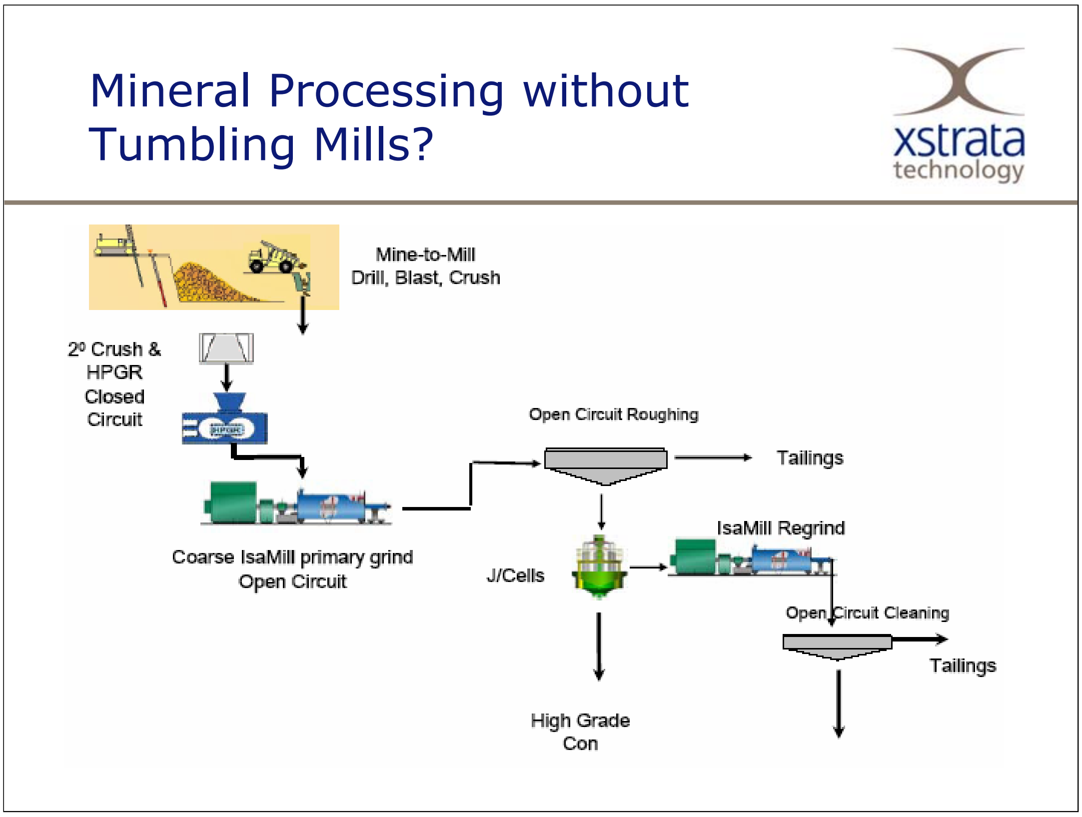
Case Study

Coarse IsaMilling at McArthur River

Joe Pease

General Manager Xstrata Technology

September 2007



At this conference in 2006, I concluded with this slide, a picture of a possible energy efficient circuit of the future. A circuit without any tumbling mills at all. I said that perhaps in a decade we would see the first plant built without any tumbling mills. Or with only a small conventional grinding stage between HPGR and IsaMills.

Well, we aren't there yet, but we are a lot closer than we thought we were even a year ago.

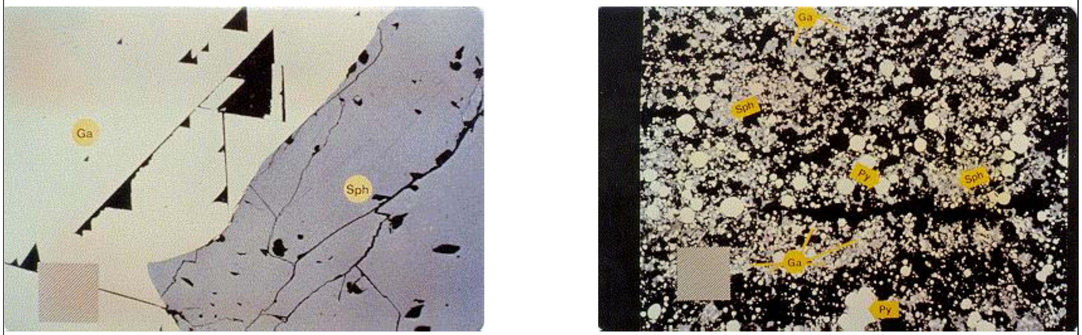
This is a story about how you can find answers in unexpected places.

And how solving one problem may end up solving other, even bigger, problems.

