Blast Fragmentation Impacts on Downstream Processing at Goldfields Cerro Corona

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ABSTRACT
The Gold Fields Cerro Corona copper-gold deposit in Peru has heterogeneous rock characteristics in terms of its mineralogical, geological and geotechnical properties. Blast design variations in these conditions directly impact the run-of-mine (ROM) fragmentation, which in turn influences downstream process efficiencies. In particular, when harder ore is processed, throughput and circuit performance may be limited.

To evaluate the potential to increase throughput and improve overall plant performance by optimising blasting practices and comminution circuit operation, Gold Fields La Cima engaged Metso Process Technology and Innovation (PTI) to conduct a full process integration and optimisation project at Cerro Corona. Blasting, crushing and grinding processes were reviewed to identify the potential to achieve substantial improvements in productivity when treating the most competent ore types.

Site-specific models of the blasting, crushing and milling processes were developed using SmartTag™ ore tracking technology for calibration and validation. Ore tracking permitted locations in the blast volume to be queried against the geotechnical block model to determine the hardness and structural parameters of the feed to the comminution circuit. They also ensured surveys were conducted when ore from the audit blast was flowing through the crushing and grinding circuits.

The predictive models developed enabled PTI to demonstrate how changes in blast design influenced both ROM fragmentation and the performance of downstream comminution processes. Outcomes of the project suggested changes to blast designs and comminution practices, and these were partially implemented for a validation trial. The trial demonstrated a 14.8 per cent increase in mill throughput for the specific ore selected for the study, and an average increase of 5.7 per cent for all ore types. There is potential to further increase throughput and process performance if all recommendations are implemented. This paper describes the methodology used and benefits to the operation from the mine to plant.

INTRODUCTION
Gold Fields La Cima engaged Metso Process Technology and Innovation (PTI) to optimise and integrate the blasting and comminution processes with the aim of increasing the current plant throughput when processing the hardest ores. Blasting, crushing and grinding processes were reviewed in October 2011 to identify the potential to achieve substantial improvements in productivity. Integrated site-specific models of drilling and blasting, crushing and milling operations were developed, calibrated and validated using PTI’s SmartTag™ ore tracking technology, which links ore properties with blasting and plant performance (throughput, grade, recovery, etc) in real-time (La Rosa et al, 2007). In July 2012, a validation trial was conducted to determine how blast design and implementation affected the ROM fragmentation and subsequently, downstream processes. The methodology and results obtained at Cerro Corona are presented in this paper.

BACKGROUND
The Cerro Corona operation is located in the Andes Mountains in northern Peru (Figure 1). The mine has porphyry style mineralisation hosted in diorite which is extracted by conventional open pit mining methods. The processing plant treats approximately 19 200 t/d of ore (6.6 Mt/a) by...
crushing, grinding and flotation to produce copper and gold concentrates. The comminution flow sheet is shown in Figure 2.

The heterogeneous nature of the orebody results in variable conditions for blast design and implementation which directly impact fragmentation and downstream throughput and circuit performance. A complete audit and survey from the mine to the plant was conducted to identify potential blast design modifications which would improve primary crushing, semi-autogenous grinding (SAG) and ball mill operation.

**ROCK MASS AND BLASTABILITY CHARACTERISATION**

The copper-gold deposit is hosted by diorite porphyry. Within the porphyry, the mineralisation has zones of stockwork quartz veining that carry a high gold content. The deposit is also characterised by several domains with different degrees of oxidation and weathering. Four mineral audit regions with distinct metallurgical behaviour can be identified. The topmost region is the oxide zone beneath which is the sulfide zone with three separate regions based on the degree of oxidation. These three regions are mixed, supergene (enriched copper blanket with one per cent copper grade) and hypogene (primary sulfide zone).

Metso PTI methodology involves rock characterisation in terms of strength and structure to determine domains within the orebody that will generate similar blast fragmentation. The fines generated in a blast are related to explosives and rock strength, therefore standard blast patterns for each of the domains based on rock characteristics can be established that will generate similar fragmentation distributions. Ore characterisation to estimate rock strength and structure was carried out on polygon P3810007, selected for the benchmarking phase of the project.

