Minesure Pty Ltd

Recommendation for Blasting Procedures and Clearances

Mina Do Barroso Project

Client: Slipstream Resources PLC

Draft

Nigel Spicer

30 May 2019

Minesure Pty Ltd

Date:1 June 2019

Client: Slipstream Resources PLC

Attention: Mr Dale Ferguson

Dear Sir

RE: Recommendation for Blasting Procedures and Clearances

Please find enclosed our draft report on the study compiled for the Mina Do Barroso Project.

For and on behalf of Minesure Pty Ltd

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DOCUMENT INFORMATION

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Date:	11 June 2019		
Project Number:	Mina Do Barroso Project		
Version / Status:	draft		
Path & File Name:	C:_tosh_Port Files\A_Savannah_Lith\Blasting Study Mk 2\Blasting Procedures - Mina Do Barroso_20190529_Draft2.docx		

Document Review and Sign Off

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EXECUTIVE SUMMARY

Introduction

Savannah Resources Plc., a London exchange listed company, owns, through its Portuguese subsidiary Slipstream Resources the Mina do Barroso lithium project in northern Portugal. The Project proposes to mine multiple pegmatite deposits for lithium, and possible quartz and feldspar as by-products.

The Mina do Barroso project is located in the northern part of Portugal in the parish of Covas do Barroso, municipality of Boticas, district of Vila Real.

The village of Romainho lies approximately 750m to the north of the northern boundary of the proposed Grandao pit and there is a single dwelling approximately 550m from the proposed pit boundary. The village of Covas is located approximately 800m north west of Romainho and is approximately 800m distant from the edge of the Reservatorio pit final design. Because Covas is sufficiently distant from any blasting activities it is highly unlikely that any effects of blasting could be endured by the residents.

Grandao pit is proposed to be mined in three stages. The northern boundary, closest to Romainho is approximately 100 m inside of the final pit and hence 850m distant from Romainho. It is expected to take four years to complete mining of the first stage which will give ample time in order to optimise the drilling and blast techniques in order to maximise efficiency and minimise any potential risk posed by flyrock.

The Pineiro deposit is located 200m away from the proposed plant location. Given such close proximity precautions, as will be described later, will need to be taken to minimise the risk of damage to infrastructure.

Drilling and Blasting Operations

Where possible rock will be broken by ripping with a dozer however it is expected that drilling and blasting will be required for the majority of the rock. Drilling and blasting consists of drilling a vertical into the rock, placing a primer at the base of the hole ad pouring in a pre-determined quantity of explosives. The remainder of the hole is filled with crushed rock to contain the energy of the explosion. The holes are drilled in a pattern which is designed, upon blasting, to give sufficient rock breakage without producing flyrock or excessive vibration. Low gas emitting emulsion type explosives will be used which provide the required blasting strength without producing high quantities of gas which could lead to flyrock generation.

Designing Blasts

Optimum blast design is dependent on three main factors:

- Energy Distribution
- Energy Confinement
- Explosive Energy Level

Each of these elements determines how efficiently a blast will perform. Poor fragmentation will result if the energy (explosive) is not distributed adequately along the length of the hole. Balanced against this is the need to confine the energy (using stemming) which requires space within the blast hole. The energy level input, ie quantity of explosives, needs to be adequate for the required fracturing but not excessive or too little. Excessive energy results in over fragmentation and excessive throw and the revers results in under-breakage.

Potential issues arising from Blasting

It is proposed that blasting will only take place at midday and 15.00 hours on weekdays so as to minimise any nuisance to the community. Blasting will not take place every day but it is anticipated that two or three blasts per week will be required.

Flyrock

Flyrock can result from:

- Overcharging of explosives;
- Inadequate stemming;
- Loose rocks covering a blast and
- Face break out.

Overcharging of holes means that there is too much explosive in a hole which results with less than optimum stemming. This allows the collar of the hole to break out and be ejected, usually vertically.

The length of stemming is required to contain the explosive energy. If the length is insufficient the results is the same as for overcharging with a visible plume of ejecta.

Loose rocks overlying the blast have the potential to become projectiles especially in conjunction with either of the two previous examples.

Face break out occurs when there is inadequate burden in from of the front row of holes.

The causes of flyrock are operational issues which are easily managed using the correct procedures.

It should be noted that well designed and executed blasts do not generate flyrock.

Potential Flyrock Range

There are no hard and fast rules governing how far flyrock can travel however in 1981 Lundborg published a paper titled “Probability of Flyrock” in the International Journal of Rock Mechanics and Mining Sciences. The work derived a relationship between the maximum travel distance and blast hole diameter. It is proposed that blasting will utilise 102mm (4”) diameter holes as this is consistent with the proposed five metre bench height. Lundborg’s paper shows that the expected maximum throw could be 650m. Whilst

the maximum range is shown as 650m it is highly unlikely that flyrock would actually travel that far under normal circumstances. Another chart developed by Lundborg shows the maximum throw to be 620m.

A current industry standard is to evacuate por place under cover personnel if within 70% of the maximum throw distance. This equates to 500m, using the chosen parameters.

The nearest dwelling is located 550m from the edge of the Grandao final pit so it is not expected to be necessary for any of the inhabitants to vacate buildings during blasting.

Air Over Pressure

This is essentially a shock wave that may be generated by the rapid expansion of gasses from the blasting activities. This can be the result of venting:

- through the stemming (Rifling)
- through the fee face (insufficient burden)
- through the bench crest (over charging)

Venting is usually controlled through the correct design and implementation of blast patterns. The perceived impact will be influenced by meteorological conditions such as:

- Wind direction and speed
- Cloudiness and altitude
- Atmospheric Inversions
- Air Temperature
- Background Noise levels

Air blast may be heard by people if it contains energy in the audible frequency range, typically between 20Hz and 20kHz. However, some of the energy is sub-audible which could manifest itself as the rattling of windows and doors. At distances where both effects are above perceptible levels, air blast is usually felt after any ground vibration.

Mina do Barroso will utilise blast designs and practices that control the production of air overpressure. Control of air overpressure (which represents a manifestation of wasted explosive energy) is also inherent in the optimisation of blasting. Control will be achieved by adhering to strict design parameters.

Blast-Induced Ground Vibration

Ground vibration from blasting is the radiation of mechanical energy within a rock mass or soil. The magnitude of the ground vibration, together with ground vibration frequency, is commonly used to define damage criteria. Studies and experience show that well designed and controlled blasts are unlikely to create ground vibrations of a magnitude that causes damage.

Blast-Induced Dust

The amount of blast-induced dust produced is very dependent upon the friability of the rock being blasted and the ground water conditions. Some rock types such as shales and mudstones disintegrate to dust very easily on blasting whilst the more siliceous rocks tend not to. If the rock is inherently wet or even damp it tends to create less dust whilst blasting than if it were dry.

Impact on the Local Community

Blasting has the potential to create a nuisance for neighbouring residents. The physical effects that may be experienced are:

- Noise
- Overpressure
- Dust
- Smell
- Vibration

Noise is generated by the rapid expansion of gasses during blasting. On a clear day with a northerly wind, inhabitants will hear a slight rumble however with a southerly wind and overcast skies the noise will be much louder and sharper being very similar to a nearby thunderclap. Blasts which are nearby to dwellings should be deferred if the weather conditions are not favourable.

The physical sensation of overpressure may be experienced in conjunction with the noise. It may result in the rattling of windows but should not result in breakage.

As with the noise generation, if the wind is northerly the dust will blow away from the village otherwise blasting should be deferred.

In concentration blasting fumes are toxic however they are very quickly diluted to non toxic levels by the air. Again blasting should only take place if the weather conditions are favourable.

The amount of vibration generated depends on the quantity of explosives initiated and its impact relates to the distance from the blast. Slipstream will install vibration monitoring stations at various locations to monitor any extreme vibration events. Given the planned holes sizes and bench heights vibration levels experienced in Romainho will be well within proscribed limits. Residents may experience a slight ground vibration but it should be very minor and not cause any damage. Slipstream will offer to undertake Dilapidation Inspections of all properties with a 1km radius of the mine in order to establish a base line in case of claims for vibration induced damage.

Slipstream will set up a community relations representative whose contact details will be made available to the local residents to liaise with in the event they have a complaint or wish to make comments about the projects activities.

Blasting precautions and Mitigation Measures

The only structures that will be within the 500m exclusion zone will be associated with the processing plant. The plant is located approximately 200m west of Pineiro pit final design and is thus at risk of being struck by flyrock.

In all instances the same procedures will be followed to minimise risk. These procedures as a minimum will be:

- All blasts to be designed by a competent experienced blasting engineer. Designs will show the position of each hole to be drilled, drill depth of each hole; estimated volume to be blasted, quantity of explosive to be charge per hole; length of stemming per hole and detonator timing delay;
- Each blast is to be designed to blast away from structures.
- Each blast design is to be checked and approved by the Mining Manager.
- Hole positions to be marked on the ground by a surveyor.
- Hole positions to be checked on the ground by the Blasting Engineer and changed if required.
- Holes to be drilled to the blast design specifications in terms of location, depth and inclination.
- The two front rows of the pattern are to be drilled last in case of over-excavation of the face.
- Final drilled hole collars to be located by a surveyor and plotted/checked against the design; any irregularities must be amended.
- The depth of each hole is to be measured and checked against the design; any short holes are to be re-drilled.
- After priming each hole is to be charged with the design quantity of explosives; the shot-firer will record the quantity charged for each hole and this is to be checked against the design; any overcharged holes are to be pumped out to the correct quantity; after charging of each blast the total quantity loaded will be checked against the design total quantity and any anomalies rectified.
- After checking that the charge is correct the remaining depth of holes will be measured to ensure that the correct quantity was charged and that sufficient depth remains in the hole for stemming.
- Holes are then to be stemmed with crushed coarse hard rock aggregate of nominal size 25mm.
- The shotfirer will lay out the surface delay detonators and, before they are tied in, the blasting engineer will check that they are in accordance with the blast design.
- The delays and connectors will be tied in ready for blasting and the blasting engineer will visually check that it is in accordance with the design.