The mother of invention

Figure 2 : Different Grain Size of Broken Hill and McArthur River Ores

(both photos at the same magnification)



Broken Hill Ore

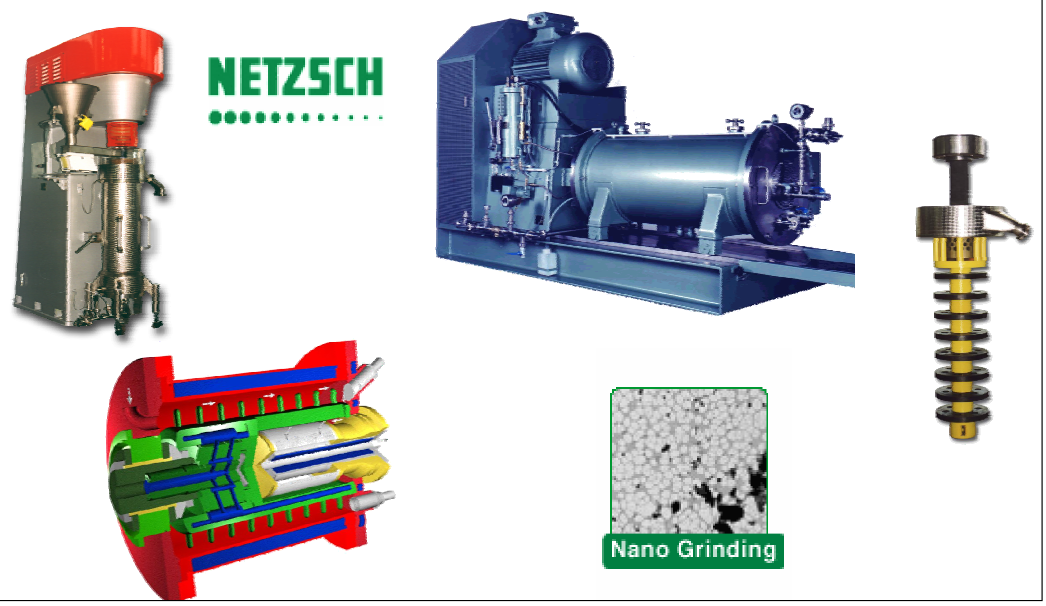
McArthur River Ore

The story starts at McArthur River. This huge lead zinc deposit was discovered in 1955, but remained undeveloped for 40 years. There was simply no technology that could economically treat the ultra fine grained minerals.

As always, necessity was the mother of invention. Keeping the orebody, and survival in our other fine grained orebodies, simply required that we find a more efficient way to grind fine, or else go out of business. We had to make a step change in fine grinding. Conventional grinding, in ball or tower mills, was uneconomic for 3 reasons :

- it used too much energy
- the media cost was too high
- the large amount of steel media consumed harmed subsequent flotation.

Fine Grinding in Manufacturing



Mt Isa’s head of research, Bill Johnson, knew that the answer to the problem didn’t lie in the minerals industry – we had looked there for decades. So he asked the question, who else has to grind fine ?

In fact, there was good established technology for fine grinding of high value manufactured products – like printer inks, pharmaceuticals, paint pigments, chocolate.

The pioneers in the field, and still the leaders, were Netzsch of Germany. We chose to work with them

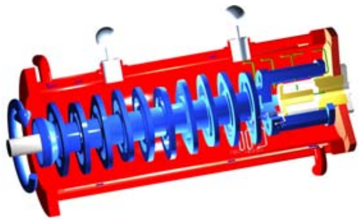
As an aside, my wife says that if Bill had had only listened to her, he would have looked to chocolate to find answers long before he actually did.

Crossover to Minerals

xstrata technology

Redesign and scale up to :

- **Much bigger scale**
- **Continuous**
- **Low cost Media**



So the concept was in manufacturing, but it had to be modified to minerals.

The manufacturing applications were for very high value products – like printer ink and chocolate. They are much higher value than zinc, which at the time was trading at about 40 c/lb. So these applications were small mills, often batch, and used very high cost media – ensuring no contamination of the product was much more important than the cost of grinding media.

To be economic to treat large tonnages of low value streams, we had to make the mills much bigger, operate continuously and robustly, and be able to use low cost media.

McArthur River

The end result was the IsaMill. This was the enabling technology for McArthur River, and then for the George Fisher and Black Star orebodies at Mt Isa.

This shows the 6 mills at McArthur River. They are 1 MW drive – 6 times bigger than the previous biggest Netzsch mills.

They operate continuously, and for the first 7 years their grinding media was ore gravel screened from the SAG mill discharge. That is, this was fully autogenous grinding to 7 microns !

The previously untreatable orebody became economic, and achieves over 80% recovery into a 55% Zn+ Pb bulk concentrate.