**Rock structure**

Rock quality designation (RQD) indicates the degree of fracture and jointing in a rock mass, providing a good indication of rock mass structure. It also provides the ability to roughly estimate in situ block sizes which control the top size of ROM fragmentation. For this project, PTI used existing P3810007 geotechnical data in conjunction with three dimensional face mapping to estimate the impact of localised rock structure, mainly in situ block sizes, on ROM fragmentation.

RQD values greater than 75 per cent represent high-quality, massive rock, whereas RQD values below 50 per cent represent low quality, jointed/fractured rock. On average, the RQD results indicated that the polygon showed low-quality rock in terms of rock mass structure. This data was used in calibrating the PTI blast fragmentation model which uses RQD as an estimator for in situ block size.

**Rock strength**

The point load test (PLT) (International Society for Rock Mechanics, 1985) provides an Is50 index for rock strength classification and is commonly used as a quick and simple method to predict unconfined compressive strength (UCS). Polygon P3810007 contained three different rock hardness categories (as defined by Cerro Corona), and these are shown in Figure 3.

The green zone is Hardness 3 (25–50 MPa), the blue zone is Hardness 4 (50–100 MPa) and the pink zone is Hardness 5 (100–250 MPa). The polygon did not only contain the hardest ore (as intended for this study) but also some softer components. The material fed to the plant during the survey, in which 40 samples were collected and sent for analysis.
hardness testing, had an average of 71.2 MPa, indicating a moderately hard ore. This value was used to calibrate the blast fragmentation model as it was the most representative of the blend of ore from the audit polygon going through the mill at the time of the survey.

**Breakage and grinding characteristics**

In addition to assessing rock strength and structure, further testing was conducted to determine the comminution properties of the ore. The drop weight test (DWT) was used to determine rock strength (or competency) by measuring the resistance to impact and abrasion breakage. This index gives an indication of how an ore will behave during crushing and SAG milling. The Bond test was used to determine a value of the Bond Work Index (BWi) which is a measure of an ore’s resistance to ball milling. Table 1 shows the DWT parameters and BWi test results for the samples collected during the survey.

The DWT A*b value put the ore in the moderately soft range of resistance to impact breakage and the t_a value fell into the soft abrasion range. The BWi test conducted at a closing sieve size of 106 µm resulted in a BWi of 13 kWh/t, indicating that the ore was of medium hardness for ball milling.

**BENCHMARKING AND MODEL DEVELOPMENT**

Metso PTI’s SmartTag hardware was installed to track the ore from the mine through to the primary crusher. Subsequently, 132 tags were inserted midway into the stemming of all blastholes for the audited polygon and 40 were placed on the blasted muck pile. Tag detection software automatically recorded the time, source and ID of the tag for correlation with the process data extracted from the mine’s data historian, in this case OSIsoft’s PI system.

**Drill and blast practices**

The blast design parameters for polygon P3810007 are listed in Table 2. The geometry of the blast design was measured to check the accuracy of implementation and in this case hole placement was very precise due to the use of high precision GPS on the drill rigs. Stemming materials totalling 4.5 m included both mill scats (first 2 m from the collar) and 2.5 m of drill cuttings beneath the mill scats. For dry holes, ANFO/HA 46 (40 per cent emulsion : 60 per cent ANFO) with a density of 1.2 g/cm³ was augered into the holes while heavy ANFO HA 64 (60 per cent emulsion : 40 per cent ANFO) with a density of 1.28 g/cm³ was used in wet holes. The downhole initiation system was non-electric with a 600 ms delay. The surface delays were also non-electric, with delays of 17 ms between holes and 25 ms between rows. Figure 4 shows the layout of the blast.