- If the blasting engineer is satisfied that the blast pattern has been loaded and timed in accordance with the design he will sign an approval to blast.
- Prior to the blast the exclusion area will be cleared of personnel and guards positioned to prevent entry. A siren, at a location, to be approved by the company and residents will sound throughout the blasting and only be turned off when the shotfirer has declared the area safe for re-entry.
- A video of each blast will be recorded from a safe vantage point and examined afterwards to identify any rifling indicating potential flyrock.
- Following the blast, the blasting engineer will visually inspect the outcome and note any issues such as over or under break. Photographs of the result will be taken and recorded with the blast design for future reference.

By following this procedure it is ensured that overcharging has not taken place and that holes will explode in the correct sequence thus minimising the risk of flyrock.

Any variations must be approved in advance and in writing by the Mining Manager.

Examples of Towns Near Mines

Having open pit mines near towns is very common as the town growth is in many cases the result of the presence of the mine. The following are examples of where this has occurred. The author personally supervised blasting operation at the first three listed so has first-hand knowledge of the situation.

Southern Cross

The Frazer's pit is located very close to the regional centre of Southern Cross. There are significant number of dwelling within a 500m radius of the pit however evacuation was not considered necessary as controlled blasting methods ensured that there was very little chance of flyrock traveling towards the town. The towns people were alerted when a blast was imminent and advised to take cover although very few did after the first few blasts. The blasting and excavation operations were designed to proceed from south to north so that all blasts were directed away from town. There were no recorded instances of damage to the town buildings.

Marvel Loch

A large proportion of the township is within the 500m zone from the pit edge. The waste rock is completely un-altered and hence very hard. It was only necessary to evacuate one household which was 100m from the edge of the pit whilst blasting near surface along the western edge. The towns people were alerted to blasts by a nearby siren and blast guards were placed to prevent persons getting close to the blast. As with Southern Cross there were no recorded instances of blast damage.

Val D'Or Quebec Canada

Val D'Or is a regional centre in Quebec Province, Canada. The town has a population in excess of 32,000 people. A large number of dwellings are within the 500m radius of the Sigma open pit. The rock is comparatively fresh and hard requiring a high powder factor to achieve fragmentation. The road

bordering the south of the pit is the main highway to the north of the province. It was impractical to evacuate such a large number of people from their homes and, as demonstrated, unnecessary if the correct procedures are followed. Any blasts which occurred within 200m of the road were overlain with blast mats.

Super-Pit Kalgoorlie Western Australia

Whilst the number of dwelling within 500m is less than the previous examples there are still a significant number. The waste at the top of the pit is oxidised and required only light blasting. Consequently it was not necessary to evacuate personnel during blasting.

Summary and Conclusions

- The village of Romainho is located approximately 750m from the northern edge of the Grandao final pit and a single house is located approximately 550 from the edge of the pit.
- The village of Covas is located 800m to the north east of the Reservatorio pit.
- Blasting activities will be required to fragment the ore and waste so that it can be excavated.
- Blasting has the potential to create flyrock which can travel a maximum of 650m based on 102mm diameter blast holes.
- The risk of generating flyrock can be minimised if not eliminated entirely by adhering to the stated procedures.
- Initially blasting will take place approximately one kilometre from the village which gives the mine the opportunity to optimise its blasting practises over several months in order to minimise flyrock.
- Blasting activities generate overpressure, vibration, noise and dust. The nuisance impact of these can be managed by observing correct procedures.
- There are numerous examples world-wide of mines being located a lot closer to towns than is the case at Mina Do Barroso and these have been operated safely.
- In the opinion of the author, blasting operation if undertaken correctly, will pose no danger and minimal inconvenience to the local residents.

1 INTRODUCTION

1.1 Location

Savannah Resources Plc., a London exchange listed company, owns, through its Portuguese subsidiary Slipstream Resources the Mina do Barroso lithium project in the Vila Real district in northern Portugal. The Project proposes to mine multiple pegmatite deposits for lithium, and possible quartz and feldspar as by-products. The ore is to be processed on site to produce a spodumene concentrate which will be trucked elsewhere for further processing. The processing plant is proposed to have a nominal annual throughput of 1.5Mt/y.

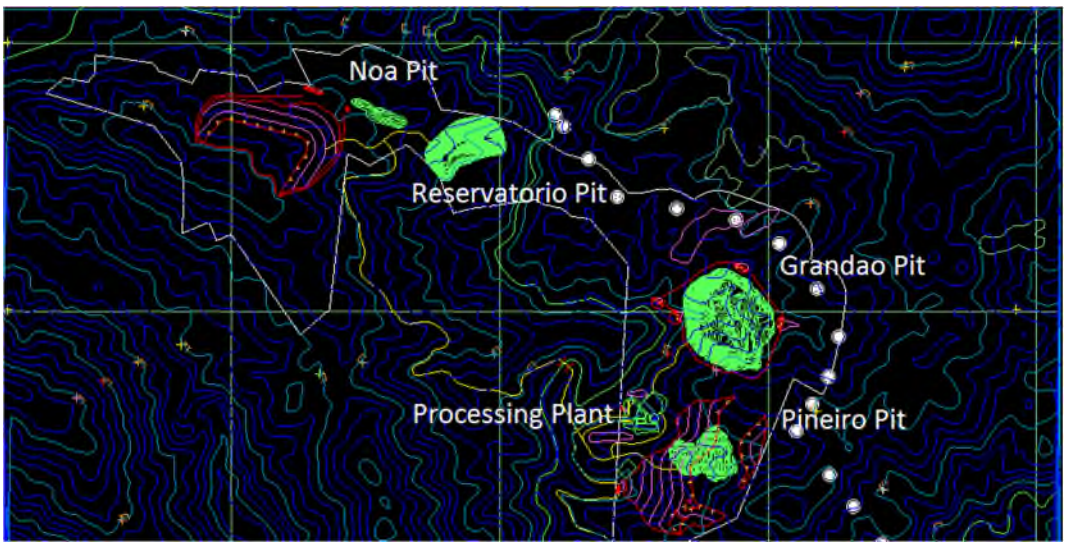
The Mina do Barroso project is located (Figure 1.1_1) in the northern part of Portugal in the parish of Covas do Barroso, municipality of Boticas, district of Vila Real. It lies between the Serra do Barroso and the river Tâmega, approximately 12km to the Southwest of Boticas.

Figure 1.1_1
Project Location

1.2 Proposed Operations

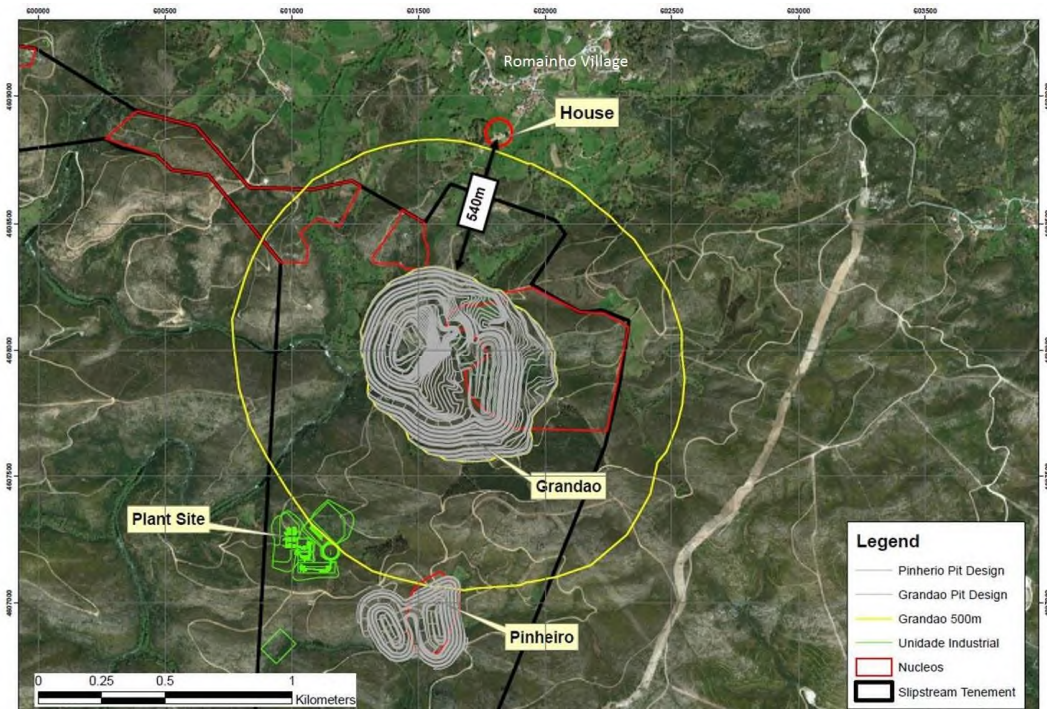
As at the date of this report Slipstream proposes to exploit four main deposits within its approved leases. The general layout of the project is shown in Figure 1.2_1

