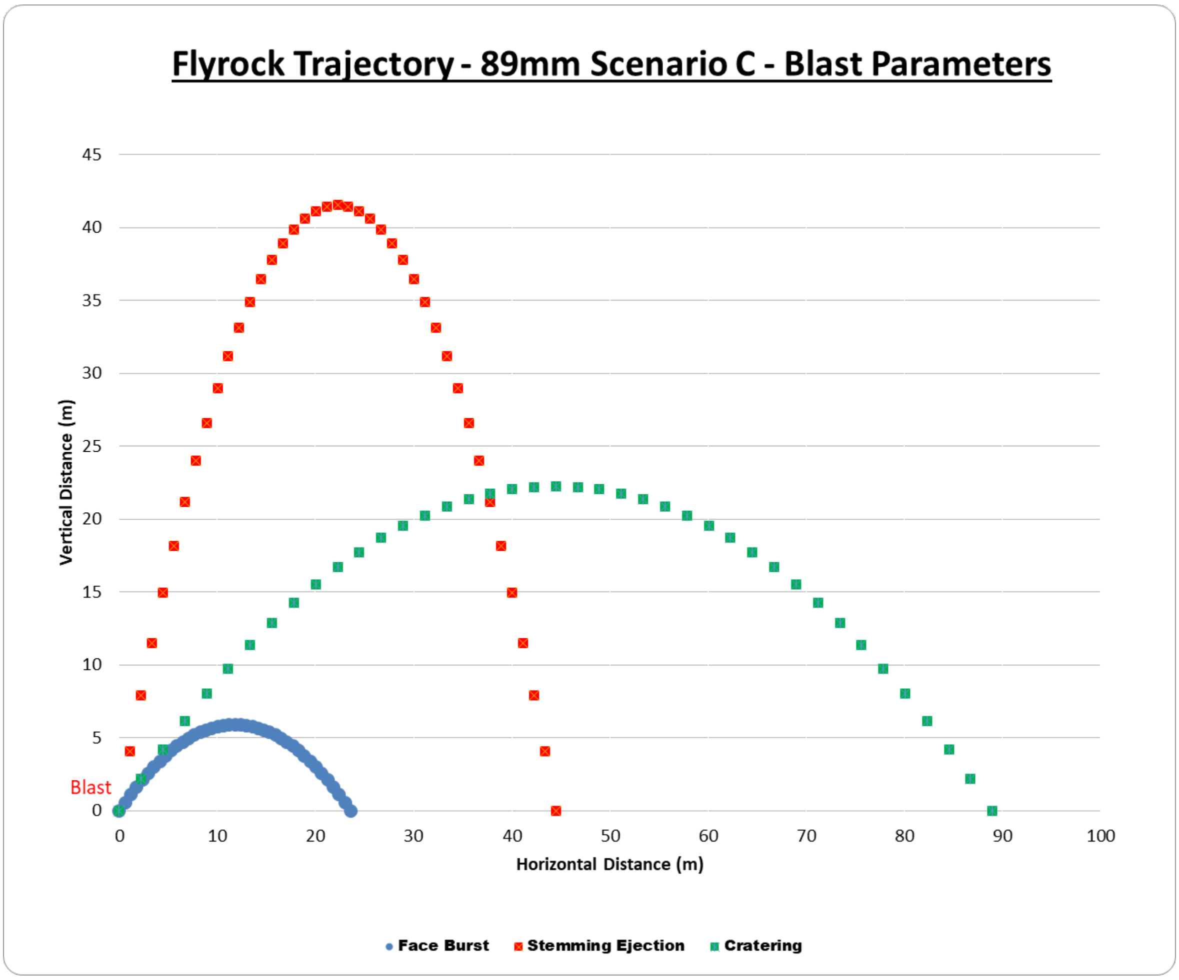
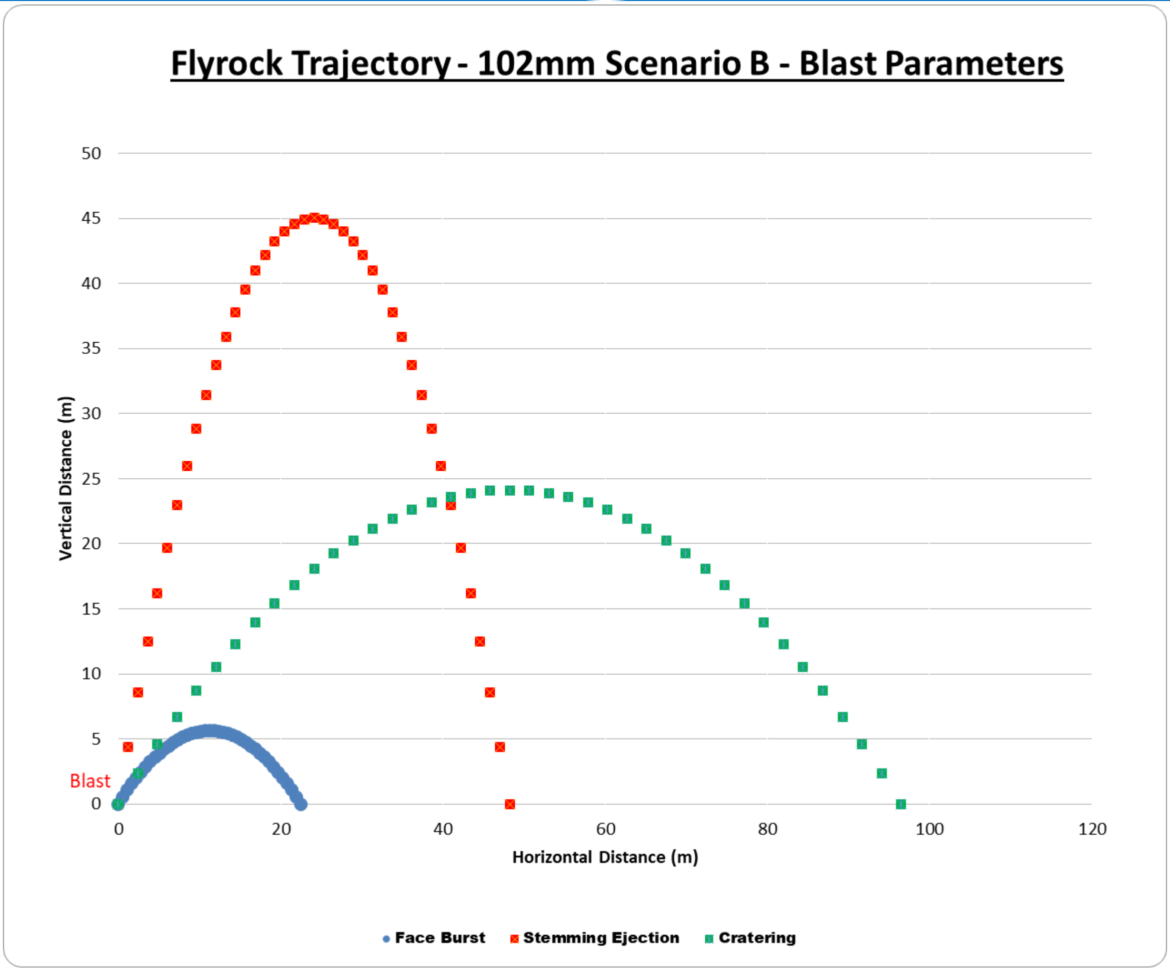
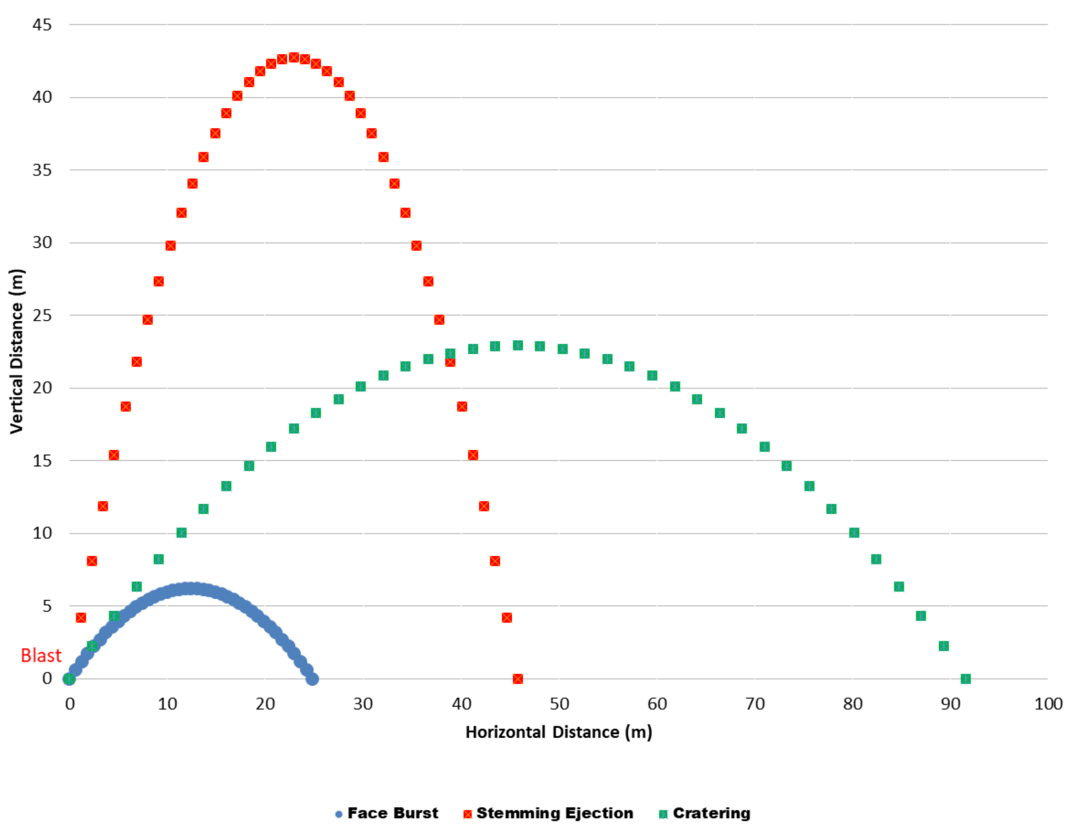
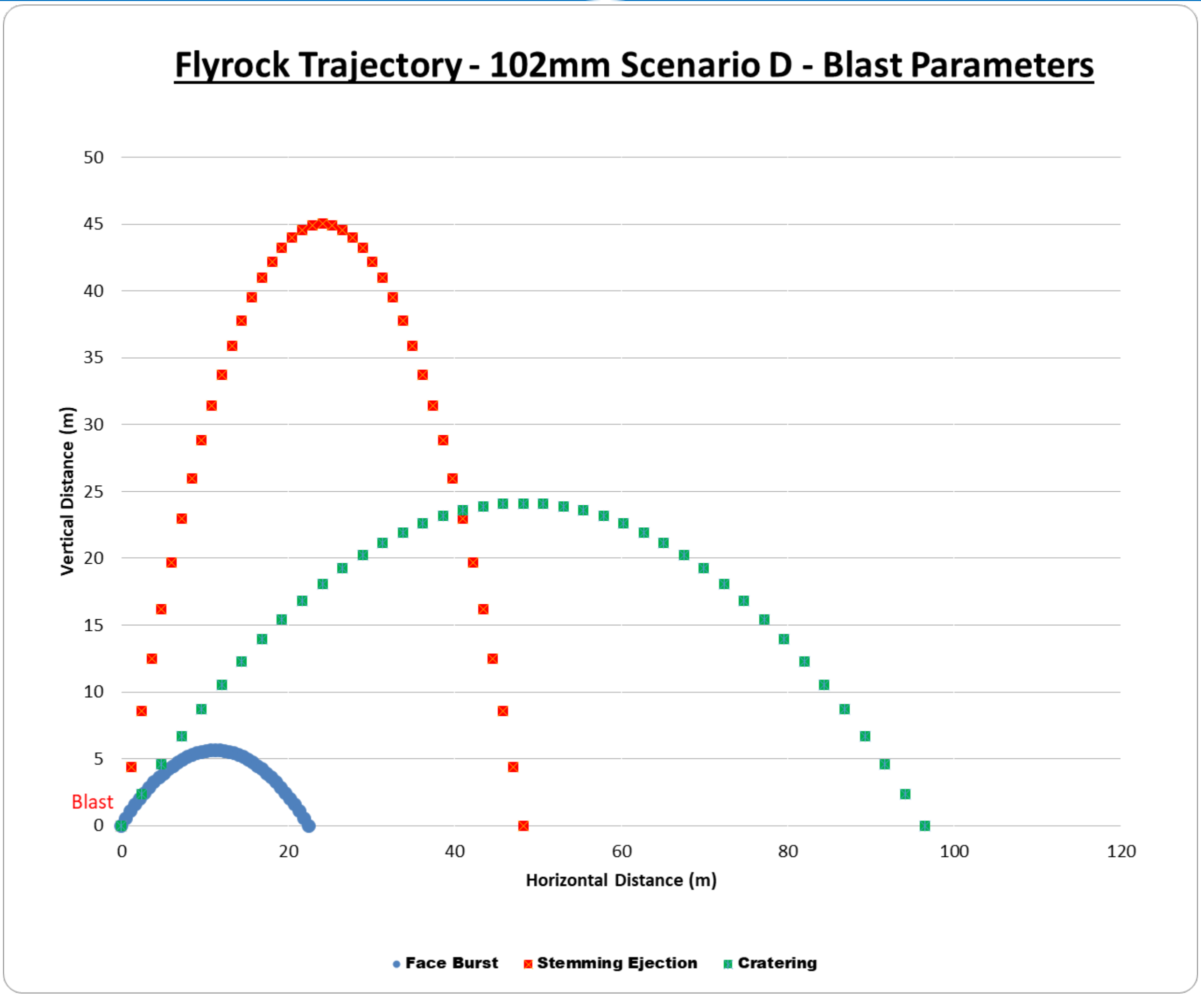

Flyrock Trajectory - 89mm Scenario C - Blast Parameters
Vertical Distance (m)