3 MW, M10,000 IsaMill

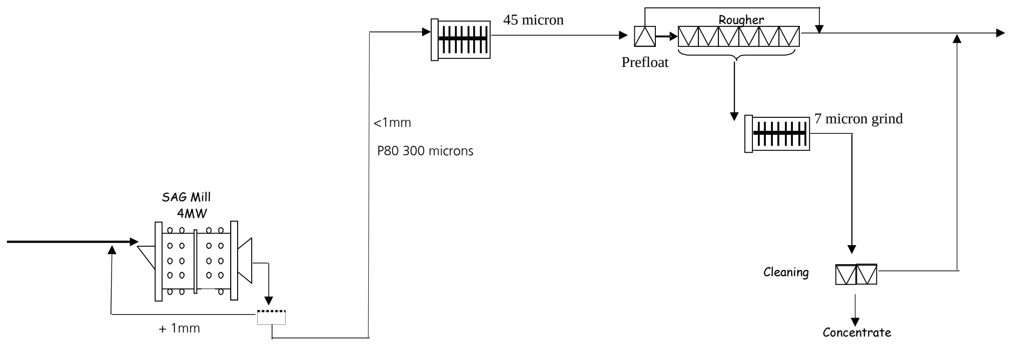
xstrata technology

So by looking in an unexpected area, a problem was solved, and a new technology was developed.

For many in the audience there is nothing new in this story, it has been told before. But now there is a a new, unexpected twist to the story, and again McArthur River is at the forefront.

They are currently installing IsaMills to grind SAG mill discharge.

McArthur River : New Circuit 2008



In early 2008, two 3 MW M10,000 IsaMills will be installed to treat SAG mill product before flotation.

So we are a lot closer to a circuit without tumbling mills than most of us expected.

What is the IsaMill?

xstrata technology

Firstly, what is the IsaMill?

The IsaMill was developed at Mt Isa in the early 1990's as an economical grinding solution for fine grained ore bodies.

Pictured here is a 3.0 MW M10,000 (litre) IsaMill. This is the largest IsaMill currently available with up to a 3.0MW motor. Motor, gearbox, bearings, mill

The motor turns a horizontal shaft within the mill, the shell remains stationary.

The IsaMill

xstrata technology

- **High intensity**
  - Small footprint – 3MW in 10 m3 grinding volume
- **High Power efficiency**
  - Small media
- **Inert grinding**
  - Clean surfaces, no steel effects
- **Internal Classifier**
  - Low cost media
  - Sharp size without cyclones
- **Horizontal**

These are the characteristics of the IsaMill that make it quite different from conventional grinding.

The high intensity means a small mill footprint and installation size. The IsaMill has a power intensity of 300 kW per cubic metre, versus about 20 for a ball mill or Tower Mill - that is about 10 times higher. This means a significantly different installation, even for things like media – the entire first charge of media for a 3 MW mill is only 7 cubic metres.

The high power efficiency simply comes from the small media, as discussed in my previous presentation. In fact, the high power intensity and high power efficiency are linked in practice. A slow stirred ball or Tower Mill using 2 mm media would also be efficient for fine grinding. But the low power intensity would make the installation uneconomic – a huge installation, with prohibitively high consumption of prohibitively high cost media. The high power intensity in the IsaMill comes from the high stirring speed – about 20 m/second. This means that the fine media can do a lot of work in a small volume.