**Blast fragmentation measurement and modelling**

PTI’s blast fragmentation model was used for the project. It is site specific and requires calibration for each operation. The measurement of the actual ROM size distribution is critical in ensuring that the model results follow those observed in the field. Previous field work studies by PTI at numerous operations worldwide have demonstrated that image analysis systems are an effective and accurate way to measure ROM size distributions and a good alternative to full-scale screening (La Rosa et al., 2001). In fact, for post-blast muck piles, this is the only practical way to get a quantitative measurement of the particle size distribution. Commercially available software allows the user to manually process multiple images captured from cameras to measure the size distribution of blasted rock (Gillot, 2015). PTI utilises Split Desktop for this purpose.

The blast fragmentation model was calibrated with data from blast P3810007 and this was used to optimise the ROM fragmentation for both mining and downstream processing. Once calibrated, changes in ROM size distribution could be predicted from changes made to the blast designs. These

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Hole diameter (mm)</td>
<td>200</td>
</tr>
<tr>
<td>Burden (m)</td>
<td>5.2</td>
</tr>
<tr>
<td>Spacing (m)</td>
<td>6</td>
</tr>
<tr>
<td>Stemming (m)</td>
<td>4.5</td>
</tr>
<tr>
<td>Subdrill (m)</td>
<td>1</td>
</tr>
<tr>
<td>Bench height (m)</td>
<td>10</td>
</tr>
<tr>
<td>Explosive</td>
<td>Heavy ANFO HA 46 and HA 64</td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>1.2–1.28</td>
</tr>
<tr>
<td>Pentolite primer (g)</td>
<td>450</td>
</tr>
</tbody>
</table>
Implement electronic detonators. Prior to PTI's work in 2011, electronic detonators were not used.

To obtain a reliable measure of the actual fragmentation achieved from the current blasting operations, image analysis was conducted on 14 images of the audited blast muck pile, stockpiles and material being fed into the crusher. Since the muck pile surface is not a true representation of the fragmentation of the entire blast, image analysis was only used to quantify the coarse fraction of the blast, roughly plus 100 mm in size, regardless of the rock type. The fine end of the distribution was determined from measured belt cut samples from the primary crusher product. Typically, the primary crusher is expected to generate three to five per cent fines therefore the fines end of the curve for the measured Split data was adjusted using the parameters in the software to be approximately five per cent less at the 10 mm size bin.

The site-specific blast fragmentation model was developed using the rock mass characterisation data and actual blast implementation parameters. The model results show a good match at both the coarse and fine ends of the particle size distribution. Figure 5 shows the comparison between the ROM obtained from image analysis, the model results and the primary crusher survey results.

Simulations using the calibrated fragmentation model with different blast designs were conducted to determine their effect on ROM fragmentation. The scenarios investigated included changing explosive type, reducing stemming length, and increasing powder factor. Fragmentation for different ore domains with varying rock strength was also simulated.

Grinding circuit survey

A comprehensive grinding circuit survey was conducted when the circuit was treating ore from the P3810007 blast audit. All samples were analysed to determine per cent solids and size distributions. These results, together with the historical plant data gathered from the PI system and charge measurements comprised the full survey data set. The survey data were mass balanced to confirm the data quality and estimate any streamflow rates that could not be measured. The data were used to calibrate a model of the comminution circuit as it was operating at the time of the surveys. This was then used to perform simulations in conjunction with the blast fragmentation model size distribution.

Crushing circuit

Based on historical plant data, the primary crushing operation tended to operate well below its installed power. One crusher operated at below 225 kW for 98 per cent of the time, and the other crusher drew less than 225 kW for 99 per cent of the time. A power draw of 225 kW corresponds to 60 per cent of the nominal power of the crusher (373 kW); therefore, there was potential to increase primary crusher power utilisation. The underutilisation of primary crushing would also be exacerbated if a finer ROM size distribution were to be fed to it through optimised blast fragmentation. There was enough available power to reduce the top size to be fed to the SAG mill with the current conditions, and if changes in blasting were implemented to provide a finer ROM size distribution, the top size could be reduced even further.

According to operational data, the tonnage crushed per machine was reducing over time due to the higher proportion of hypogene ore.

Grinding circuit

Hypogene ore is the dominant feed to the plant. SAG feed throughput variations are largely due to operating practices, which tend to overload the mill and then sharply reduce the feed rate for a period of time in response until the mill load is reduced. This operating practice is not recommended as it introduces unnecessary variations in flotation feed rate, adversely affecting mineral recovery.

