Controlling fragmentation

Stuart Thomson* explains how this improves productivity and environmental performance with some innovative new Orica products

The fragmentation of rock is fundamental to mining. It is the first preparatory stage in the extraction process – making rock small enough and loose enough to be efficiently excavated.

But this simple statement is biased toward the next downstream process and underestimates how important and pervasive the results of this activity are through the whole mining operation. By optimising fragmentation, you can achieve significant improvements in waste productivity, mill throughput, lump fines and wall stability. This article will look at fragmentation in the broader context of mining, outline the tools and techniques that can help to improve a mine's performance and give practical case examples of successful fragmentation management.

The conclusions are compelling. A step change in the available range of explosive energy combined with the accuracy of electronic timing and other services, is delivering measurable gains in fragmentation management.

Blends such as Orica's Vistis™ product, due for market launch in 2013, will offer more than twice the Relative Bulk Strength (RBS) of ANFO. More detail is covered later.

Mining has some defining features that differentiate it from other 'production process' industries. Four key features that define the mining industry are:

1. Process volatility
2. Asset scale
3. Energy intensity
4. Fragmentation for product value

Process volatility

If we consider a 'production train' consisting of an excavator and fleet of trucks, the production rate of that 'train' on an hourly and daily basis can regularly vary by greater than 50% from the mean. On few occasions will the 'train' achieve its true maximum capacity. The graphic profile of daily excavator production is what the author terms 'hairy'.

This production profile shown in Figure 1 is the norm rather than the exception. It needs to be emphasised that this is the critical path and primary production equipment at the very start of the mining process.

Image 1: Considerable advances have been made in fragmentation. The image is of a muckpile, with the left half of the blast loaded with a commonly used bulk explosive and the right half loaded with a higher energy alternative

Similar, but dampened, profiles exist for downstream equipment such as crushers and SAG mills despite the buffering effects of intermediate stockpiles.

Why is the mining production and processing train more volatile than other industries? Well, there are many factors such as human operator performance and weather, but one of the key differences is a lack of control on the input materials. For the mining industry, the input materials are the *in-situ* rock mass.

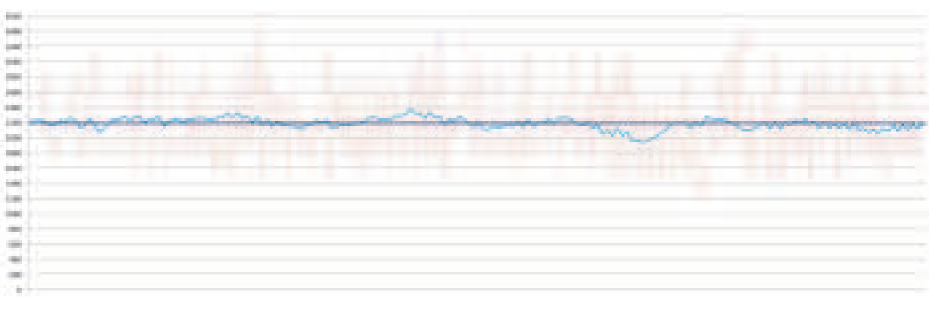
Most industrial processes have strict controls on the input materials, such as physical and chemical properties, delivery rate and timing. They have the ability to reject them if they are not to specification.

Despite a mining fleet being mobile, it has highly limited ability to modify the inputs to the process. There will be a defined short, medium and long term mining sequence and 'you'll get what you're given' as the rock mass is presented in front of the excavator.