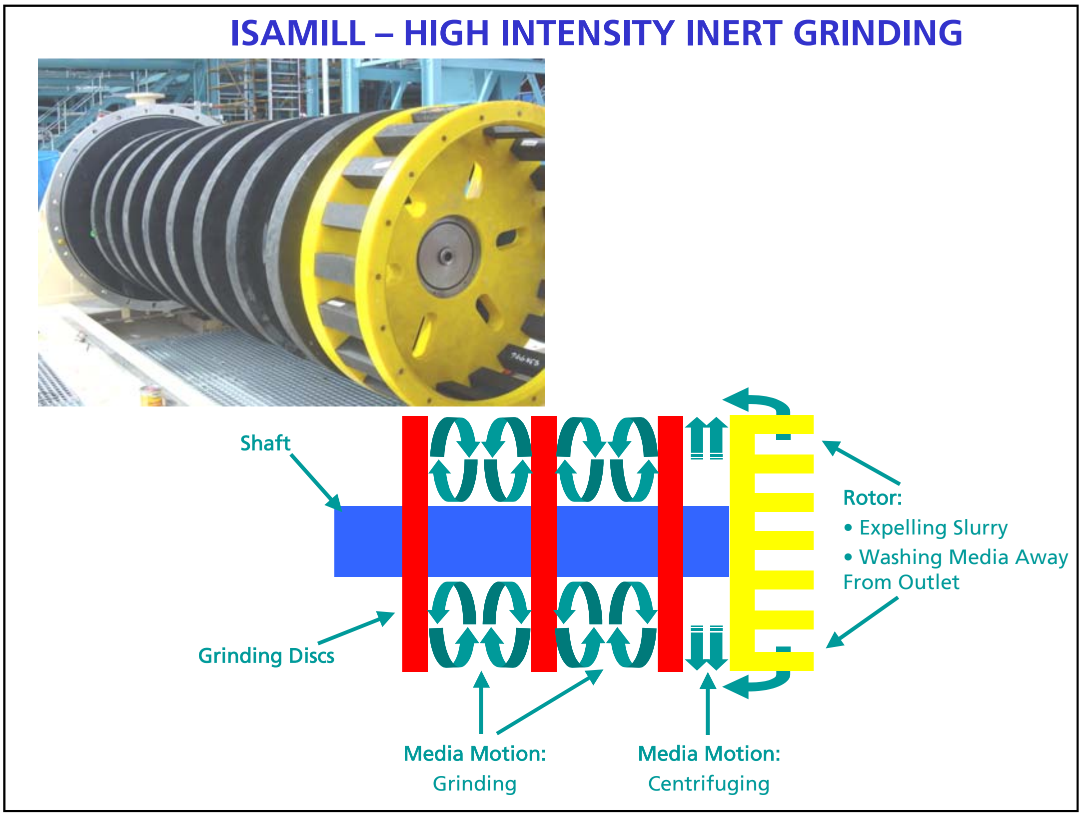
The internal classifier really is the great innovation of the IsaMill. How do you keep fine media, eg 1-2 mm, inside a mill, while allowing product to exit, and without using screens. We knew any solution that used screens just wasn't going to work at a large scale – the screens would block and peg, and would be an operating and maintenance nightmare. Further, having screens would dictate that you could only use high qualtiy, high cost media, because low quality media would break and block the screen. The answer was the product separator, basically a centrifuge to keep media in the mill without screens. It was the breakthrough that allowed us to use virtually free media – ore gravel at McArthur River, discard smelter slag at Mt Isa.

A happy consequence of this is that the mill doesn't need to be closed circuited with cyclones. This is hard to get used to – we have always known that grinding mills need cyclones and a circulating load. But the IsaMill doesn't.

The final point is obvious – this is a horizontal mill. But this simple point has big implications.

Our partners, Netzsch, make both vertical and horizontal stirred mills for manufacturing. They told us that both configurations have advantages. But there was one overwhelming factor in favour of the horizontal configuration – scale up to larger sizes. This is because of start-up torque. Netzsch advised that they simply wouldn’t build a stirred mill over 400 kW, because the mechanical design would be dominated by the start-up torque on the bottom stirrer after a shutdown – the bottom stirrer has to be able to remobilise the settled load. For big mills this would dominate the design of stirrer, shaft, crane etc. In contrast, in a horizontal mill, all 8 stirrers are available.   This helps explain why the IsaMill has scaled up 10 fold from 300 kw to 3 MW in a decade, already almost 3 times bigger than the biggest installation Tower Mills have achieved in over 50 years.

The picture shows the 8 grinding discs (black) and the product separator (yellow) at the mill discharge.



In operation the mill is 70-80% filled with media, which is stirred at high speed – up to the stirrer tip speed of about 20 m/s. New feed has to pass through 8 different grinding chambers before it gets to see the product separator, or centrifuge, at the end of the mill. At this point media is returned to the grinding discs, and fine solids and water is discharged. The mill operates full and pressurised, with average residence time in the mill is 30-60 seconds. Once again, this is fundamentally different from conventional grinding. It also explains why the mill doesn't need cyclones to make a sharp product size – there is little time for overgrinding, but particles have to pass through 8 grinding chambers in series before leaving the mill.

The best way to describe this is to have a look at a small mill in operation.

This video shows why the IsaMill gets a sharp size distribution. The action of the product separator compresses the media between the 8 grinding discs. Feed has to pass through effectively 8 grinding chambers in series before it reaches the exit. When dye is introduced to the mill, its slow movement down the mill demonstrates the almost plug-flow path for new feed.

1995 : From Ink to Zinc.
2007 : From fine to Coarse.

xstrata technology

- **Larger mill capacity**
  - M10,000, 3.0MW
- **Ceramic media**
  - Natural media limits feed size - media SG, size
  - MT1 ceramic developed with Magotteaux
  - High SG (3.7) and range of sizes to 3.5mm
  - Allows high breakage rates of coarse particles

Developing the mill from grinding printer ink and chocolate to grinding zinc was the big step.

Compared with that, the move from fine grinding minerals to coarser grinds was relatively simple.