Simulations using the calibrated fragmentation model with different blast designs were conducted to determine their effect on ROM fragmentation. The scenarios investigated included changing explosive type, reducing stemming length, and increasing powder factor. Fragmentation for different ore domains with varying rock strength was also simulated.

**FIG 5** - Blast fragmentation model calibrated with run-of-mine size distribution.

Based on daily summary production data it was concluded that throughputs with hypogene ore was most frequently in the 800–850 t/h range (dry tonnes). Power consumption with this feed typically ranged between 2900 to 3800 kW; however, there were several times when power draw exceeded the design level of 3800 kW. The SAG mill speed was constant at 9.6 rev/min during the previous year, which corresponds to 60 per cent of critical speed. This value was considered low compared to other operations.

The ball mill average power consumption was 6200 kW, which represents about 82 per cent of the installed power of 7600 kW. Ball mill power had never exceeded 7600 kW. Therefore, an increase in the ball mill charge level could be considered, assuming the mechanical design limits of the ball mill are not exceeded.

The cyclone efficiency determined from the survey appeared to be in line with other sites; however, it could be improved by five per cent through an optimised operation. Analysis of the cyclone feed pump capacity curves indicated that each pump could cope with ten to 15 per cent additional flow (at same head and slurry density) while maintaining the same levels of efficiency.

**RECOMMENDATIONS**

Following the benchmarking study, PTI made several recommendations to optimise blasting and comminution operations at Cerro Corona. Mathematical models of all units in the flow sheet were developed and simulations indicated that plant throughput could be increased by treating finer ROM material from an optimised blast. Furthermore, the benchmarking study showed that the highest increase in throughput could be achieved by optimising the primary crusher, SAG mill, ball mills and hydrocyclones. Based on the results of the simulations, as well as from observations made of the audited blast, the following changes were recommended for implementation of a validation trial.

**Blasting**

Changes recommended for blasting were to:

- Implement electronic detonators. Prior to PTI's work in 2011, electronic detonators were not used.

**FIG 3** - Blast fragmentation model calibrated with run-of-mine size distribution.
Use 20 mm crushed aggregate for the full stemming length. The use of drill cuttings for stemming should be avoided; if crushed material is unavailable, mill scats should be used in preference over drill cuttings.

Decrease stemming length from 4.5 to 3.5 m. The principle of scaled depth of burial (SD) was considered in order to determine the ideal stemming length for a controlled energy blast with minimal flyrock generation (Chiappetta, 2014). This is expected when the recommended stemming material is used.

Use explosive HA 73 (70 per cent emulsion: 30 per cent ANFO) with a density of 1.3 g/cm³ in all holes. This explosive has a higher density and velocity of detonation (VOD) increasing the available blast energy. This explosive is a blended emulsion which will work in dry holes, more importantly in wet holes due to improved water resistance which may assist in reducing post blast fumes. VOD was not measured therefore theoretical values were used for modelling.

Increase powder factor to 1.6 kg/m³, and use a pattern with 4.0 m burden and 4.7 m spacing, with 200 mm diameter holes.

Use delays of 20 ms between holes and 100 ms between rows to allow more time for movement of the rock mass.

The changes implemented included increasing the powder factor, reducing the stemming length (3.5 m for harder lithologies and 4.5 for softer lithologies), reduced burden and spacing and use of an electronic detonation system. The blast model for the validation blast is depicted in Figure 6.

**Primary crusher**

A reduction of the crusher gap was suggested in combination with the implementation of a higher powder factor in the blast.

**Semi-autogenous grinding mill**

Changes recommended for the SAG mill were to:

- provide a finer feed to the SAG mill by implementing the recommended blasting design and closing the primary crusher gap
- increase the SAG mill ball charge to 17–18 per cent
- run the SAG mill with a stable feed rate.