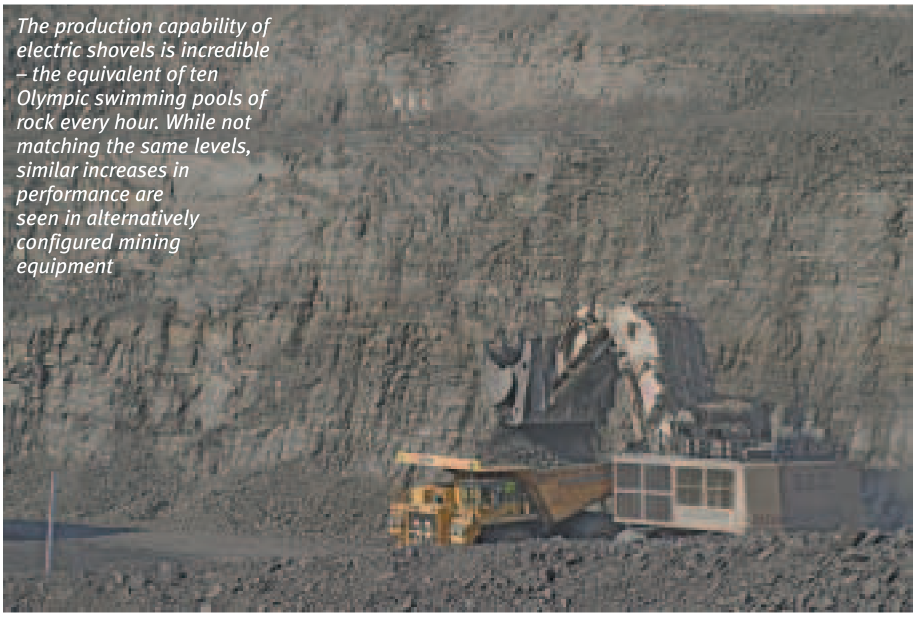
But the industry does have the ability to modify one aspect. It can modify the physical properties of the presented rock in terms of its fragmentation, looseness and sequence. Sequence refers to making sure the next available broken stocks are according to plan. These factors (fragmentation, looseness and sequence) are key drivers in increasing overall production performance and reducing volatility – thereby increasing predictability in performance.

Conclusion #1: Fragmentation control is one of the few ways to reduce volatility and increase overall production. This will be discussed further in a later section, giving case examples that consider a mine's geology, the mining objectives, energy range of bulk explosives, blast design and initiating systems.

Figure 1



*Orica's Global Bulk and Packaged Explosives Product Manager.



The production capability of electric shovels is incredible – the equivalent of ten Olympic swimming pools of rock every hour. While not matching the same levels, similar increases in performance are seen in alternatively configured mining equipment

Asset scale

This includes the trend to 'bigger' in all aspects of mining. An increasing proportion of minerals are being produced from bigger, deeper, higher strip ratio, lower grade deposits. This in turn increases the need for productivity from the mining fleet, as well as efficient mine designs and production trains. This has created an increased focus on:

- Faster vertical advance to successfully complete high strip ratio panels/cutbacks to reach ore/coal on time
- Steep, but competent, walls to reduce strip ratios but without disruptive wall failures or ore loss through wall step-outs.

The stretch for higher productivity has led to bigger machinery. In the 1920s a shovel weighed 25 t and had a bucket capacity of 0.38 m^3 (0.5 yd^3). By the 1970s the bucket was 19 m3 (25 yd^3). Today the machine could weigh 1,500 t and have a 63 m^3 (82 yd^3) bucket.

This performance creates quite a challenge for the drill and blast team, in terms of feeding such large equipment. Bench heights, blasthole diameter and therefore blasthole yield have not increased at a similar rate, so the team has to blast larger surface areas to keep up.

At the same time, mine planning has tried to squeeze cutback widths to aid sequencing in deep mines. All this leads to a critical requirement for drill and blast productivity in delivering broken stocks for excavators to maintain production and vertical rates of advance.

There have been some excellent papers written on the diminishing returns from increasing scale of mining fleet and how achieving good utilisation is fundamental in realising their potential. These papers also emphasise how quickly the productivity benefit becomes a negative if those utilisation targets are not achieved. Every time one of these excavators has to stop for blasting or move to another area because the broken stocks aren't ready, there is a utilisation impact.

High volatility (as discussed earlier) has also been shown to reduce overall asset productivity. A consistent stream of loose, well fragmented rock is fundamental to getting the benefits out of large production assets.

Conclusion #2: Production efficiency and good wall control are critical for the viability of modern mines. Fragmentation control is a key driver of this efficiency and is again included in the Fragmentation control for production section.

Energy intensity

The visible energy component is that being used to power the huge excavators and haul trucks. We've touched on how fragmentation energy helps with this earlier. What isn't so visible or well known is the disproportionate amount of electrical energy that is used for fragmenting the rock during processing, particularly for metal mines. At one site in Australia, each of the mill lines uses 44 MW of power. There are six lines at the site.

In most mines the greatest proportion of this energy is in crushing and grinding the ore. Unfortunately it's also well known that the energy efficiency of key processing units such as SAG mills is less than 5%. To give some context, an example metal mine might spend $5.00/t of ore on electricity; an equivalent amount on grinding media in the SAG circuit alone; but only $0.30/t of broken ore on explosives at the drill and blast stage. Yet, the blasting process is a much more energy efficient method of fragmenting rock.