45
40
35
30
25
20
15
10
5
0
Blast
0
10
20
30
40
50
60
70
80
90
100
Horizontal Distance (m)
Face Burst
Stemming Ejection
Cratering



Flyrock Trajectory - 102mm Scenario B - Blast Parameters
Vertical Distance (m)
50
45
40
35
30
25
20
15
10
5
0
Blast
0
20
40
60
80
100
120
Horizontal Distance (m)
Face Burst
Stemming Ejection
Cratering

Flyrock Trajectory - 115mm Scenario C - Blast Parameters




Flyrock Trajectory - 102mm Scenario D - Blast Parameters
Vertical Distance (m)
Horizontal Distance (m)
Blast
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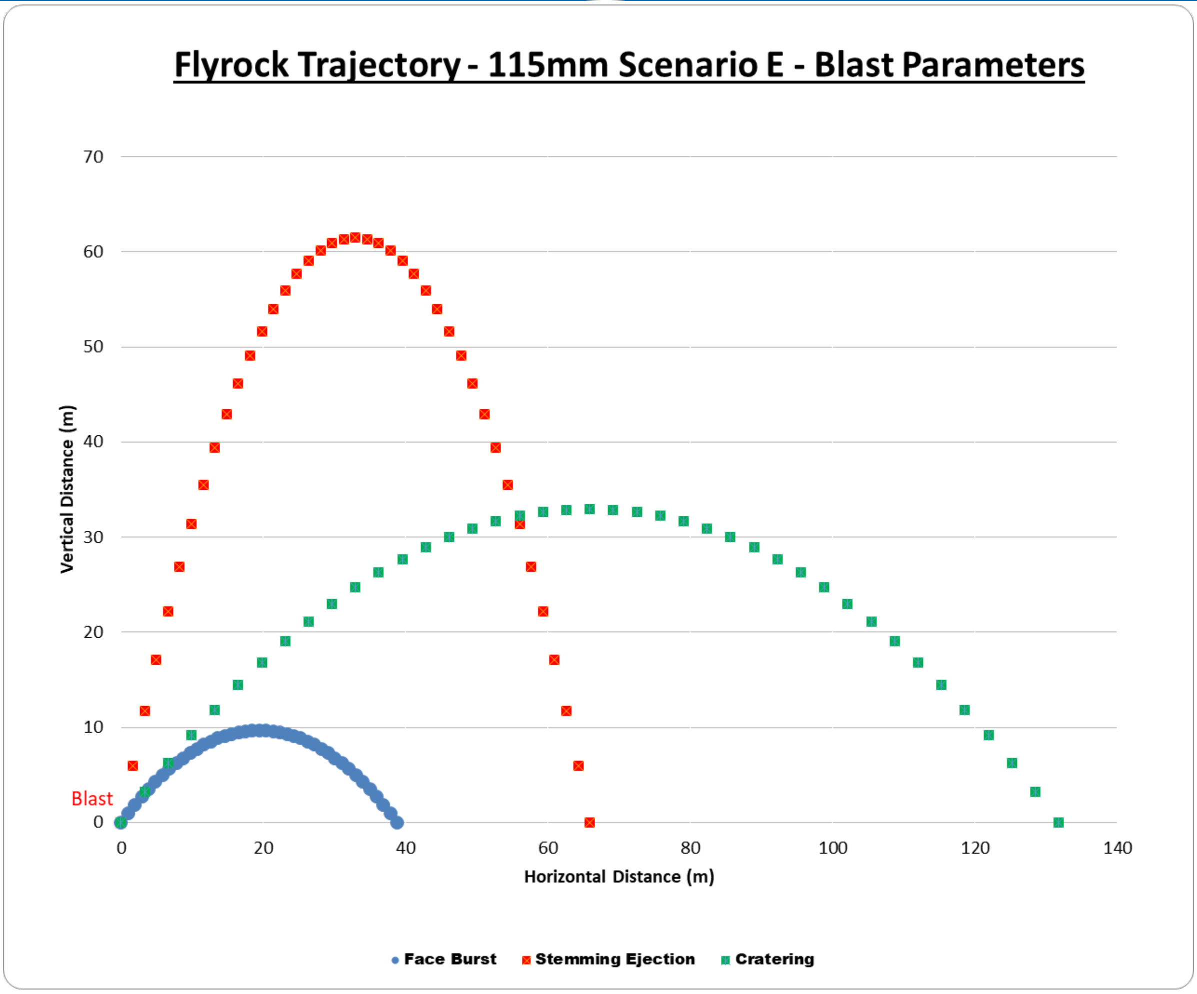
5
10
15
20
25
30
35
40
45
50
0
20
40
60
80
100
120
Face Burst
Stemming Ejection
Cratering


Flyrock Trajectory - 115mm Scenario E - Blast Parameters
Vertical Distance (m)
Horizontal Distance (m)
Blast
0
10
20
30
40
50
60
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0
20
40
60
80
100
120
140
Face Burst
Stemming Ejection
Cratering