We were always fascinated by the potential to take the energy efficiency, small footprint, and inert grinding to mainstream applications. But there were two things we needed to do. We needed a bigger mill. We now have this with the 3 MW M10,000 mill.

Secondly, we needed better media. The ability to use low quality, free media like slag, ore gravel, or local sand, is remarkable, but it restricts the use of the mill to fine grinding. These grinding medias have relatively low density, and small natural grain size. This restricts the size of the ore particle they can break, even at the high stirring speed in an IsaMill. To be practical for mainstream coarse grinding, the media needed to be consistent quality, and high enough density and size to break the biggest particles in mill feed. And still be lower operating cost than using steel balls in conventional mills.

This was achieved by the development of MT1 Keramax ceramic by Maggoteaux.

Energy per Media Particle

$$E \propto d^3.v^2.SG$$

- d = media diameter
- v = media velocity
- SG = media density

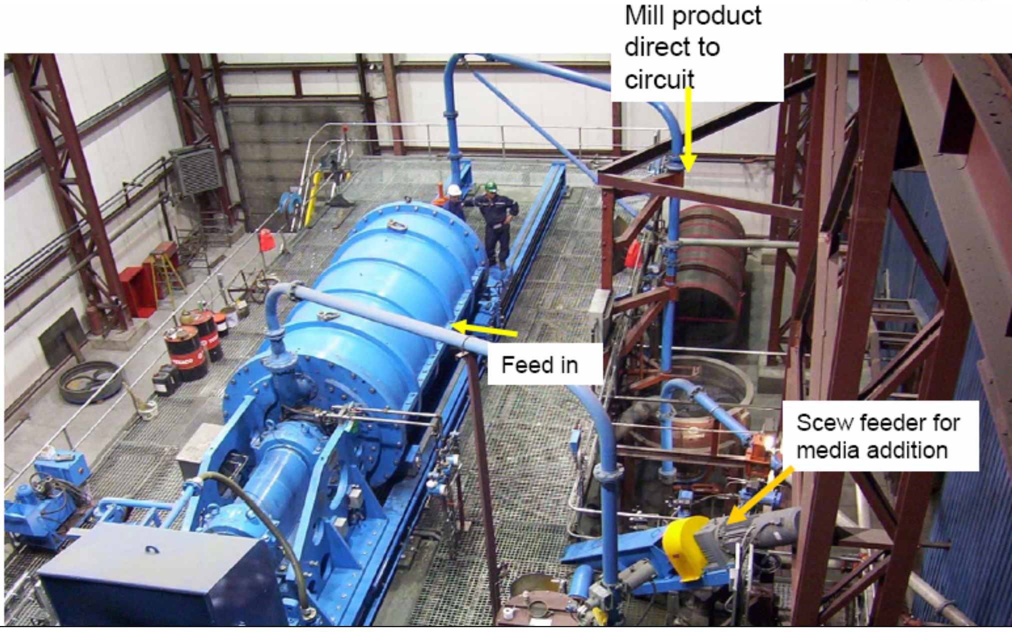
I promise that this will be the only formula in this presentation. But it is important to the McArthur River coarse grinding story.

Media particles need enough energy to break the largest particles in the mill feed, as quickly as they are entering the mill. If they don't, the coarse particles will build up in the mill and reduce the grinding efficiency – we are all familiar with critical size fractions from Autogenous and SAG milling.

In a ball mill, some steel balls are picked up and dropped the diameter of the mill – plenty of energy. In fact, probably too much energy, so some is wasted, but the coarsest particles will be broken.

Similarly in the IsaMill, we need enough energy in enough collisions to break the feed. We can either increase the SG of the media, increase its diameter, or increase its speed. The much high speeds in the IsaMill, , 20 m/sec, explains why small media can grind coarse particles. We don't want to increase speed any more, so we increased the media diameter and density. The MT1 ceramic has density of 3.7, compared with 2.4 for sand. Maggoteaux currently produce it up to 3.5 mm diameter, enough for grinding duties up to 300 micron P80 feed.

3 MW IsaMill, ceramic media



McArthur River Expansion Project

- **From underground to open cut mining**
- **Increase plant tonnage 33 %**
- **Reduce Flotation feed sizing : 75 to 45 microns**
  - Back to original design
- **Continue 7 micron regrind of cleaner feed**

McArthur River is now going through its next phase of development. It is moving from underground mining to Open Cut mining. Feed tonnage will be increased by 33%, from 230 t/h to 305 t/h (2.4 Mt/y). The project will also reduce flotation feed sizing from 75 microns back to the original design of 45 microns (increases in feed tonnage over the years caused the coarsening flotation feed)..

Of course, to make concentrate grade and recovery, all minerals have to be ground to 7 microns before cleaning.