The need for energy efficient processing is becoming increasingly important as we continue to mine lower grade deposits and need to process (fragment) increasing amounts of rock to liberate the same amount of metal. The world recognises the link between energy use and greenhouse gases (GHG) and our need to reduce GHG intensity.

Conclusion #3: Blasting energy for fragmentation can be used to replace inefficient electrical energy downstream, thereby massively reducing costs and/or improving throughput. This is covered in further detail in the section below.

Fragmentation for product value

Fragmentation for product value relates to only a few minerals, but is a significant part of the mining industry and its customers' needs.

Earlier we covered controls on input properties to processes. The downstream customers of iron ore mines want a specific size range for hematite entering their processes and it has been known that these customers are prepared to pay a 20%premium for 'lump' product. This premium can be achieved with minimal additional costs of production for the iron ore mine and is a very valuable EBIT lever. Therefore the ability to control fragmentation for the end product is valuable. Similar requirements also exist in the industrial minerals sector.

Conclusion #4: Controlling energy during blasting can realise higher profits through higher value end product.

Fragmentation control for production

Control is an interesting word as it implies that you:

- Have relevant and timely data to make a decision
- Have the ability to change inputs to a process that will influence its outcome
- Have the ability to assess the result prior to starting again, if it is an iterative process.

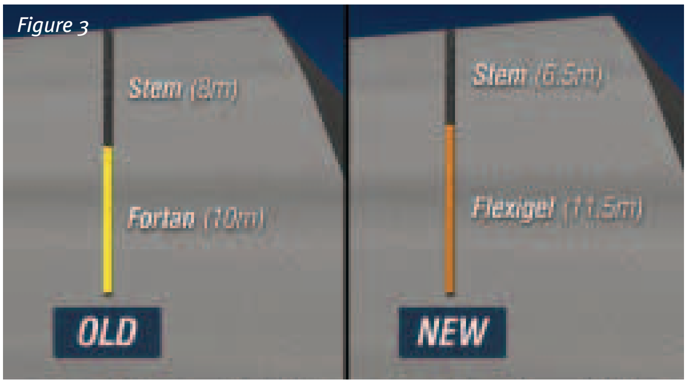
Taking each one of these steps individually in most blasting situations, we have access to broad brush information on the geology (hard, soft, jointed, massive) from what can be seen on the bench and face. We'll also know the desired end result, such as whether you are blasting waste or in an ore zone.

In any mine we'd expect there to be a different blasting template for each and every geological domain along with modification for hole conditions and desired end result – when approaching a wet final wall for instance. The process of assessing geology and outcomes to develop a catalogue of tailored design templates can result in substantial changes in mining performance. Two case examples are a large truck-shovel mine in China and an open-pit metals mine in Australia.

The mine in China had relatively simple geology and initially had five basic templates.

Figure 2

Figure 3



Orica took over management of the drill and blast operations and following a full assessment developed 18 distinct templates. The result was a greater than 30% improvement in production at a lower overall powder factor.

To cite a different case, from Australia, the mine initially suffered from low productivity due to significant oversize in a challenging cover sequence rock type. Due to the high strip ratio, this impacted the reliable supply of ore to the plant.

Orica was engaged to provide a 'Rock to Specification' service at the mine. After detailed assessment, 10 distinct blasting domains were identified. Following full implementation, the service delivered a 77% reduction in secondary breakage of oversize with an average load and haul productivity improvement of almost 10%. This was achieved with 15% less drilling and reduced overall powder factor.

Implementing a plethora of templates could be very difficult for a drill and blast engineer. To help and encourage them to implement a portfolio of templates Orica has developed tools within SHOTPlus 5®, the specialist blast design software, which makes template and loading rules easy to create, apply and communicate for a blast.

Optimal blasting occurs when the blasting energy varies at the same 'resolution' that the geology varies. In some rock masses this resolution could be on 1-m spacing down the hole. The technology exists to measure this type of variation through 'Measure-While-Drilling' (MWD) and in some cases post drilling measurement tools such as gamma loggers. This can provide a wealth of information. But, is it useful?

It is the author's opinion that MWD has not yet developed as well as it should have, because it has provided the drill and blast engineer information that he/she has been unable to act upon. If the drill hole revealed a need for increased energy, the engineer hasn't been able to increase the powder factor by pulling the holes closer together. It was too late once the holes were drilled.

The other energy lever was explosive energy but that has previously been limited as the difference in RBSs for various bulk explosive products has not been significant. But as you'll read further, this is all about to change

The second requirement for 'control' is the ability to make changes to inputs in order to influence the outcome. From an explosives point of view, the primary dimensions for change are the RBS; Velocity of Detonation (VoD) and product density. These factors influence the amount of shock and heave in the rock mass.