Figure 1.2_1
General Site Layout



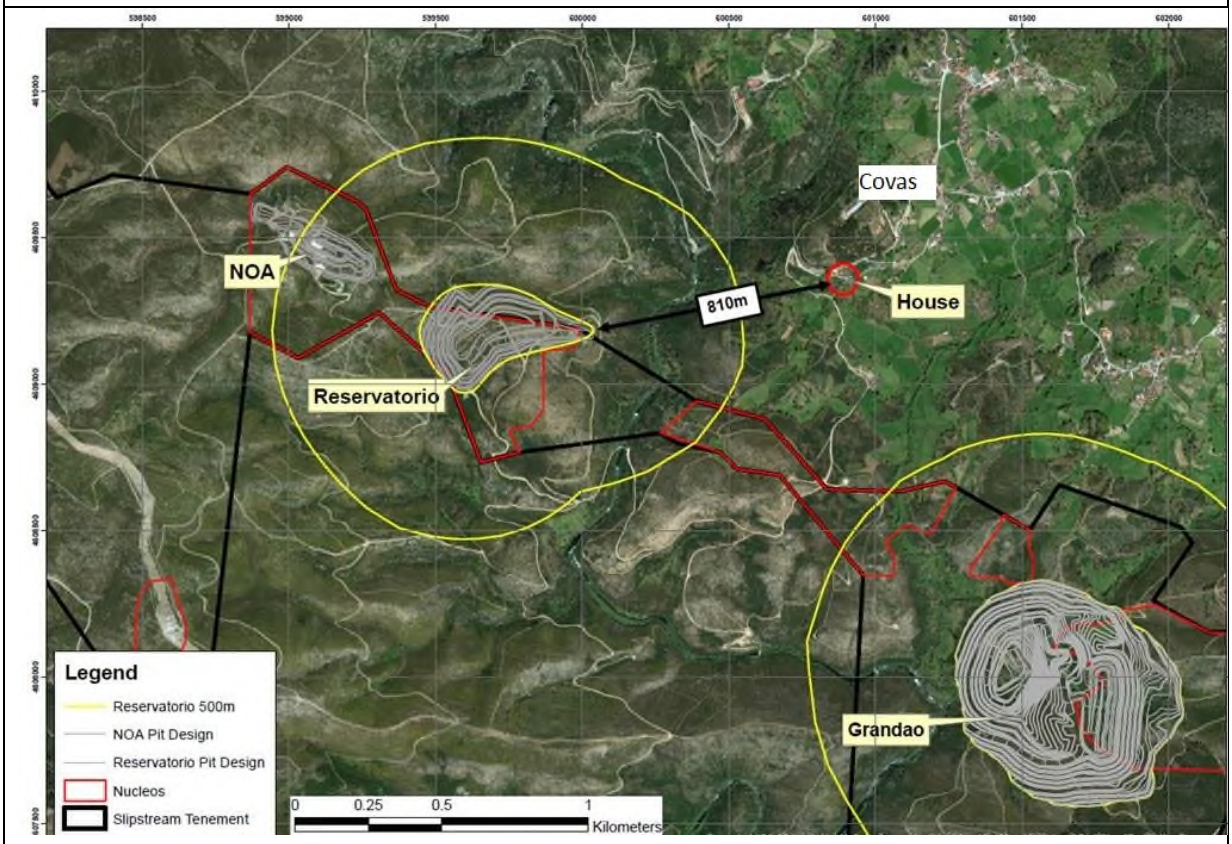
The village of Romainho lies approximately 750m to the north of the northern boundary of the proposed Grandao pit as shown in Figure 1.2_2. As shown in the Figure there is a single dwelling approximately 550m from the proposed pit boundary.

Figure 1.2_2
Grandao Pit in Relation to Romainho



The village of Covas is located approximately 800m north west of Romainho. As shown in Figure 1.2_3 the closest dwelling is approximately 800m distant from the edge of the Reservatorio pit final design.

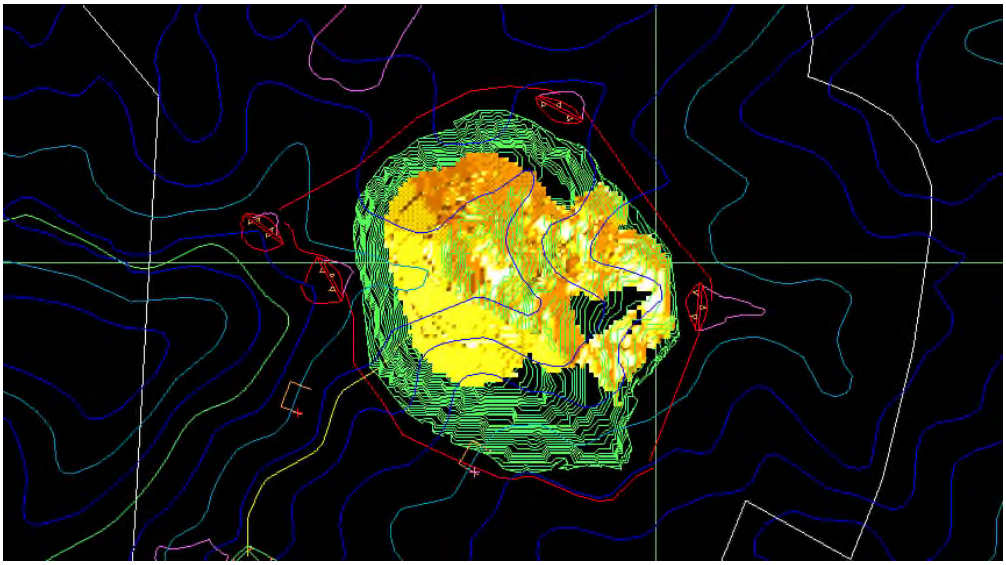
Figure 1.2_3
Reservatorio Pit in Relation to Covas



Because Covas is sufficiently distant from any blasting activities it is highly unlikely that any effects of blasting could be endured by the residents.

Grandao pit is proposed to be mined in three stages. The first stage is the brown shape within the green final design shown in Figure 1.2_3. It shows that the northern boundary, closest to Romainho is approximately 100 m inside of the final pit and hence 800m distant from Romainho. It is expected to take four years to complete mining of the first stage.

Figure 1.2_3
Grandao Stage 1 Pit inside the Final Design



The second stage of mining at Grandao is expected to commence three years after the commencement of operations. The northern boundary of the second stage is coincident with the final design and occurs approximately 700m from Romainho. The three years of mining the first stage is ample time in order to optimise the drilling and blast techniques in order to maximise efficiency and minimise any potential risk posed by flyrock.

The Pineiro deposit is located approximately 500m south of Grandao and is approximately three kilometres south of Romainho. Blasting operations will pose absolutely no risk to Romainho. It is however only 200m away from the proposed plant location. Given such close proximity precautions, as will be described later, will need to be taken to minimise the risk of damage to infrastructure.

The Reservatorio and NOA pits are located 2.5km west of Romainho and as with Pineiro blasting will pose no risk.

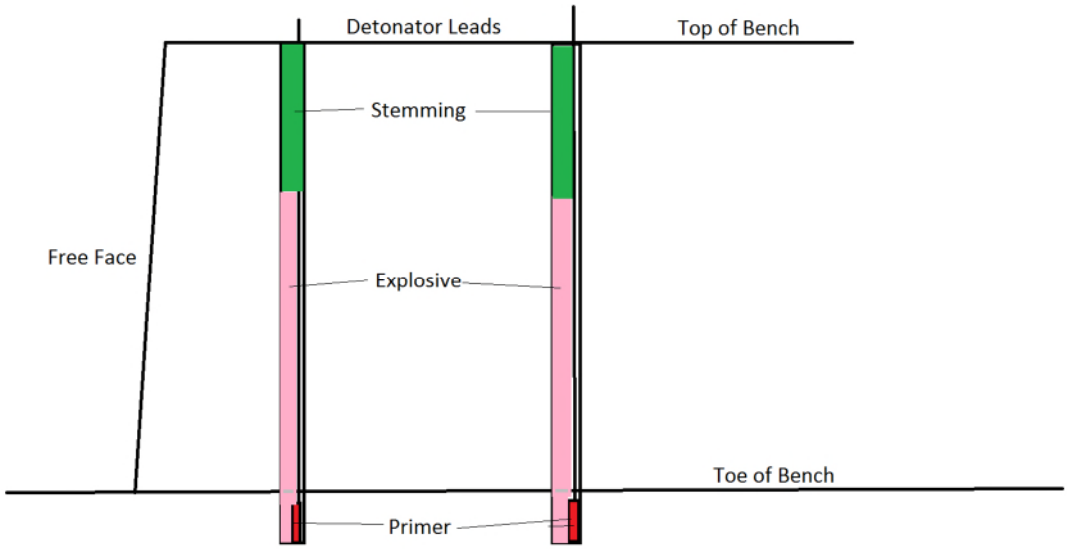
2 DRILLING AND BLASTING OPERATIONS

Drilling and blasting operations are used in mining to break rock which could not otherwise be broken by mechanical means. Near surface oxidised and transitional rock can usually be excavated after being ripped by a dozer and it is expected that this will be the case at Mina Do Barroso. Inefficient blasting can take place on the surface due to irregularities in the rock hardness and cavities. It is preferred to rip oxidised material as opposed to blasting because it is usually less expensive and more productive. It is proposed to rip the surface material down to a depth of at least ten metres if practical. This will benefit the control of movement of blasted material in providing a back stop for the blast.

Drilling and blasting consists of drilling a vertical or steeply dipping hole into the rock. The holes is drilled to a pre-determined depth which in the majority of holes at Mina Do Barroso will be five metres plus a small allowance for “sub-drill”. Sub-drill is additional hole length required to ensure the ground breaks to the required depth and is usually 10% of the holes length. The number and location of holes for each

blast is designed by a blasting engineer who also estimates how much explosive should be charged into each hole. When all the holes in a pattern have been drilled a detonator inserted into a high explosive charge (Primer) is then inserted into the base of the hole. The detonator is connected to the top of the hole by a plastic “shock” tube. The correct weight of explosives is then poured into the hole. At Mina Do Barroso it is proposed to use only “emulsion” type explosives which are liquid with the consistency of thick mud. The emulsion is discharged from a bulk supply truck which very accurately measures how much explosive is poured. When the correct weight of explosives has been poured into the hole the rest of the hole is filled with crushed rock known as stemming. The purpose of stemming is to contain the power of the explosive inside the hole. Upon detonation the stemming, which comprises angular rocks of say 25mm size interlock and form a rigid plug in the hole. This prevents the explosive force ejecting through the top of the hole and contains the energy to break the rock. Two primed, charged and stemmed holes are shown in Figure 2_1.