**Ball mill**

Changes recommended for the ball mill were to:

- Increase the make-up ball top size to compensate for the increased ball mill feed size. The ball make-up should consist of 70 per cent 2.5’’ balls and 30 per cent 3.0’’ balls.
- Increase the ball charge to 35 per cent to fully utilise the installed power.
- Reduce the cyclone feed density by installing larger (290–300 mm) vortex finders. Simulations indicated that this would reduce the final product P80 at the increased throughput rates expected from the changes recommended for blasting, primary crusher and SAG mill operation. A control strategy should be implemented to maintain cyclone feed density at 56–57 per cent.

**VALIDATION SURVEY**

A validation trial was conducted in June of 2012 to evaluate the impact of the changes in blast design and consequent ROM fragmentation on downstream processes. The rock mass treated during the validation trial was classified as medium hardness with high and low hardness zones occurring in the same polygon. The breakage properties were similar for the benchmarking and validation trials, but there was less variation in ore hardness in the benchmark survey. For both benchmarking and validation trials, the geological structure varied from fractured to moderately fractured.

Additional rock mass and ore characterisation testing was conducted to verify the ore treated during the validation trial was comparable to the ore treated during the benchmark survey. The polygon for the validation trial was located on level 3800, a level lower than the benchmark phase polygon (located on level 3810) and was split into two parts (P3800017 and P3800018) in order to better control the newly adopted parameters. Samples for hardness testing were collected from both parts totalling 40 samples, which had an average UCS of 56 MPa indicating a medium hardness ore. The blasts of the selected polygons were audited and 223 tags were inserted midway into the stemming while 53 were placed on the blasted muck piles. Ore tracking was used to confirm that ore from the audited blasts was being processed during the survey of comminution circuits. Image analysis was conducted on 16 images to obtain a reliable measure of the actual fragmentation achieved from the validation trial blast muck pile. As performed in the benchmarking phase, 10 m of primary crusher product bulk cut was sized to calibrate the fine end of the distribution.

**Blast design**

Recommendations provided by Metso PTI to generate finer fragmentation were only partially adopted by site personnel. The changes implemented included increasing the powder factor, reducing the stemming length (3.5 m for harder lithologies and 4.5 for softer lithologies), reduced burden and spacing and use of an electronic detonation system. The powder factor was increased; however, it was lower than that recommended. The suggested explosive type HA 73 was also not used. HA 55 with a density of 1.28 g/cm³ was used in dry holes and HA 64 with a density of 1.3 g/cm³ was used in wet holes. Only partial changes to detonation timing and sequence were made and orange fumes were still visible after the blast. The blast design parameters for the initial conditions at Cerro Corona, the benchmarking trial, optimal simulation with PTI recommendations and validation trial are shown in Table 3.

Fragmentation results for each blast and the fragmentation curve for the benchmarking phase are shown in Figure 7. The size distributions indicate a greater presence of fines in P3800017 than in P3800018. However, the powder factor was lower for polygon P3800017, which indicated lower hardness values than in P3800018.
**TABLE 3**
Blast design parameters for each phase.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Benchmark P3810007</th>
<th>Simulation: PTI recommendations</th>
<th>Validation trial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powder factor (kg/m³)</td>
<td>0.67</td>
<td>0.79</td>
<td>1.60</td>
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<tr>
<td>Rock</td>
<td>Hypogene</td>
<td>Hypogene</td>
<td>Hypogene</td>
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<tr>
<td>Rock density (g/cm³)</td>
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<td>2.50</td>
<td>2.50</td>
</tr>
<tr>
<td>Bench (m)</td>
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<td>10.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Diameter (mm)</td>
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<td>200</td>
<td>200</td>
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<tr>
<td>Burden (m)</td>
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<td>5.20</td>
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<td>Inclination (°)</td>
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<td>Subdrill (m)</td>
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<td>1.00</td>
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<td>Stemming (m)</td>
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<td>3.50</td>
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<tr>
<td>Volume/hole (m³)</td>
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<td>312</td>
<td>188</td>
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**Explosive**

