AusIMM | Metallurgical Society

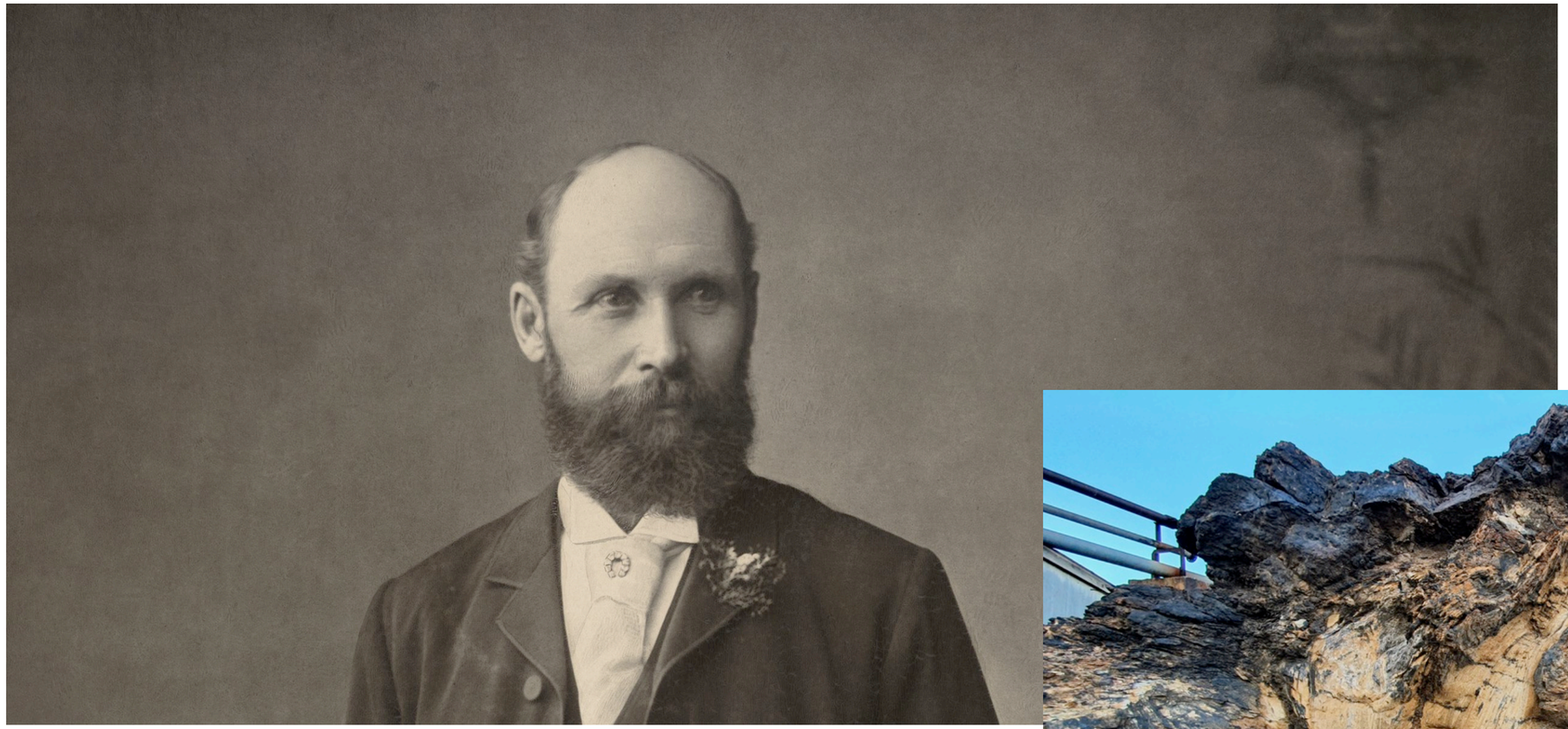
It’s at times like these that a Jim’s Mowing franchise starts to look good!