Figure 2_1
Primed, Charged and Stemmed Blast Holes



Upon blasting a signal is transmitted to each detonator according to a designed timing schedule. The holes at the front of the blast are initiated first with the following rows following sequentially. By blasting rows sequentially it allows time for the broken rock in front to move slightly forward and provide an opening for the next row to fill. By designing the timing of the detonations accurately the forward movement (throw) of the broken rock can be controlled. For a five metre high face the throw should not exceed five to ten metres.

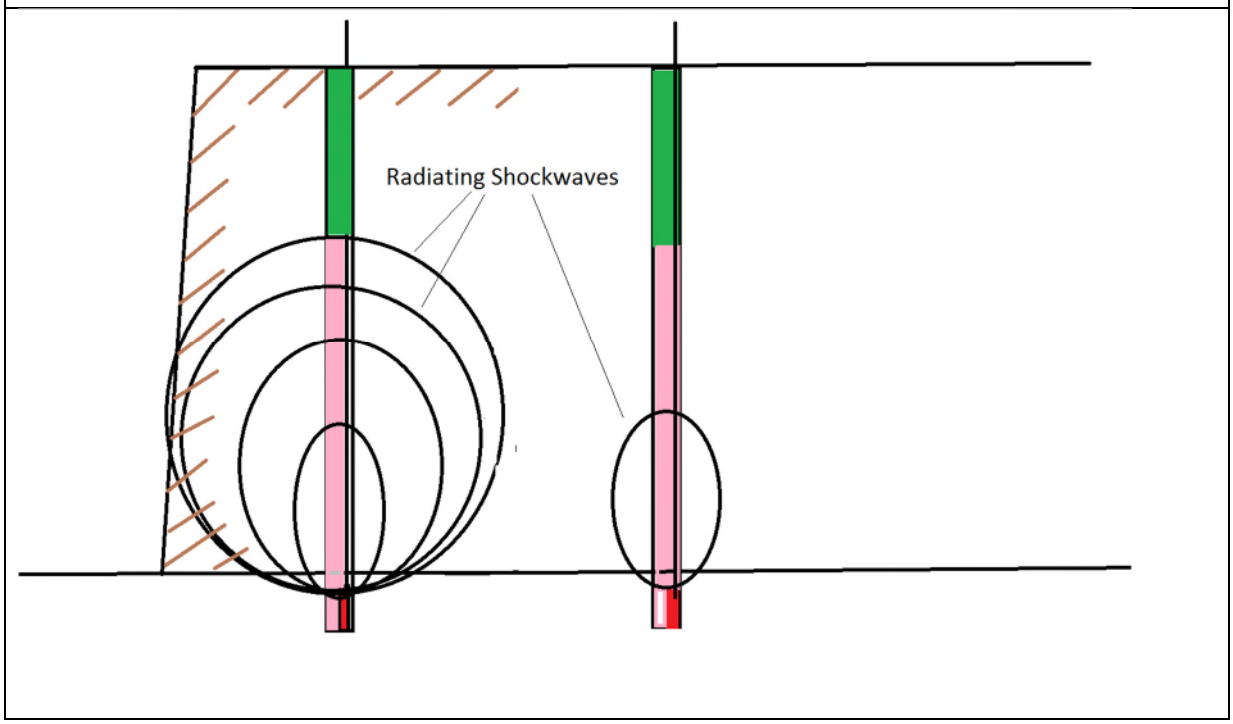
There are two components to blasting that must be considered:

- Shock waves
- Gas generation

The shock waves does the actual fracturing of the rock. Figure 2_2 shows a simulation of the shock waves generated by the blasting. The shock starts at the detonator and radiates out in a concentric wave like manner and this fractures the rock.

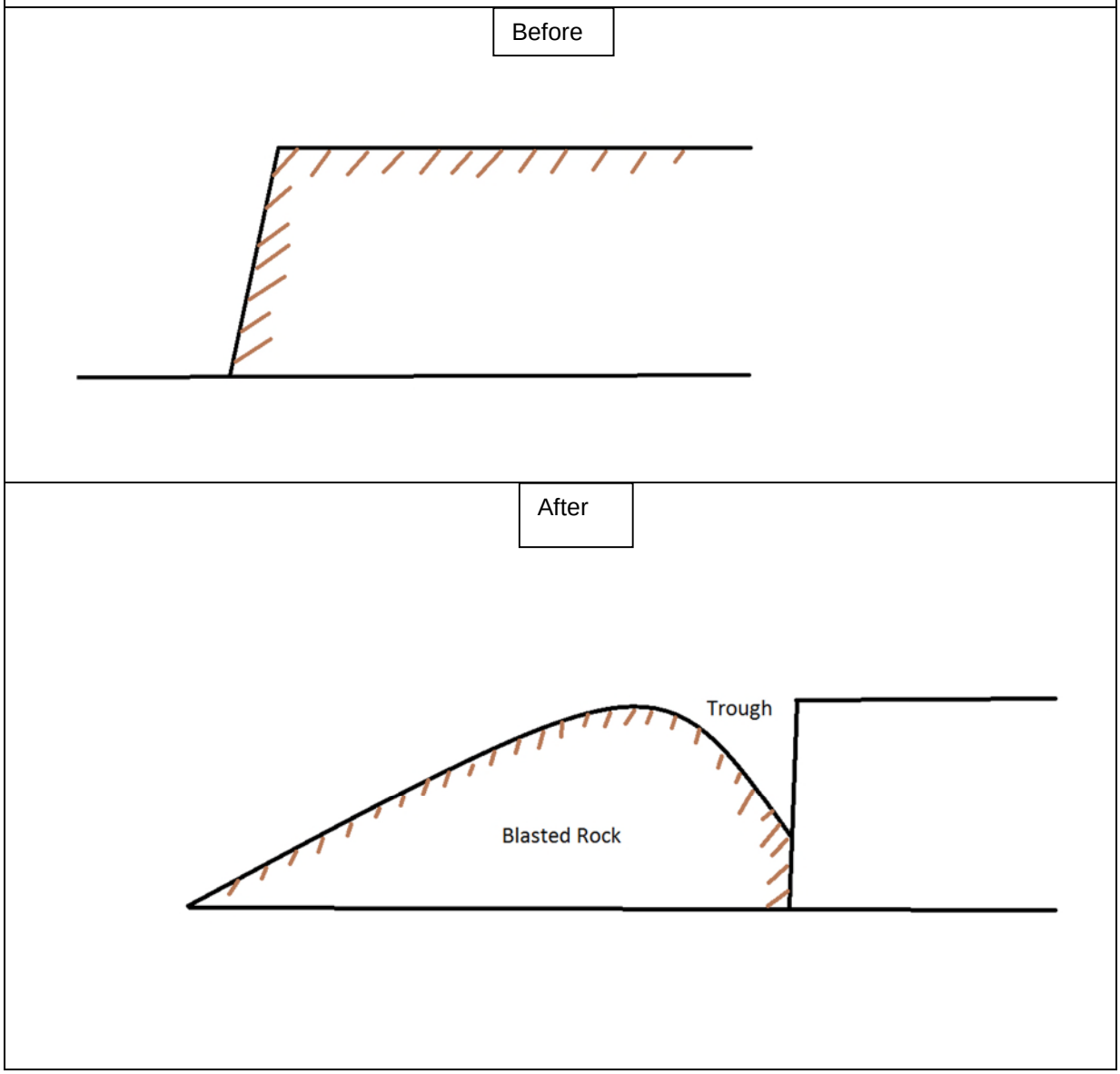
Figure 2_2

Blasting Simulation



A by-product of an explosion is the production of gas. This is responsible for moving the broken rock forward. The more gas that is generated the more movement (throw) occurs. It is generally desired to minimise the throw to make it easier to excavate the broken rock. It is proposed to use an emulsion type explosive which has a low gas generation characteristic in order to minimise throw. Before and after profiles of a blast pattern are shown in Figure 2_3.

Figure 2_3
Section of Bench Prior to and After Blasting



The after figure shows the ideal result with a narrow trough towards the rear of the blast and the majority of the broken rock in a neat pile.

3 DESIGNING BLASTS

3.1 Optimisation of Blast Design

Optimum blast design is dependent on three main factors:

- Energy Distribution
- Energy Confinement

- Explosive Energy Level

Each of these elements determines how efficiently a blast will perform. Poor fragmentation will result if the energy (explosive) is not distributed adequately along the length of the hole. Balanced against this is the need to confine the energy (using stemming) which requires space within the blast hole. The energy level input, ie quantity of explosives, needs to be adequate for the required fracturing but not excessive or too little. Excessive energy results in over fragmentation and excessive throw and the revers results in under-breakage.

3.1.1 Energy Distribution

To achieve the required fragmentation the explosive must be evenly distributed throughout the volume to be blasted. The vertical distribution is proportional to the height of the bench and the diameter of the blast hole. Horizontal distribution is relative to the burden between rows and spacing between holes in each row. To achieve the necessary distribution the blast pattern must be designed to its optimum and then implemented as accurately as possibly.

There is a trade-off between the ideal hole size for uniform distribution and the practical hole size. Peppering a blast with small diameter holes which would give extremely good distribution is a lot more expensive than drilling large holes. Too large diameter holes would concentrate the explosive energy at the bottom of the hole reducing the rock in the immediate vicinity to dust whilst the rock along the remaining length of the hole would probably remain intact. The extract from the Dyno Nobel Blasting guide(Figure 3.1.1_1 illustrates how the design parameters can be initially estimated.

Figure 3.1.1_1
"Rules of Thumb" for Blast Design

Rules of thumb

These rules provide a first estimate in the absence of any better data.