McArthur River Existing Circuit 2007

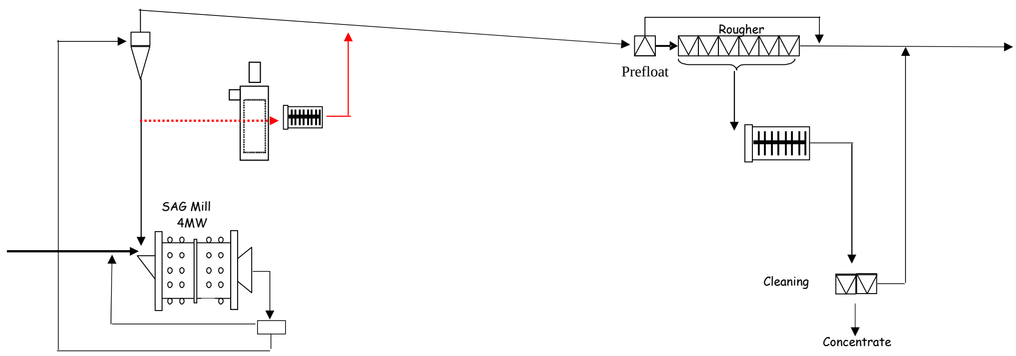
The original circuit was a SAG mill in closed circuit with cyclone and double deck screen to produce a P80 45 microns product for flotation. Media for the IsaMills was from the second screen deck (0.8-1.8mm). The IsaMills grind rougher con from 50 to 7 microns. Later, the IsaMill media was changed to sand. This decoupled SAG mill operation from IsaMill operation, allowing both to improve efficiency and throughput.

Feed tonnage has increased since start up. A 935 kW Tower Mill was installed to grind part of the cyclone underflow to partly compensate the tonnage increase. This is not the ideal duty for a Tower Mill, but it was chosen simply because a second hand unit was available – these were the days of 37 cent zinc ! Even so, flotation feed has coarsened to about 70 microns at the higher tonnage. Increasing the efficiency of the IsaMills helped compensate for the coarser feed, by maintaining a 7 micron grind of cleaner feed.

The ore from the open cut is lower grade and a bit more complex than the original orebodies treated. So McArthur needed to both increase tonnage, and return to design flotation feed size, while maintaining regrind size at 7 microns. IsaMills offered an efficient way to do this, while also bringing some of the advantages of inert grinding to rougher flotation.

McArthur River undertook a test program to evaluate the IsaMill for the coarse grinding duty.

First IsaMill Trials



The first trial was to test the mill on a similar stream to the Tower Mill, ie treat a portion of SAG mill underflow.

Initial testwork was done initially in the 4 litre M4 laboratory mill. This indicated that 3.5 mm ceramic media would grind the stream at higher efficiency and with a sharper size distribution than the Tower Mill. As a result, the product could be sent straight to flotation rather than back to the SAG mill cylcone.

We then did in-plant pilot work using the M20 (20 litre) mill, treating SAG cyclone underflow. The target was to produce approximately 45 micron product from the IsaMill.

Pilot IsaMill Coarse Grinding at MRM

xstrata technology

- **3.5 mm media could grind the feed**
- **More efficient than Tower Mill**
- **Sharper size distribution than Tower Mill**

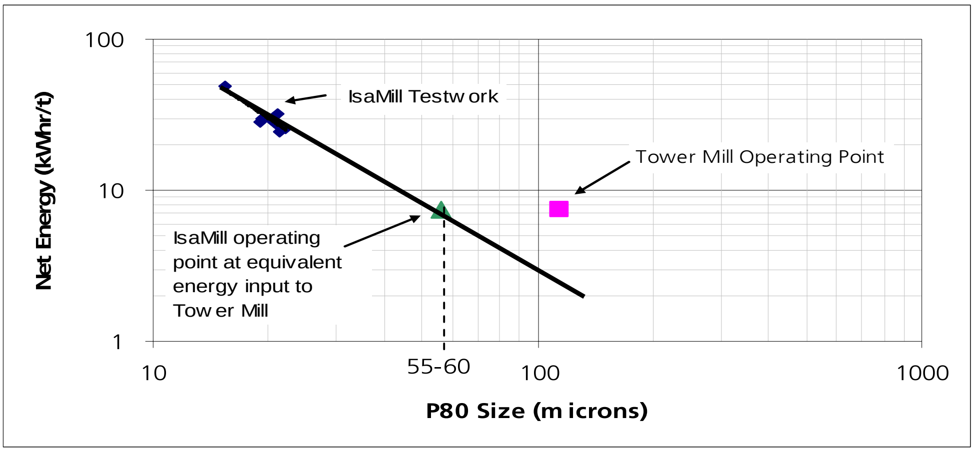
But :

- **Hampered by steel scats and +1 mm chips**
- **Had to reduce throughput, increase power to prevent "critical mass"**
  - Meaning grind was finer than target (25 micron)

The site pilot testwork confirmed the laboratory work that the IsaMill with 3.5 mm ceramic media could grind the cyclone underflow with the +1mm screened out. Efficiency and size distribution was better than the Tower Mill But the operation was hampered by build up of steel scats and coarse (up to 1mm) particles in this stream.