Explosives can be considered along with drilling, which is another primary lever that incorporates variables such as hole diameter and geometry. The ability to create change through drilling is limited. There is a limited range of hole diameters for a rig configuration and when drill fleet capacity is fixed there's not much opportunity to focus drilling intensity on parts of the mine without affecting other areas or the overall schedule.

At Orica this year, we have taken a 'clean-sheet' approach to assessing the geological conditions of mines, as well as the myriad of outcomes that our customers are aiming to achieve. Naturally we've also considered these needs versus our range of explosive energy.

Through this analysis, we have developed a matrix of bulk strength (measured as RBS against the ANFO benchmark of 100) versus VoD and have developed the EnergyMap™. Having developed the EnergyMap it became clear that the existing portfolio of readily available bulk explosives sat within a range from RBS 100 to RBS 170. This presented the opportunity to introduce an expanded range of lower and higher energy explosives to match mining's needs.

We have developed a bulk explosive range that extends from RBS 30 (Flexigel™) all the way through to RBS 250 (Vistis & Vistan™). The range will be made available progressively after being launched in 2013. If you consider this against the benchmark of ANFO, this range includes products that can be either less than half, or more than double the RBS of ANFO. Importantly the majority of this range is also able to be used in wet conditions.

Earlier, Conclusion 1 stated that we could use fragmentation control to control production volatility. The following examples illustrate the concept.

Drilling demand and capacity vary over time between areas of the mine. There are a limited number of rigs available and relocating them is time consuming. If a drill rig breaks down on a blast then the production manager typically has two options, relocate a rig from another area or shorten the blast. This usually requires a 'bridge' and results in existing holes being damaged - further reducing drilled stocks. But now there is an alternative solution.

We anticipate that because the Vistan product produces double the effective energy of the traditional range, it will enable the engineer to expand the remaining pattern and get the shot away on time. Merging two partially drilled patterns on one shot is possible using SHOTPlus 5® software and the flexibility and accuracy of the i-kon™ II electronic blasting system. This is a powerful way of ensuring the volatility caused by drilling capacity-demand fluctuations can be smoothed to increase overall mining productivity and delivery to plan.

It was also Conclusion 2 that stated that we need to control fragmentation for large scale mining fleets and manage highwalls. What follows are two innovative examples of the application of the lower end of the energy range. They are thought provoking as it's an example of how to use lower energy to increase fragmentation. Ordinarily this is not a logical combination. It's also a practical example of changing energy 'resolution' within the hole.

The first case is reducing cap-rock by controlling the energy distribution. Cap-rock is a common problem, but previously the 'medicine has been worse than the symptoms'. Options like close patterns, stab-holes and pocket charges are time consuming and expensive.

The solution in this case is getting the energy higher up in the rock mass. How? Introduce a top charge of lower energy bulk explosive, like Flexigel, to reduce the stemming height while maintaining control of vertical heave. The resultant better energy distribution produces a much more consistent fragmentation in the muck pile, without increased stemming ejection or risk of fly rock. Figure 2 illustrates the design.

Figure 3 shows hole cross sections in a 'side by side' comparison blast where the single main charge has been replaced by Flexigel. In the

Figure 4

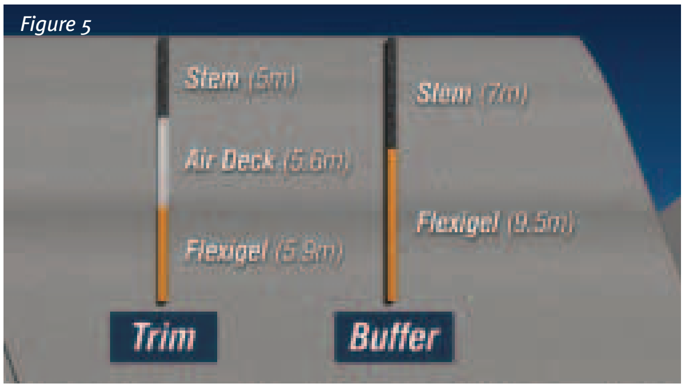


Figure 5

second case, there was a clear reduction in the oversize.

The fragmentation improvement was a useful secondary benefit against the primary objective of ensuring good final walls in wet ground. This has always been difficult. Buffer zones close to walls require evenly distributed, low level energy to protect the wall. Traditional wet hole explosives are high density, high energy, high VoD – the opposite to what is required. Figure 4 shows the traditional buffer design.