<table>
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<tr>
<th>Type</th>
<th>HA 46/64</th>
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<th>HA 73</th>
<th>HA 55/64</th>
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<tr>
<td>Density (g/cm³)</td>
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<td>1.20/1.28</td>
<td>1.30</td>
<td>1.28/1.30</td>
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<td>Primer (g)</td>
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<td>450</td>
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<td>450</td>
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<tr>
<td>Hole charge (kg)</td>
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<td>245.0</td>
<td>306.3</td>
<td>247.0/253.0</td>
<td>302.0/309.0</td>
</tr>
<tr>
<td>PF (kg/m³)</td>
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<td>0.79</td>
<td>1.63</td>
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<td>1.62</td>
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<tr>
<td>PF (kg/t)</td>
<td>0.27</td>
<td>0.31</td>
<td>0.65</td>
<td>0.52</td>
<td>0.65</td>
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**Initiation system**

<table>
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<th>Type of detonator</th>
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<th>Non-electric</th>
<th>Electronic</th>
<th>Electronic</th>
<th>Electronic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inter hole (ms)</td>
<td>17</td>
<td>17</td>
<td>20</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Inter row (ms)</td>
<td>25/42</td>
<td>25/42</td>
<td>100</td>
<td>83</td>
<td>83</td>
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</table>

**FIG 7** – Fragmentation for benchmarking and validation polygons.
Ore characterisation data indicated that P3800018 had a greater range of ore hardness, including a higher maximum ore hardness value than measured for P3800017. In the region of these blasts, the UCS varied from lower than 50 MPa to higher than 250 MPa. The expected ROM size distribution curves for different UCS values ranging from 50 to 250 MPa are shown in Figure 8 in increments of 50 MPa using the blast fragmentation model with recommended blast parameters from the benchmarking study. The variation in UCS has a significant effect, especially in the fines region of the ROM size distribution curve.

**Comminution circuit**

Some recommended changes to the SAG mill were implemented, including an increase in the ball charge and decrease in mill speed. However, the crusher gap was not reduced, and the recommended changes to the ball mill circuit were also only partially implemented. Higher throughput will only be achieved if these recommendations are fully implemented.

**FRAGMENTATION IMPACTS ON DOWNSTREAM PROCESSING**

Blast optimisation and fragmentation modelling of Cerro Corona in conjunction with the site specific comminution model allowed PTI to predict and then validate the downstream impacts of finer fragmentation. Optimising the blasting practice improved efficiency in downstream processes including crushing and grinding.

**Crushing and grinding**

The effects of finer fragmentation on the crushing circuit included higher crusher throughput and reduced wear and power draw of crushers, screens and feeders. The primary crusher product from the validation trial was sized and compared to the primary crusher product from the benchmarking trial and is shown in Figure 9.
The crusher gap was not reduced as per the recommendations, and this resulted in a similar crusher product 80 per cent passing size for the benchmark and validation surveys. A higher throughput may have been achieved if the crusher gap was reduced. There is still significant opportunity to better utilise crusher power and improve plant throughput by reducing the crusher gap.

The fines content of the SAG mill feed was much higher (18 per cent) for the validation trial due to the optimised blast design. The percentage of fines (-10 mm) in the SAG mill feed increased from 34 per cent for the benchmarking survey to 52 per cent for the validation survey. Another noticeable benefit of finer fragmentation was the reduction of the SAG mill specific energy by 9.2 per cent.

| TABLE 4 | Summary of validation survey results with finer run-of-mine fragmentation. |
|---|---|---|---|---|
| Semi-autogenous grinding mill feed | Unit | Benchmark | Validation | % Change |
| F80 | mm | 59.1 | 58.2 | -2% |
| % Fines (-10 mm) | % | 34 | 52 | 53% |
| Transfer size | T50 | mm | 2.41 | 1.71 | -29% |
| Final product size | P80 | µm | 154 | 141 | -8% |
| Total Throughput | Dry t/h | 784.9 | 936.7 | 19.4% |
| Specific energy consumption (grinding) | kWh/t | 11.5 | 10.1 | -12% |