The perils of conducting plant trials

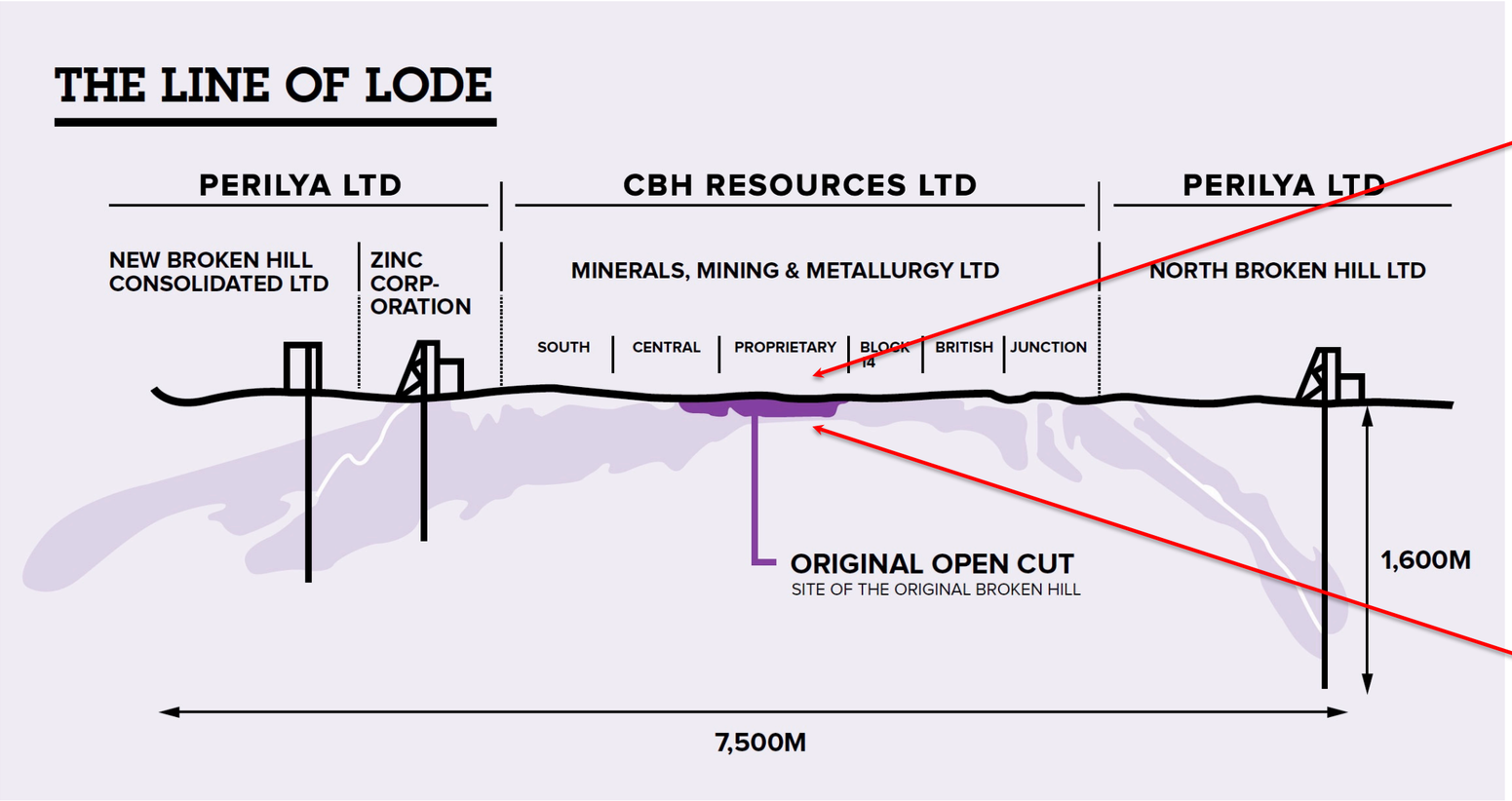
Dr Chris Greet

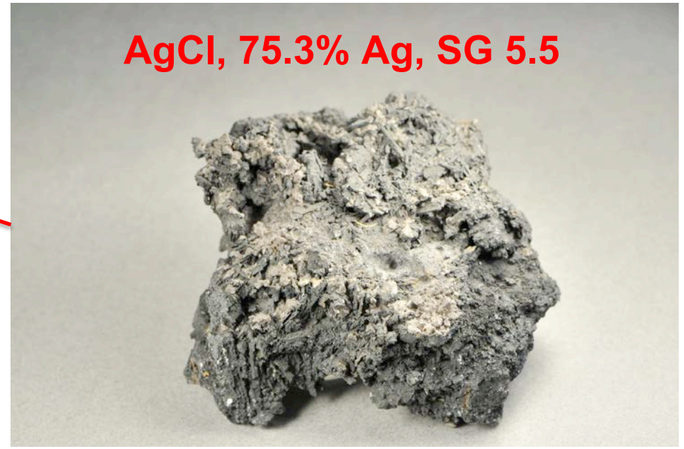
MAGOTTEAUX

Our story begins . . .



The line of lode





Profitability

	1886	1888	1890	1892	1894	1896	1898	1900	1902
Total kilotonnes mined at Broken Hill	15	126		403	643	820	891	1424	1115
Kilotonnes mined by BHP	10	80	190	300	590	440	400	520	660
BHP dividends and bonuses, £A x 1000	50	370	1000	800	580	420	280	180	110
BHP dividends and bonuses per kilotonnes, £A	5	4.6	5.3	2.7	1	0.95	0.70	0.34	0.16

As the oxide ores were depleted, from early 1890's sulphide ores became the predominant feed to the various plants. Recoveries declined significantly, the race was on to solve the sulphide problem.

Grinding (for mineral liberation), gravity concentration to recovery the galena, amalgamation to recovery the silver, leaching and electrolysis for zinc recovery and even magnetic separation were all tried . . . but the tailings dumps containing huge quantities of metal kept growing.

Delprat

Appointed General Manager of BHP in 1899.

His research experience told him that the solution would start in the laboratory.

Using sodium bisulphate he was able to float marmatite in the laboratory.

Being the General Manager he had the resources and authority to move quickly to take the laboratory work to plant trial.