Blast hole diameter in mm ≤	15 x Bench height (BH) in metres
Bench height (BH) in metres ≥	(Blast hole diameter (D) in mm)/15
Burden (B) =	(25 to 40) x (D)
Spacing (S) =	1.15 x B (This gives an equilateral pattern)
Subdrill =	(3 to 15) x D
Charge length (C) ≥	20 D
Stemming ≥	20 x D or (0.7 - 1.2) x B
Burden stiffness ratio =	BH/B : 2 to 3.5 good fragmentation : > 3.5 very good fragmentation
Stemming material size =	D/10 to D/20 (Angular material with minimum fines)

3.1.2 Energy confinement

In order to maximise the efficiency in blasting the explosive energy must be confined sufficiently long after detonation to create fracturing. This is achieved by stemming the blast holes with suitable material which will act as a plug to stop the release of energy out through the collar of the hole. Similarly, the burden in front of the hole needs to hold intact long enough for the rock between holes to become fractured. If the depth of stemming is too long it does not allow the energy to fracture the upper levels resulting large rocks (oversize).

3.1.3 Energy Level

The energy level must be sufficient to fracture the rock by overcoming its structural strength and at the same time provide controlled displacement of the broken rock. There is a relationship between the strength of rock and the energy needed to fracture it. Whilst this can be estimated theoretically it can only be accurately determined by field trials.

Drilling and blasting is typically a third of the cost of mining so each blast is planned to minimise the cost and maximise the efficiency. This in turn minimises the risk of flyrock generation. The amount of energy required to fracture rock to the desired size depends on many factors with the main one being the rock hardness. Generally the harder the rock the more power is needed to break it. There are two main types of rock at Mina Do Barroso:

- Schist
- Pegmatite

Schist comprises a compressed shale type rock which is typically highly foliated and includes substantial quantities of mica. The mica occurs as small platelets along the foliations and has a lubricating effect on the rock. Consequently the rock becomes friable if disturbed and is hence easily broken.

Pegmatite is mainly a coarse grained quartz matrix with minor inclusions of feldspar, mica and lithia (lithium dioxide). Unaltered pegmatite is a strong competent rock however the strength is very dependent on how much it has been altered by tectonic and environmental conditions. Near surface pegmatite will tend to be friable due to the actions of moisture over millions of years and deeper rocks could be folded and faulted by tectonic activities which induce fracture planes at micro and macro levels. Based on observation of similar deposits it is expected that the pegmatite would be friable down to a depth of 20m to 30m below surface.

The quantity of explosive (kg) required to break one bank cubic metre (bcm) of rock is known as the powder factor and as explained above varies by rock type and degree of alteration. Typical powder factors for the present rock types are shown in Table 3.1.3_1

Table 3.1.3_1 Rock Types and Powder Factors			
Rock Type	Hard or Soft	Powder factor kg/bcm	Predicted % (Grandao)
Altered Schist	Soft	0.4 – 0.55	13
Altered Pegmatite	Medium Soft to Hard	0.5 -0.65	2
Fresh Schist	Medium	0.5 - 0.65	72
Fresh Pegmatite	Hard	0.7 – 0.9	13

The table demonstrates that the majority (87%) of the material to be blasted will have a low powder factor. Only the fresh pegmatite will have a high factor and this will occur in the deeper parts of the pit.

4 POTENTIAL ISSUES ARISING FROM BLASTING

It is proposed that blasting will only take place at midday and 15.00 hours on weekdays so as to minimise any nuisance to the community. Blasting will not take place every day but it is anticipated that two or three blasts per week will be required.

4.1 Flyrock

4.1.1 Causes

Flyrock can result from the following:

- Overcharging of explosives;
- Inadequate stemming;
- Loose rocks covering a blast and
- Face break out.

Overcharging of holes means that there is too much explosive in a hole which results with less than optimum stemming. This allows the collar of the hole to break out and be ejected, usually vertically. This is known as rifling. The ejected smoke and dust trail, similar to a rocket launch, can easily be seen.

The length of stemming is required to contain the explosive energy. If the length is insufficient the results is the same as for overcharging with a visible plume of ejecta.

Loose rocks overlying the blast have the potential to become projectiles especially in conjunction with either of the two previous examples.

Face break out occurs when there is inadequate burden in from of the front row of holes. In order to work efficiently each row requires a certain amount of resistance and if for example the face has been over excavated there is not enough containment of the force such that the rocks in front of the holes become projectiles.

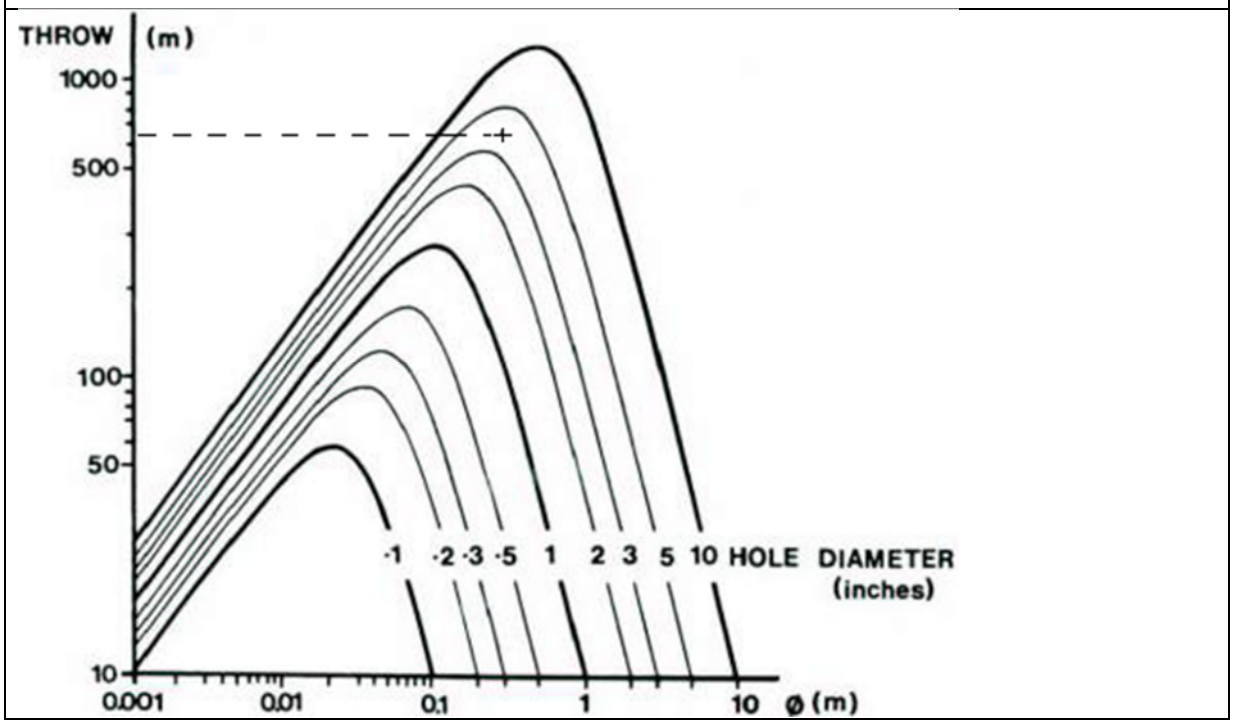
The causes of flyrock are operational issues which are easily managed using the correct procedures.

It should be noted that well designed and executed blasts do not generate flyrock.

4.1.2 Potential Flyrock Range

There are no hard and fast rules governing how far flyrock can travel. In 1981 Lundborg published a paper titled “Probability of Flyrock” in the International Journal of Rock Mechanics and Mining Sciences. The work was based on observations and as such is empirical. The work derived a relationship between the maximum travel distance and blast hole diameter. The relationship is shown in chart form in Figure 4.1.2_1.

Figure 4.1.2_1
Flyrock Maximum Throw Chart (Lundborg 1981)

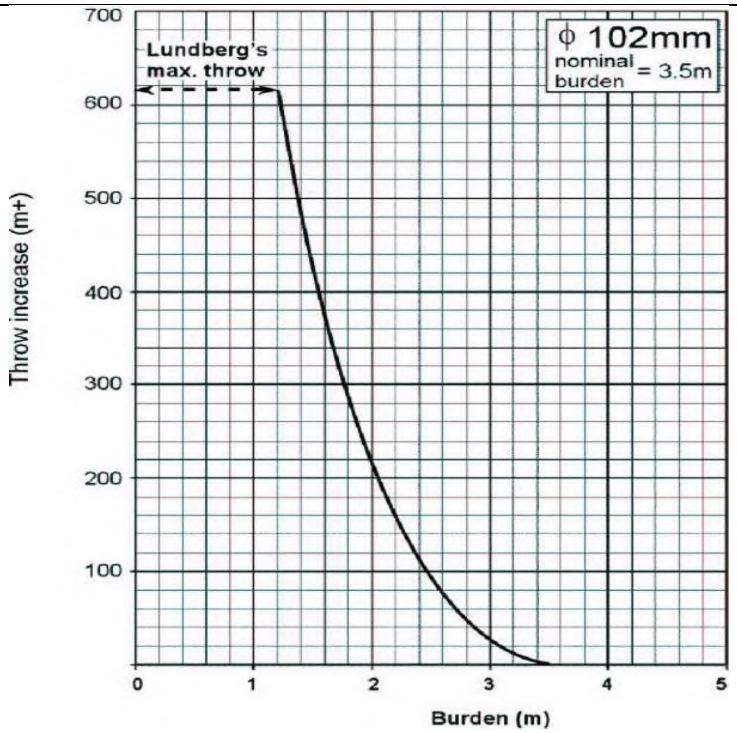


It is proposed that blasting will utilise 102mm (4”) diameter holes as this is consistent with the proposed five metre bench height. The dotted line shows the expected maximum throw which equates to 650m.