| TABLE 5 | Effects of fragmentation on downstream processes. |
|---|---|---|---|---|---|
| Primary crusher | Adjust explosive | Adjust stemming | Powder factor 1.2 kg/m³ | Powder factor 1.4 kg/m³ | Powder factor 1.6 kg/m³ |
| Fresh feed (t/h) | 790 | 795 | 820 | 850 | 880 |
| Change in throughput (%) | 0.6 | 1.3 | 4.5 | 8.3 | 12.1 |
| Fresh feed F80 (mm) | 196.6 | 175.8 | 146.4 | 131.3 | 116.7 |
| Fresh feed -10 mm (%) | 29.2 | 30.7 | 35.9 | 39.6 | 43.3 |
| Tooth crusher power (kW) | 245 | 235 | 214 | 204 | 193 |
| Semi-autogenous grinding (SAG) mills | | | | | |
| SAG mill total feed (t/h) | 822 | 827 | 851 | 881 | 911 |
| SAG mill total feed F80 (mm) | 63.7 | 62.6 | 57 | 52.7 | 48.2 |
| Power (kW) | 2934 | 2934 | 2934 | 2934 | 2934 |
| % of critical speed | 80.4 | 80.4 | 80.4 | 80.4 | 80.4 |
| Volumetric total load (%) | 16 | 16 | 16 | 16 | 16 |
| Volumetric ball charge (%) | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 |
| Scats production (t/h) | 32 | 32 | 31 | 31 | 31 |
| Ball mill | | | | | |
| Ball mill power (kW) | 6581 | 6581 | 6581 | 6581 | 6581 |
| Volumetric ball charge (%) | 32.2 | 32.2 | 32.2 | 32.2 | 32.2 |
| % of critical speed | 74.7 | 74.7 | 74.7 | 74.7 | 74.7 |
| Ball mill P80 (mm) | 0.406 | 0.406 | 0.407 | 0.414 | 0.417 |
| Circulating load (%) | 254 | 254 | 247 | 239 | 230 |
| Cyclones | | | | | |
| Number of operating cyclones | 5 | 5 | 5 | 5 | 5 |
| Cyclone feed % solids | 57.7 | 57.7 | 58 | 58.6 | 59.1 |
| Cyclone pressure (kPa) | 102 | 103 | 104 | 104 | 104 |
| Overall cyclone P80 (mm) | 0.153 | 0.154 | 0.154 | 0.157 | 0.158 |
| Total power (kW) | 9760 | 9750 | 9729 | 9719 | 9708 |
| Ball mill kWh/t | 8.3 | 8.3 | 8.0 | 7.7 | 7.5 |
| Overall kWh/t | 12.4 | 12.3 | 11.9 | 11.4 | 11.0 |
The operating parameters were more stable during the validation survey than during the benchmarking survey. At that time, the mill was regularly overloaded, resulting in high bearing pressures that then required a reduction in circuit feed rate to bring the process back under control.

A summary of the validation survey results attributed mainly to the finer ROM sizing produced in the higher intensity blast is shown in Table 4.

The effects of finer fragmentation in the validation trial resulted in a significant improvement in circuit performance, including a 19.4 per cent increase in throughput, and reduced grinding energy consumption. An average throughput of 929 t/h was achieved for the validation trial compared to 809 t/h for the benchmark phase, a 14.8 per cent increase.

A summary of simulations performed with varying ROM fragmentation and corresponding downstream effects is shown in Table 5. As the powder factor increases, resulting in finer fragmentation, there are clear benefits in crushing, SAG mill, ball mill and cyclone operation.

CONCLUSIONS
Following the partial implementation of PTI’s recommendations, with only changes to the blast design (resulting in an increase in powder factor), the validation survey demonstrated a 19.4 per cent increase in throughput when compared to the benchmark survey while achieving a final product size of 141 microns. It is evident that ROM fragmentation significantly impacts the operation of downstream processes.

The benchmark and validation trials were conducted while treating a hard ore type, which was the focus of the project. However, the benefits in throughput will be realised across all ore types resulting in considerable benefits to the operation regardless of the ore source.

REFERENCES
Chiappetta, R F, 2014. Optimizing your drill and blast strategy, IQPC Drill and Blast, Brisbane.