Recoveries improved.

Tailing dumps were processed.

Profitability was restored.

Industrial mineral flotation became the norm . . .

But, I am sure there were many days he asked himself why and is it worth the effort!

The Delprat Distinguished Lecture series . . .

AusIMM Society | Metallurgical

2011 Michael Nelson: Innovation in flotation machine design

2012 Alban Lynch: Mineral processing during the 20th Century: the highlights, why they happened and what happens next?

2013 Graeme Jameson: Size matters: coarse and quick flotation can reduce costs

2014 John Ralston: 21st Century challenges in the chemistry of minerals processing

2015 Bill Johnson: Future mineral processing challengers based on 45 years of applying science and engineering to mineral processing

2016 Tim Napier-Munn: Innovation in mineral processing: distinguished past and uncertain future

2017 Rob Dunn: Water: facts, perceptions and conflicts

2018 Geoffrey Blainey: 125 years of AusIMM

2019 J-P Franzidis: Mining and society

2020 Joe Pease: Innovation deconstructed: Do we seek disruption of optimisation

2021 Fran Burgess: Achieve excellence in metallurgical operations - The Challenges and Opportunities

2022 Peter Munro: The truth will set you free

2023 Peter Hayes: Time to show our mettle

MAGOTTEAUX

Plant trials

Have you got the intestinal fortitude to survive . . .