Whilst the maximum range is shown as 650m it is highly unlikely that flyrock would actually travel that far under normal circumstances.

Figure 4.1.2_2 shows another chart developed by Lundborg to show the relationship between the hole burden and maximum throw relating to the size of the blast hole. For the nominated hole diameter of 102mm the maximum throw is shown to be 620m.

Figure 4.1.2_2
Relationship Between Flyrock Throw and Burden (Lundborg 1981)



A current industry standard is to evacuate por place under cover personnel if within 70% of the maximum throw distance. This equates to 500m, using the chosen parameters. The industry standard relative to blast hole diameter is shown in Table 4.2_1

Table 4.1.2_1
Industry Standard Evacuation Distance

Nominal Bench Height	Blast Hole Diameter	Personnel Evacuation Distance
m	mm	m
5	102	500

As shown in Figure 1.2_2 there is a dwelling which is 550m from the edge of the Grandao final pit so it is not expected to be necessary for the inhabitants to vacate the building during blasting.

4.2 Air Over Pressure

This is essentially a shock wave that may generated by the rapid expansion of gasses from the blasting activities. This can be the result of venting:

- through the stemming (Rifling)

- through the fee face (insufficient burden)
- through the bench crest (over charging)

Venting is usually controlled through the correct design and implementation of blast patterns.

Atmospheric factors may exacerbate the sensation of the over pressure such as:

- Wind direction and speed
- Cloudiness and altitude
- Atmospheric Inversions
- Air Temperature
- Background Noise levels

4.2.1 Air Overpressure Prediction

Airblast may be heard by people if it contains energy in the audible frequency range, typically between 20Hz and 20kHz. However, some of the energy is sub-audible and lies in the frequency range between 2Hz and 20Hz. Such low frequency airblast is often experienced indoors as secondary audible effects, such as rattling of windows and of sliding doors. A blast perceived as loud may have a low airblast level and a blast that is barely noticeable outdoors may have a high airblast level.

At distances where both effects are above perceptible levels, airblast is usually felt after any ground vibration. Airblast is generally the cause of more complaints than ground vibration.

Because of a large dynamic range, airblast levels are measured typically on a logarithmic decibel scale (dB). On this scale, an increase of 6 decibels represents a doubling of the sound pressure levels. Airblast levels may also be reported as an A-weighted (dBA) or C-weighted (dBC) value. These scales adjust the frequency content of the measured airblast time history. Linear weighting (dBL) implies no adjustment of the frequency content in the measured records. The A-weighting is commonly associated with the hearing response of humans and is most often used for assessing general noise levels associated with machinery and vehicular traffic.

The publication (out of print) from an explosives manufacturer “ICI – Handbook of Blasting Tables” describes a method for prediction of Airblast Overpressure, as per the equation:

$$\mathbf{P = C\,(R/Q^{1/3})^{-1.2}}$$

P = pressure (kPa)

C = Constant (determined mainly by level of confinement and atmospheric conditions)

R = Range (metres)

Q = Quantity of explosives (kg per unit time)

To convert kPa to dBL the following equation is used:

$$\mathbf{dBL = 20 \log \ (P/2.0265x10^{-8})}$$

The main challenge inherent to the numerical prediction of airblast is determination of the constant C. This value must be determined from the degree of confinement of the charge combined with consideration of the atmospheric conditions at the time of firing.

The "ICI – Handbook of Blasting Tables" suggests that for "fully confined blasthole charges" in average atmospheric conditions, the constant C = 3.3 while for unconfined charges the constant C = 185.

These results from the equations assume that one hole per delay is achieved (ie no constructive interference between the wave form of different holes) and confirmation of the actual dBL will require measurement of results and the actual C constant as part of a trial blasting programme.

4.2.2 Air Over pressure Control

Mina do Barroso will utilise blast designs and practices that control the production of air overpressure. Control of air overpressure (which represents a manifestation of wasted explosive energy) is also inherent in the optimisation of blasting.

Specific strategies at Mina do Barroso will be applied to air overpressure control, and are mostly common to control of ground vibration and flyrock these include:

- Use of aggregate stemming for all blast holes.
- Setting of stemming length at a confinable level based upon hole diameter, effective burden and material type.
- Setting of face burden at a confinable level based upon hole diameter, inclination, charge mass and type, rock parameters, bench height and stem length.
- Examination of all exposed blast faces and crests to identify potential structures likely to vent explosive gas at high pressure (remedial steps may include decking or increased stemming material.
- Measurement of all explosive column heights before stemming to ensure correct stemming lengths.
- Use of delays between each presplit hole (of 17-25ms each)
- Placement of sand covering upon the crest of charged presplit holes (after blocking them with plastic bags).
- Use of shock tube-based initiators in blast holes and in surface connections, rather than detonating cord.

4.2.3 Air Overpressure Measurement

Accepted best practice in measurement of blast induced air overpressure is described in AS2187.2 (2006) and the instruction documents provided by the manufacturers of approved instrumentation.

AS1055.1 (1997) Section 6.3.1 suggests that noise measurements conducted (outdoors) where the wind velocity exceeds 5m/s may well be invalid. Consequently, Mina do Barroso should conduct measurements of wind velocity at blast time to ensure that only valid air overpressure data are recorded/reported.

4.3 Blast-Induced Ground Vibration

Ground vibration from blasting is the radiation of mechanical energy within a rock mass or soil. It comprises various vibration phases travelling at different velocities. These phases are reflected, refracted, attenuated and scattered within the rock mass or soil, so that the resulting ground vibration at any particular location will have a complex character with various peaks and frequency content.

The magnitude of the ground vibration, together with ground vibration frequency, is commonly used to define damage criteria. Studies and experience show that well designed and controlled blasts are unlikely to create ground vibrations of a magnitude that causes damage.

Cracks in buildings may be attributable to causes other than ground vibration, including ground or foundation movements (settlement and swell) associated with reactive clay soils during periods of prolonged dry or wet weather.

Many site-based factors including rock type, structure, topography, explosive type, blast design and geometry determine the vibration level that will be transmitted to a particular location remote from the blast location. Consequently, the accurate prediction of ground vibration by calculation requires the use of site measurements to quantify the site factors represented in the prediction formula.

Where data or results regarding vibration from previous blasting are not available the Australian Standard AS2187.2 (2006) Appendix J provides a prediction equation in the form:

$$\mathbf{V = K\ (R/Q^{1/2})^{-1.6}}$$

Where: V = peak particle velocity (ppv) in mm/sec

K = Site Constant

R = Range to structure (m)

Q = Charge mass per delay (kg)

The standard states that K=1140 is applicable to prediction of mean ppv for “Free face-average rock” (See paragraph J7.3). Experience has shown that where the 50% K is 1140, the 90% K is about 1800.

Most statutory authorities specify ground vibration restrictions with some limit for 90% of blasts and a higher limit for all remaining blasts.

Some authorities in Australia set these limits at 5mm/s and 10mm/s respectively. Where these are applied, blast designs must be designed for compliance with the lower limit using the 90% confidence limit equation.

The initial 90% confidence limit prediction was used to calculate peak particle velocity and back calculate minimum distance.

The initial prediction formula for Mina do Barroso 90% confidence limit prediction of ppv is:

$$V = 1800(R/Q^{1/2})^{-1.6}$$

The calculation assumptions and minimum standoff distance for various blast designs derived in the study are shown in Table 4.3_1

Table 4.3_1
Vibration Prediction Assumptions

Material	Explosive Type	Bench Height (m)	Hole Diameter (mm)	Powder factor	90% K	-b	Number of Holes per MIC event	MIC Kg	Minimum Distance for 90% 5mm/s (m)
Mixed Ore and waste	ANFO	5	102	0.78	1,800	2	4	99	395
Mixed Ore and waste	Emulsion	5	102	0.87	1,800	2	4	149	484
Waste	ANFO	10	165	0.82	1,800	2	4	552	930
Waste	Emulsion	10	165	0.91	1,800	2	4	827	1,139
Waste	Emulsion	5	115	0.88	1,800	2	4	182	534

Confirmation of the actual ppv will require measurement of results and assessment of the actual K factor as part of the trial/production blasting programme.

It is important to note that the vibration regression modelling process is applicable to assessments of blast induced ground vibration – and not the vibration response induced in man-made structures by the blast waveform. Consequently all vibration measurements should be conducted with well-coupled (e.g. bolted or bonded to small concrete blocks) geophone arrangements that are adjacent to but kept sufficiently remote from nearby structures to ensure that the blast waveform (and not the structures response) is measured and subsequently analysed (as detailed in AS2187.2 (2006) Paragraph J3.2.2).

4.4 Blast-Induced Dust

The amount of blast-induced dust produced is very dependent upon the friability of the rock being blasted and the ground water conditions. Some rock types such as shales and mudstones disintegrate to dust

very easily on blasting whilst the more siliceous rocks tend not to. If the rock is inherently wet or even damp it tends to create less dust whilst blasting than if it were dry.

In order to reduce any potential nuisance dust it is advisable to only blast when the wind is going away from the neighbouring properties.

4.5 Impact on the Local Community

As discussed above blasting has the potential to create a nuisance for neighbouring residents. The physical effects that may be experienced are:

- Noise
- Overpressure
- Dust
- Smell
- Vibration

Noise is generated by the rapid expansion of gasses during blasting. On a clear day with a northerly wind, inhabitants will hear a slight rumble however with a southerly wind and overcast skies the noise will be much louder and sharper being very similar to a nearby thunderclap. Blasts which are nearby to dwellings should be deferred if the weather conditions are not favourable.

The physical sensation of overpressure may be experienced in conjunction with the noise. It may result in the rattling of windows but should not result in breakage.

As with the noise generation, if the wind is northerly the dust will blow away from the village otherwise blasting should be deferred.