The design has weaknesses as it still involves a high energy pocket charge and extensive uncharged sections that are likely to result in poor fragmentation. The solution outlined in Figure 5 provides a more even, lower energy charge that not only improves wall quality, but also improves the overall fragmentation in the buffer zone – increasing productivity in what is traditionally a highly unproductive section of the mine.

Earlier, Conclusion 3 stated that we can use blasting energy to replace less efficient electrical energy for fragmentation downstream. This is well understood and the 'prize' is significant as shown in Figure 6 from an excellent report by AMSRI*.

But there is a question of practicality. There are many mines around the world that routinely use powder factors greater than 1 kg/m^3. However at this point the mines approach limits in terms of safe and efficient blasting.

For the traditional explosives range achieving plus 1kg/m^3 powder factors requires such tight patterns (and therefore drilling capacity) that they are not carried out.

At its most basic level, swapping from some more conventional explosives to Vistis would typically double the fragmentation energy and create detonation pressures over three times that of ANFO.

Figure 7 provides results from a copper mine in Chile. Orica carried out a side-by-side blast to compare the direct effects on SAG mill feed size using a base level (RBS 200) Vistan versus a mid level (225 RBS) Vistan. The fragmentation change in Figure 7 creates a step change in SAG mill productivity.

Image 1 gives the reader clear evidence of a muckpile, with the left half of the blast loaded with a commonly used bulk explosive and the right half loaded with a higher energy alternative.

Controlling energy and timing

The performance of the higher energy Vistis and Vistan range to date has been exceptional. Orica has invested significant resources to ensure we had the absolute best fuels and oxygen combination to realise the most effective outcomes.

We also recognise the importance of efficient storage and delivery systems that are safe and produce a consistently high quality product. With these new products, these will not be compromised.

To this end, we have developed an end-to-end system for the Flexigel and Vistis/Vistan range so that they can be seamlessly introduced into mining operations globally.

As can be seen previously in the AMSRI graph (Figure 6), the value curve steepens as powder factors start to get above 4 kg/m^3. Previously this has not been practical with traditional products and designs; however Orica has developed the products and a new technique to achieve such powder factors. The technique allows controlled application of powder factors of 4 $kg/m^3$and above.