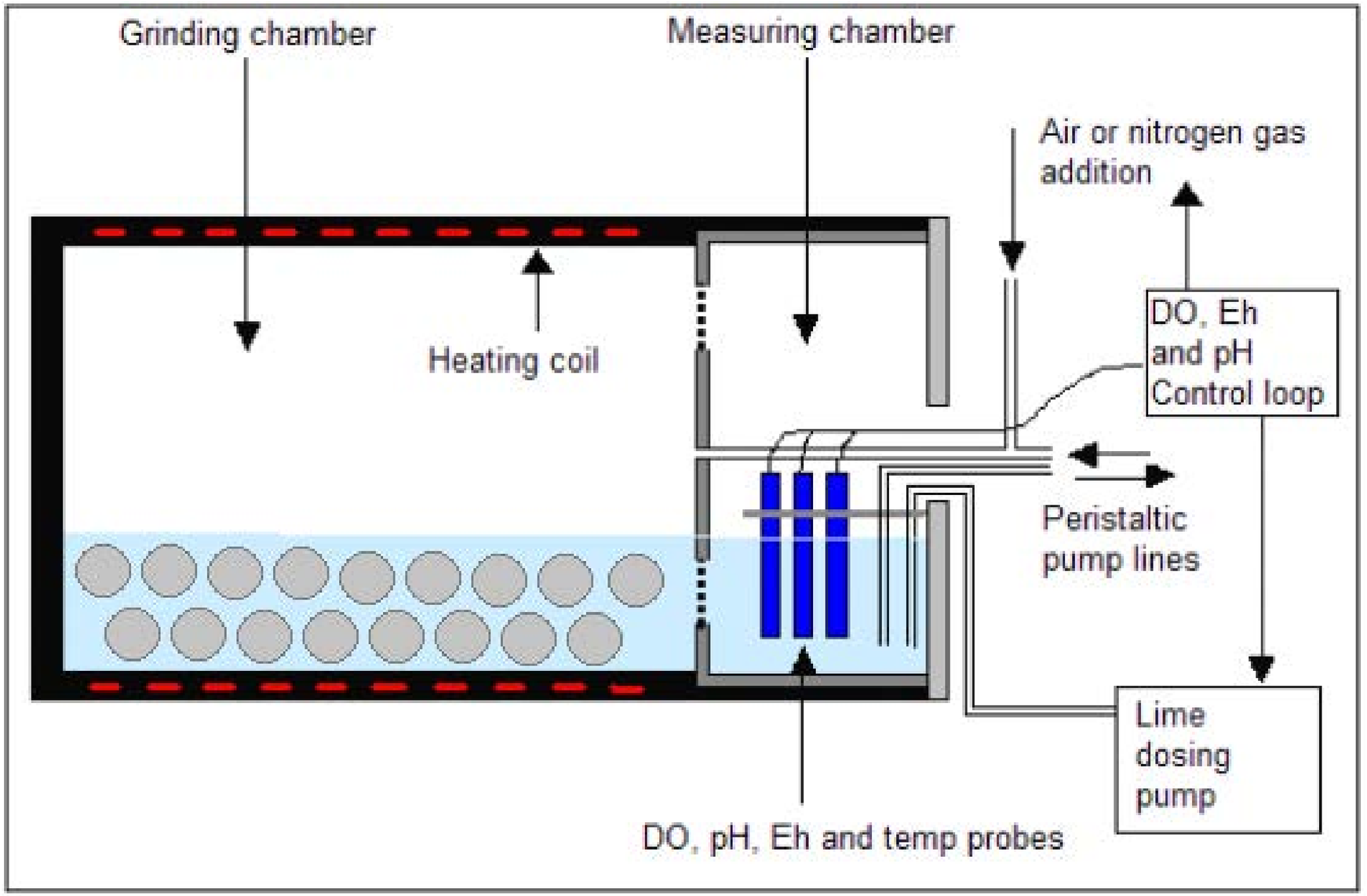
Grinding chemistry

Moving from this grey spherical ball to another grey spherical ball will have an impact on the pulp and surface chemistry of the particle we wish to separate, yield reductions in reagent consumption and improve metallurgical performance, in addition to reducing media consumption . . . crazy, right!