In concentration blasting fumes are toxic however they are very quickly diluted to non toxic levels by the air. Again blasting should only take place if the weather conditions are favourable.

The amount of vibration generated depends on the quantity of explosives initiated and its impact relates to the distance from the blast. Slipstream will install vibration monitoring stations at various locations to monitor any extreme vibration events. Given the planned holes sizes and bench heights vibration levels experienced in Romainho will be well within proscribed limits. Residents may experience a slight ground vibration but it should be very minor and not cause any damage. Slipstream will offer to undertake Dilapidation Inspections of all properties with a 1km radius of the mine in order to establish a base line in case of claims for vibration induced damage.

Slipstream will set up a community relations representative whose contact details will be made available to the local residents to liaise with in the event they have a complaint or wish to make comments about the projects activities.

5 BLASTING PRECAUTIONS AND MITIGATION MEASURES

The only structures that will be within the 500m exclusion zone will be associated with the processing plant. The plant is located approximately 200m west of Pineiro pit final design and is thus at risk of being struck by flyrock.

In all instances the same procedures will be followed to minimise risk. These procedures as a minimum will be:

- All blasts to be designed by a competent experienced blasting engineer. Designs will show the position of each hole to be drilled, drill depth of each hole; estimated volume to be blasted, quantity of explosive to be charge per hole; length of stemming per hole and detonator timing delay;
- Each blast is to be designed to blast away from structures.
- Each blast design is to be checked and approved by the Mining Manager.
- Hole positions to be marked on the ground by a surveyor.
- Hole positions to be checked on the ground by the Blasting Engineer and changed if required.
- Holes to be drilled to the blast design specifications in terms of location, depth and inclination.
- The two front rows of the pattern are to be drilled last in case of over-excavation of the face.
- Final drilled hole collars to be located by a surveyor and plotted/checked against the design; any irregularities must be amended.
- The depth of each hole is to be measured and checked against the design; any short holes are to be re-drilled.
- After priming each hole is to be charged with the design quantity of explosives; the shot-firer will record the quantity charged for each hole and this is to be checked against the design; any overcharged holes are to be pumped out to the correct quantity; after charging of each blast the total quantity loaded will be checked against the design total quantity and any anomalies rectified.
- After checking that the charge is correct the remaining depth of holes will be measured to ensure that the correct quantity was charged and that sufficient depth remains in the hole for stemming.
- Holes are then to be stemmed with crushed coarse hard rock aggregate of nominal size 25mm.
- The shotfirer will lay out the surface delay detonators and, before they are tied in, the blasting engineer will check that they are in accordance with the blast design.
- The delays and connectors will be tied in ready for blasting and the blasting engineer will visually check that it is in accordance with the design.

- If the blasting engineer is satisfied that the blast pattern has been loaded and timed in accordance with the design he will sign an approval to blast.

- Prior to the blast the exclusion area will be cleared of personnel and guards positioned to prevent entry. A siren, at a location, to be approved by the company and residents will sound throughout the blasting and only be turned off when the shotfirer has declared the area safe for re-entry.

- A video of each blast will be recorded from a safe vantage point and examined afterwards to identify any rifling indicating potential flyrock.

- Following the blast, the blasting engineer will visually inspect the outcome and note any issues such as over or under break. Photographs of the result will be taken and recorded with the blast design for future reference.

By following this procedure it is ensured that overcharging has not taken place and that holes will explode in the correct sequence thus minimising the risk of flyrock.

Any variations must be approved in advance and in writing by the Mining Manager.

6 EXAMPLES OF TOWNS NEAR MINES

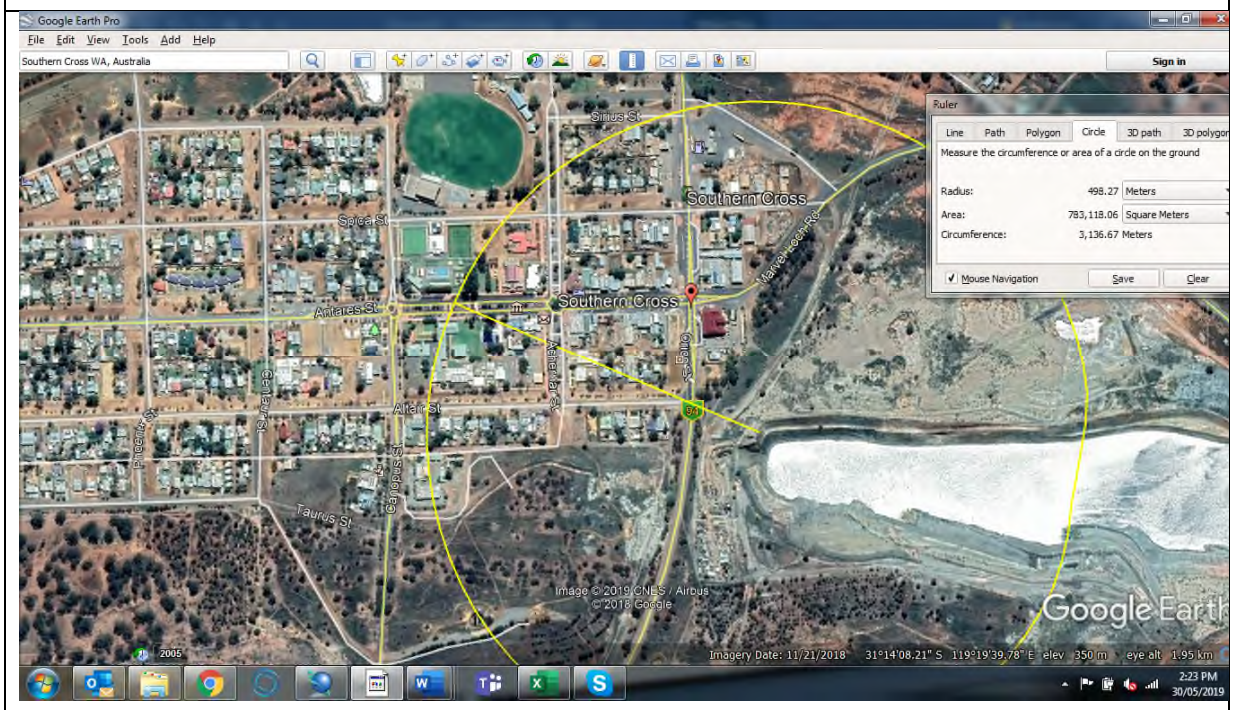
Having open pit mines near towns is very common as the town growth is in many cases the result of the presence of the mine. The following are examples of where this has occurred. The author personally supervised blasting operation at the first three listed so has first-hand knowledge of the situation.

6.1 Southern Cross – Western Australia

Figure 6.1_1 shows the edge of the Frazer's pit and the proximity to the town of Southern Cross. Southern Cross is the Yilgarn shire capital which has a population of approximately 2000 persons.

The yellow arc has a radius of 500m and shows a significant number of dwellings inside the exclusion zone. In this case it was not necessary to evacuate residents as controlled blasting methods ensured that there was very little chance of flyrock traveling towards the town. The towns people were alerted when a blast was imminent and advised to take cover although very few did after the first few blasts. The blasting and excavation operations were designed to proceed from south to north so that all blasts were directed away from town. There were no recorded instances of damage to the town buildings.

Figure 6.1_1
Frazer's Pit Southern Cross



North is on the left hand side of the figure.

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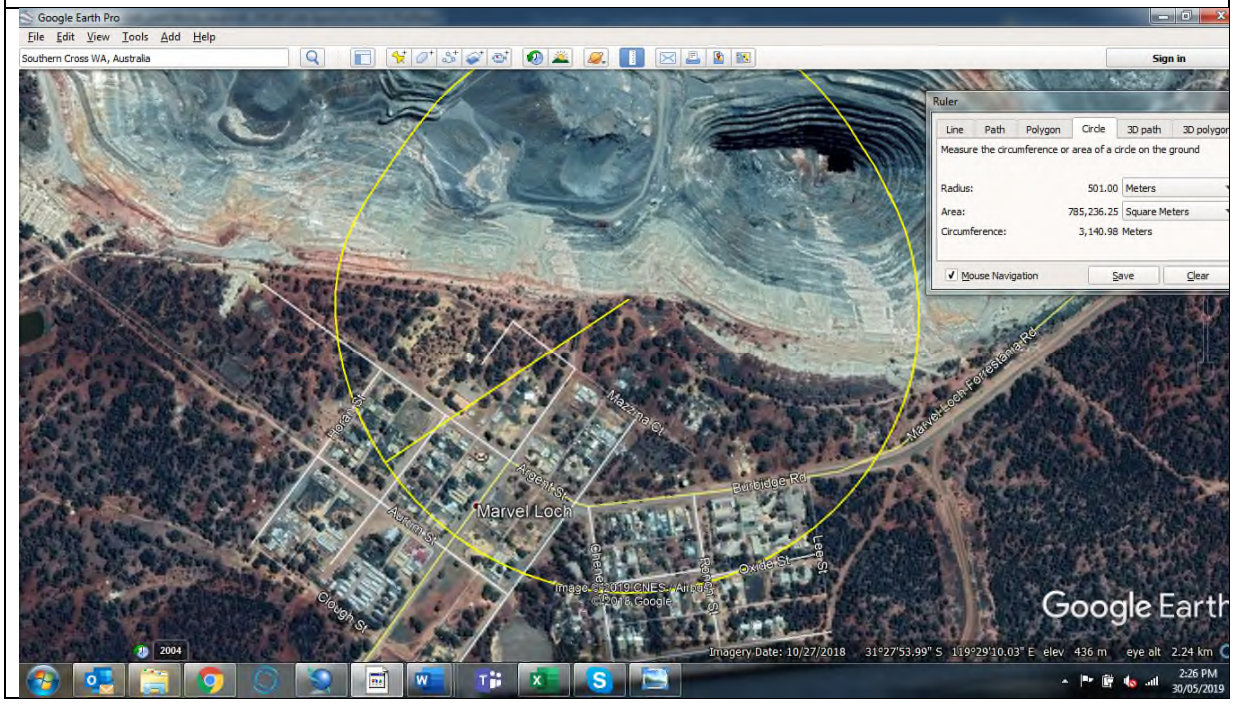
6.2 Marvel Loch – Western Australia

The proximity of the township to the Marvel Loch pit is shown in Figure 6.2_1. North is to the left of the figure.