The steel scats could be removed with a magnetic separator. However the breakage rate of coarse particles was still too low. To prevent build up of coarse particles, the mill power had to be kept high, but throughput reduced. This meant an increase in kwh/t, and the feed was ground finer than necessary, to 25 microns rather than 45 micron target. Theoretically the grind was efficient, but we didn't need to grind that fine.

Coarse Grinding SAG cyclone u/f



As expected, the IsaMill was more efficient than the Tower Mill – for the same energy input (7kwh/t) it would produce a 55-60 micron product versus a 100 micron product from the Tower Mill. However this comparison is not particularly valid, as neither mill is suited to this grinding application. The IsaMill had to be operated to control coarse particles rather than achieve target grind size. So it became clear that this was not the right location for the IsaMills.

So our first attempt told us that the IsaMill would certainly grind, but it needed to be in a better position in the circuit. We were trying to do too many stages of grinding in a single mill.

Dealing with +1mm fraction

xstrata technology

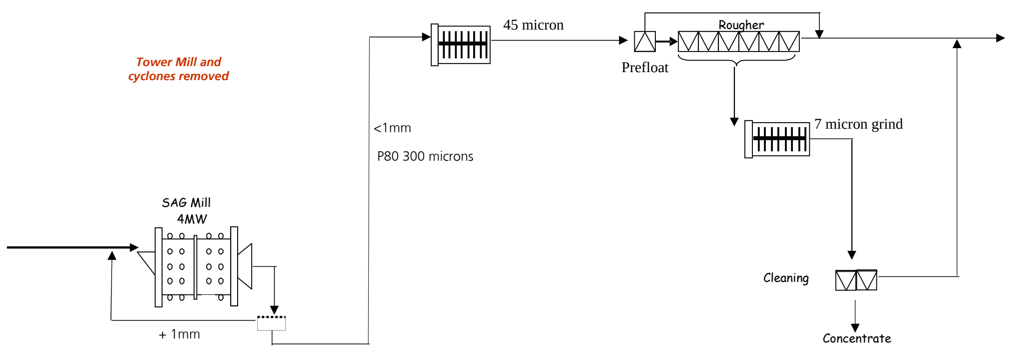
- **Increase breakage energy**
  - $E \approx d^3 \cdot v^2 \cdot SG$
  - 7mm media has 8 times the breakage energy of 3.5mm
- **Find a better location**
  - Screened SAG discharge, not cyclone underflow
- **2006-7 : SAG simulation, pilot testing, full scale testing in existing 1 MW IsaMill**
- **Project approval early 2007**

The breakage rate of coarse particles could be improved by returning to our formula – by increasing speed, media SG, or media size. In fact, the full scale mills operate with higher tip speed than the M20 unit, so should have performed better. But the biggest impact would be from bigger media – doubling the top size of media will mean an 8 times increase in maximum breakage energy available.

Currently the coarsest size of MT1 commercially available is 3.5 mm. This will increase in future. But the main point is that it became obvious we were trying to grind the wrong stream. A much better solution was to take the IsaMill out of the SAG mill circulating load. Let the SAG mill grind SAG mill feed, the IsaMill can grind the final product of that circuit.

During 2006 and 2007, McArthur River surveyed and simulated a different SAG mill configuration. This included closing the SAG mill with a 1 mm screen. Screen undersize is nominally -1mm, with a P80 of 300 micron feed. This stream would be ground in open circuit IsaMills, then sent to flotation. One of the existing 1MW has been used for full scale evaluation of IsaMilling and different medias, including ceramic and coarse sand. As a result, McArthur River are proceeding with a full scale project to install IsaMills to grind flotation feed.

McArthur River : New Circuit 2008



This is the new circuit being installed at MacArthur River. Two 3 MW M10,000 IsaMills will be installed in early 2008. Screen undersize will be sent direct to open circuit IsaMills, which will produce a P80 45 micron flotation feed. The Tower Mill and cyclones will be removed from the circuit.

MRM Expansion Project

xstrata technology

- **Add 2 IsaMills to treat 305 t/h at 40% solids *(open circuit)***
- **Remove Tower Mill and cyclones**
- **Increase feed 1.9 Mt/y to 2.5 Mt/y (33%)**
- **Reduce flotation feed P80 75 to 45 microns**
- **Potential downstream benefits**
  - Inert grinding before roughing
  - Reduced regrinding energy (finer float feed)

The mills will be fed at 40% solids.