The results stand to create a revolution in

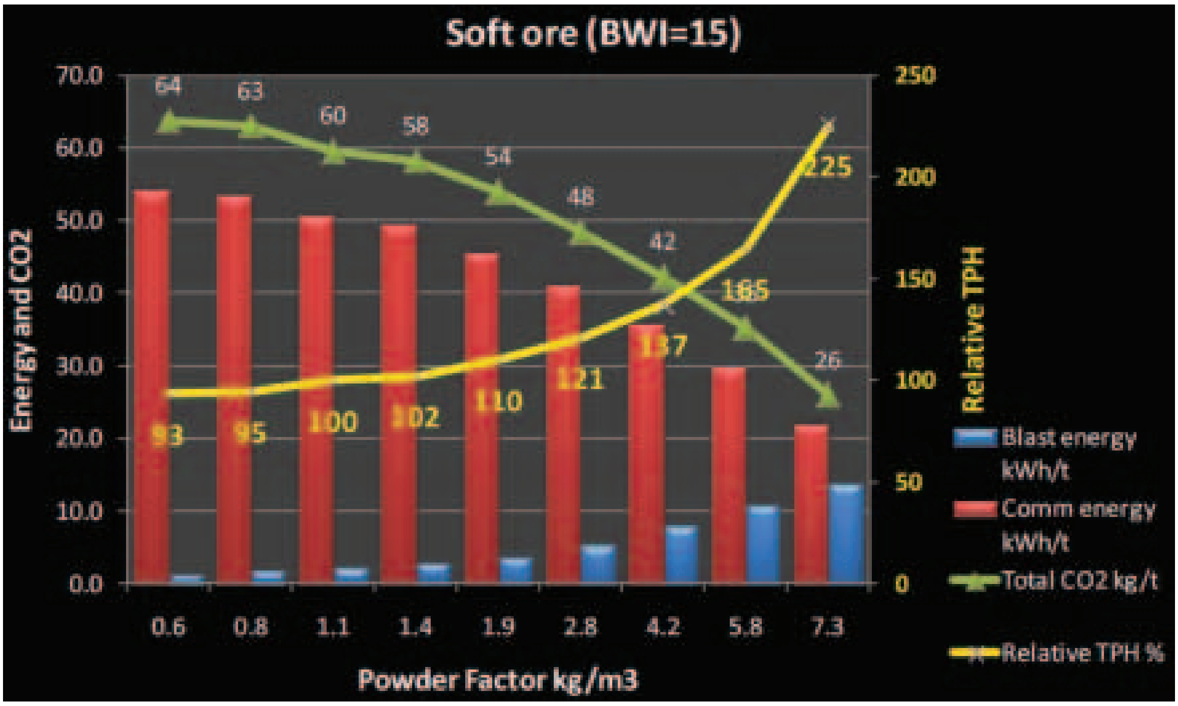


Figure 6

*Ziemski, M. 2011. *AMSRI Project Report, AMSRI Project 1.2b – Blasting for Comminution.* Brisbane: AMIRA"

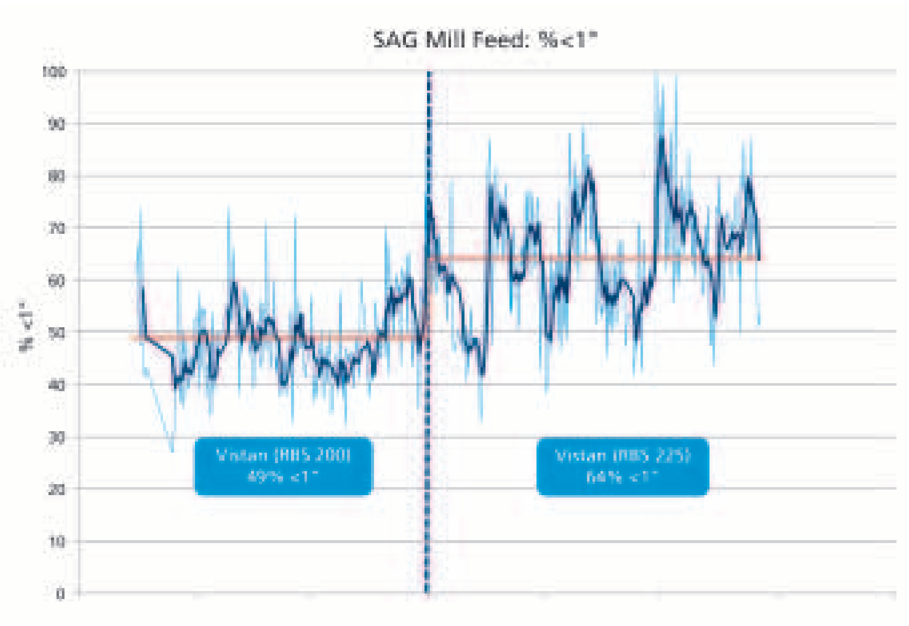


Figure 7

downstream mineral processing particularly processes involving SAG mills and hard rock types. Orica has also had to invest heavily in the initiation system to ensure it functions under these extremes.

Conclusion 4 ironically is the opposite end of the spectrum to the previous few paragraphs. It's focussed on creating fewer fines and again illustrates the need for a broader range of explosive energies. 'Lump' DSO hematite typically has a 20% selling premium to fines as it can be direct fed into furnaces without further processing.

While numerous research papers conclude that high energy and high VoD increases fines, they've also proven that low energy and low VoD increases the proportion of lump. The difficulty for the drill and blast engineer is how to implement this in wet conditions, as traditional 'wet products' have high density and high VoD, the wrong combination for creating lump.

The Flexigel range matches the need as it produces low energy (down to RBS 30) and low VoD (down to 2 km/s). This is the right combination for maximising lump. Critically it's also water resistant and can be successfully loaded into 152 mm (6 in) wet holes at densities down to 0.8 g/cc. This can reduce the powder factors by 30% or more relative to traditional wet hole products. It's also a great combination with the i-kon II electronic blasting system if trying to expand patterns to the limits.

The accurate slow timing capability of i-kon II allows the slow burden relief timings required for loose muckpiles with low powder factor products, such as Flexigel.

Combining the right products and smarts can maximise the revenue from your operations.

To conclude, the controlled application of energy can help a mine to achieve optimised fragmentation results, which will in turn result in reduced production volatility, higher downstream processing productivity and more valuable product.

Mining operations can improve mining production and milling productivity to a level previously not thought achievable. It is possible through access to a broader range of explosive energies, flexible accurate initiation timing and the technology, tools and expertise that Orica offers. ***IM***