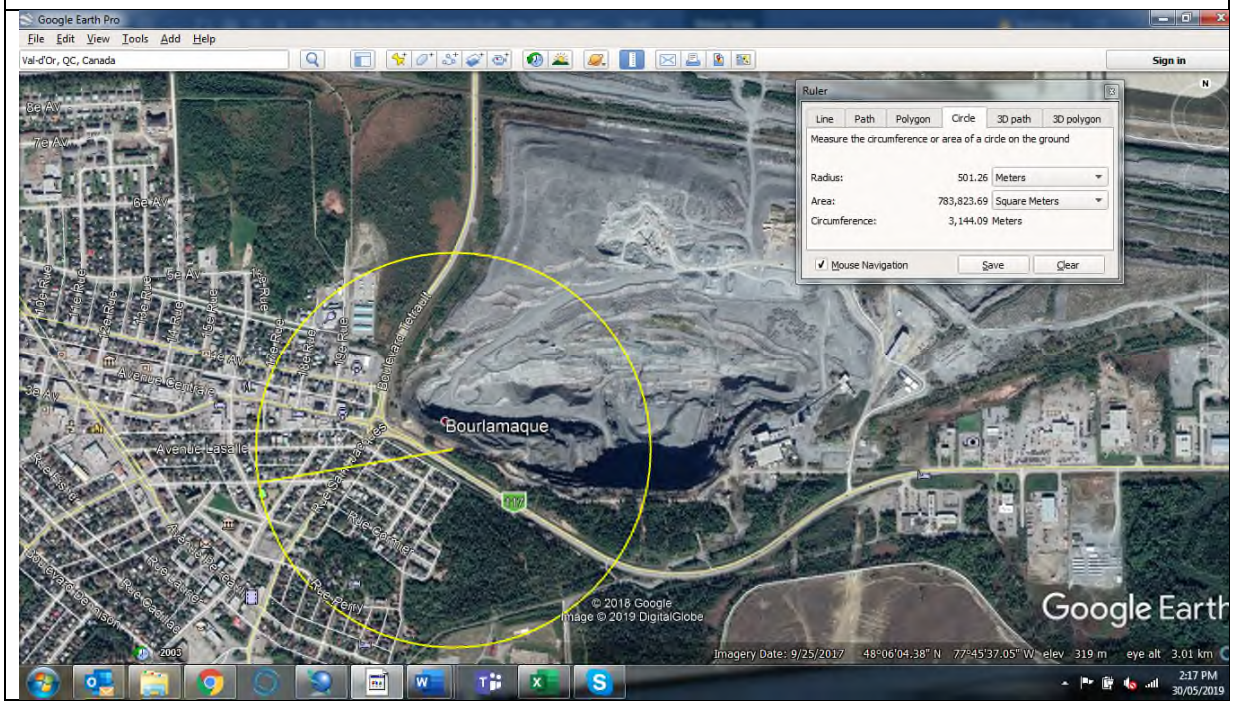
Figure 6.2_1
Marvel Loch Mine and Township



The yellow arc is 500m radius and illustrates that a large proportion of the township is within the exclusion zone. The waste rock is completely un-altered and hence very hard. A powder factor of 1.0 was required to provide adequate fracturing. It was only necessary to evacuate one household which was 100m from the edge of the pit whilst blasting near surface along the western edge. The towns people were alerted to blasts by a nearby siren and blast guards were placed to prevent persons getting close to the blast. As with Southern Cross there were no recorded instances of blast damage.

6.3 Val D'Or Quebec Canada

Figure 6.3_1
Sigma Mine and Val D'Or Town Quebec



North is at the top of the figure and the arc is a 500m radius.

Val D'Or is a regional centre in Quebec Province, Canada. The town has a population in excess of 32,000 people.

The figure shows that a large number of dwellings are within the 500m radius of the Sigma open pit. The rock is comparatively fresh and hard requiring a high powder factor to achieve fragmentation. The road bordering the south of the pit is the main highway to the north of the province.

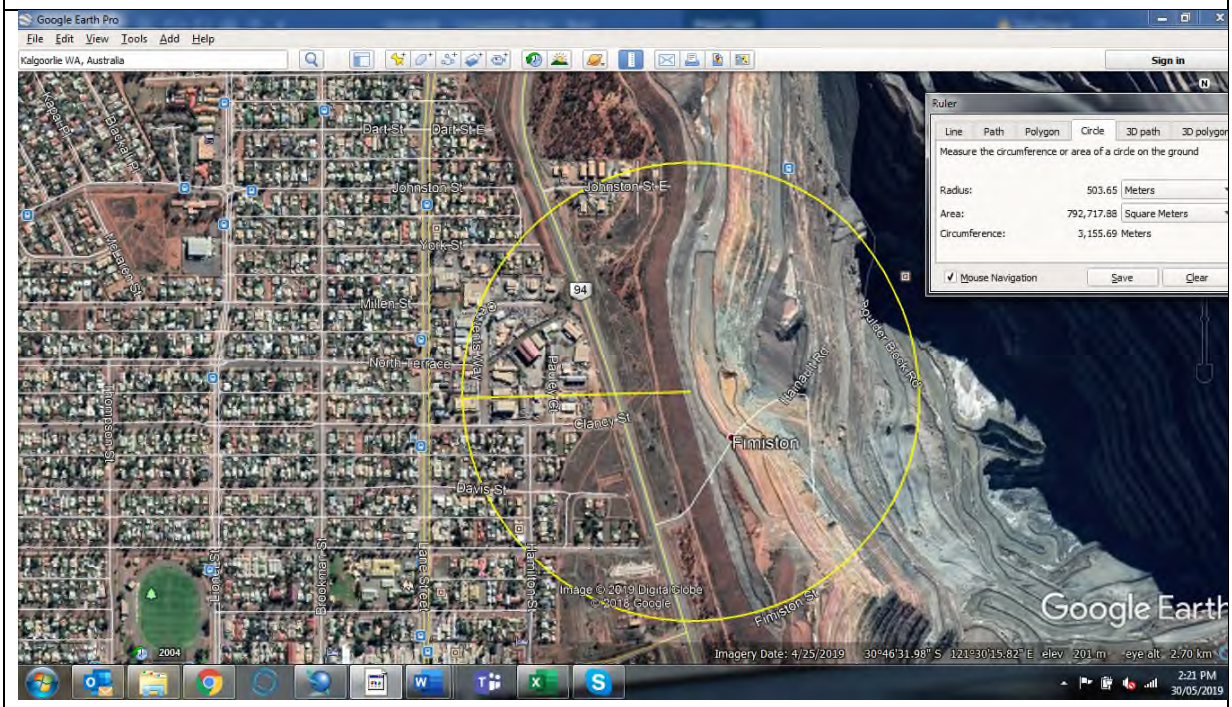
It was impractical to evacuate such a large number of people from their homes and, as demonstrated, unnecessary if the correct procedures are followed.

Any blasts which occurred within 200m of the road were overlain with blast mats. These consisted of worn truck tyres which were chained together to form six metre square mats. The surface detonator leads were first covered with sand to protect them from abrasion caused by placement of the mats. One layer of mats were carefully placed over the pattern and then a second layer placed over the top of that. Comparatively small blasts were carried out as the size of blasts was limited by the number of available mats. Smaller blasts were less likely to cause flyrock.

6.4 Super-Pit Kalgoorlie Western Australia

Figure 6.4_1 shows the Kalgoorlie Super-Pit in relation to the city.

Figure 6.4_1
Super-Pit and City of Kalgoorlie



North is at the top of the figure and the yellow arc has a radius of 500m.

Whilst the number of dwelling within 500m is less than the previous examples there are still a significant number. The waste at the top of the pit is oxidised and required only light blasting. Consequently it was not necessary to evacuate personnel during blasting.

7 SUMMARY AND CONCLUSIONS

- The village of Romainho is located approximately 750m from the northern edge of the Grandao final pit and a single house is located approximately 550 from the edge of the pit.
- The village of Covas is located 800m to the north east of the Reservatorio pit.
- Blasting activities will be required to fragment the ore and waste so that it can be excavated.
- Blasting has the potential to create flyrock which can travel a maximum of 650m based on 102mm diameter blast holes.
- The risk of generating flyrock can be minimised if not eliminated entirely by adhering to the stated procedures.

- Initially blasting will take place approximately one kilometre from the village which gives the mine the opportunity to optimise its blasting practises over several months in order to minimise flyrock.
- Blasting activities generate overpressure, vibration, noise and dust. The nuisance impact of these can be managed by observing correct procedures.
- There are numerous examples world-wide of mines being located a lot closer to towns than is the case at Mina Do Barroso and these have been operated safely.
- In the opinion of the author, blasting operation if undertaken correctly, will pose no danger and minimal inconvenience to the local residents.

8 AUTHORS QUALIFICATIONS AND EXPERIENCE

Nigel Spicer is a graduate mining engineer and holds a Bsc (hons) degree in Mining Engineering from Cardiff University UK. He is a Member of the Australian Institute of Mining and Metallurgy (MAusIMM) , and a Chartered Engineer (C Eng) with the IOM3 (UK). He holds a Western Australian Quarry Managers Certificate and Western Australian First Class Mine Managers Certificate. He has over forty years mining experience and spent several years in senior mine management positions before becoming an independent consultant.