The finer flotation feed sizing should improve roughing performance, and will slightly reduce regrinding energy need. Primary roughing may also benefit from the inert grinding – experience at other installations is improved flotation rates and selectivity for fines, and reduced reagent needs. These gains can only be evaluated at full scale, where the full impact on water chemistry and circulating loads is evident. So any gains from inert grinding are an “upside”, not part of the justification.

Coarse Grinding at Anglo Platinum

PPL 100 to 50 micron grind. Commissioned Dec 06

McArthur River have taken the coarse grinding applications of IsaMilling to the next level. Anglo Platinum have already committed to a major program of IsaMilling. This is the first installation at their PPL concentrator, which grinds scavenger feed in open circuit from around 100 microns to around 50 microns. This mill was commissioned in December 2006.

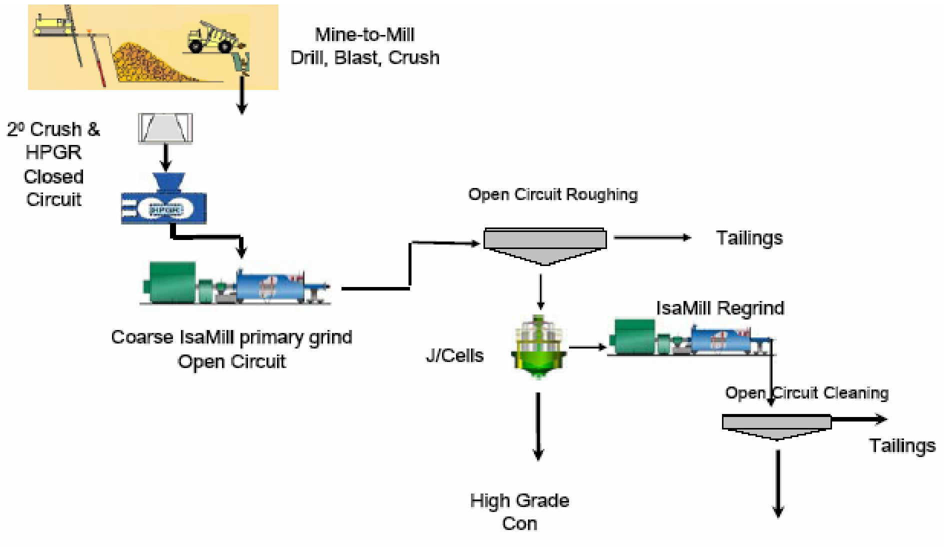
Coarse Grinding at Anglo Platinum

- **Mainstream Coarse IsaMilling to Increase liberation and recovery**
- **Concentrate Regrind to increase grade**
- **Currently installing 64 MW of IsaMills (mainly coarse)**

The success of the Anglo Platinum installations has led them to undertake a major installation program for IsaMills. Over the next 18 months they will be installing 64 MW of IsaMilling capacity. Much of it will be grinding mainstream feeds like the PPL installation – to increase liberation and recovery in roughing and/or scavenging. Other mills will be installed to increase concentrate grade, to increase smelter throughput, and reduce smelting energy and cost.

By the end of 2008, there will be 100 MW of operating IsaMill capacity. The technology has quickly moved from fine grinding to coarse – over 70% of the installations by the end of 2008 will be in conventional regrinding or mainstream grinding. (product sizes 25 to 60 microns).

Mineral Processing without Tumbling Mills?



So I return to my opening slide. Most people think of the IsaMill as a fine grinding mill. No more. A little over a decade ago it moved from grinding ink to grinding zinc. It has quickly made the adjustment to coarser grinding.

With the work at McArthur River, we are much closer to the hypothetical circuit without tumbling mills than any of us imagined even a year ago.

We aren't there yet, but we are a lot closer than we were even in 2006. The work at McArthur River for the first time will take a SAG mill discharge directly to IsaMills rather than to conventional ball mills. So further advances in increasing the feed size of IsaMills (eg with coarser or higher density media), and/or reducing the product size of HPGRs could enable this circuit. Reducing the product size of HPGRs could be achieved in several ways, including by using two or more HPGR stages in series, with each stage in either closed circuit, or in a simpler open circuit configuration.

Perhaps the HPGR discharge sizing and IsaMill feed sizing will not converge quite close enough for them to meet as we have shown in the above simplified diagram. Perhaps the P80's will be mismatched, or maybe just the coarse fraction from HPGR will be too coarse for the IsaMill. In this case, the simplified circuit above could be modified to include a conventional grinding and/or classification stage between HPGR and the IsaMill. In this way, the benefits of energy efficiency and low steel consumption of HPGR and IsaMills would be maintained, with the addition of a relatively small conventional grinding and classification step (eg ball mill or Tower Mill with or without a classification stage).