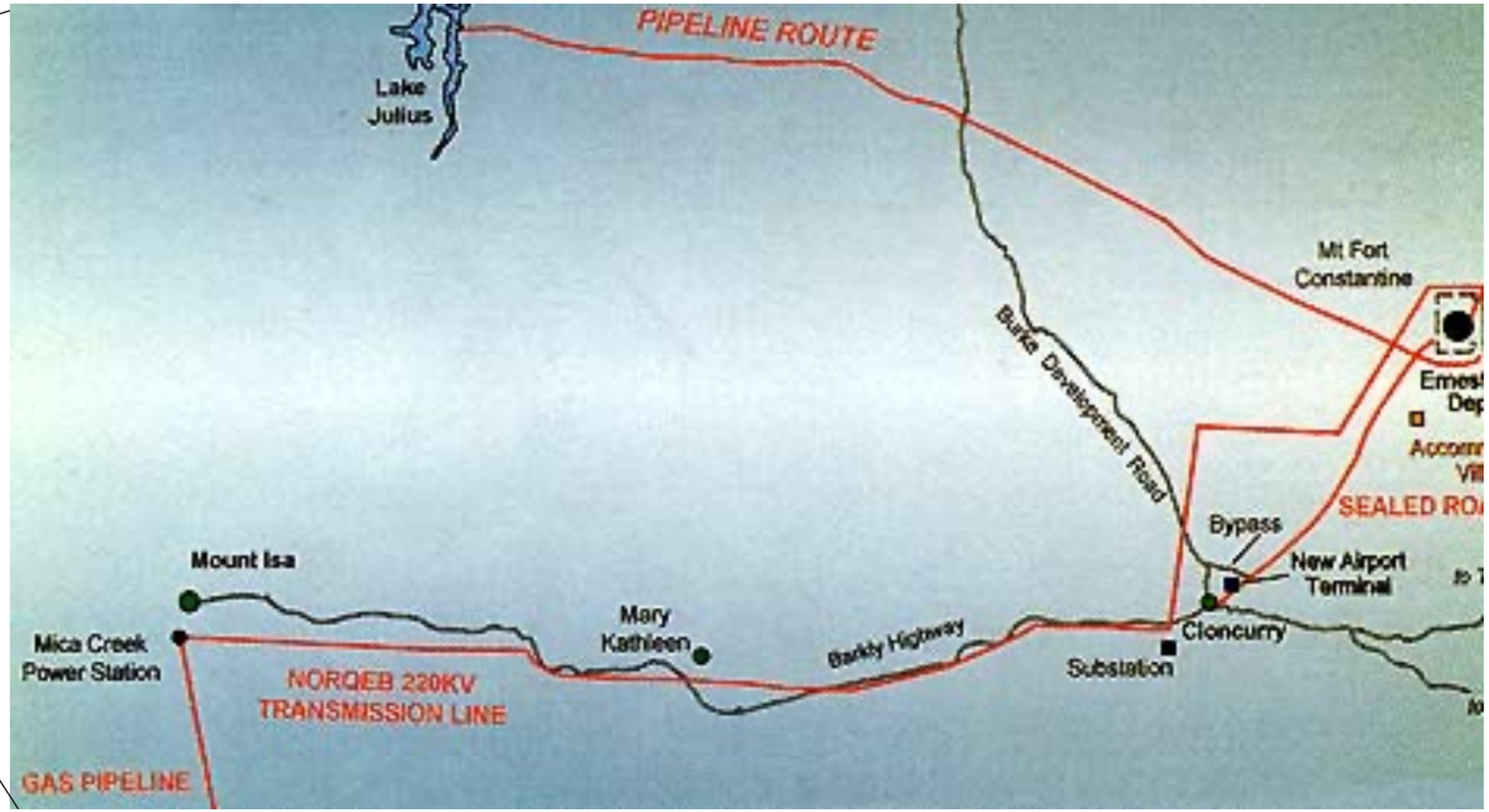
It all starts with well executed laboratory tests

- Complete a pulp chemistry survey of the plant;
- Collect a bulk sample of plant feed and process water;
- In the MagoMill® establish the grind for each grinding media to be tested to achieve the PSD of the flotation feed;
- Develop the pulp chemistry recipe for the standard media, and apply this for all test; and
- Optimise the reagent regime for the new chemistry.

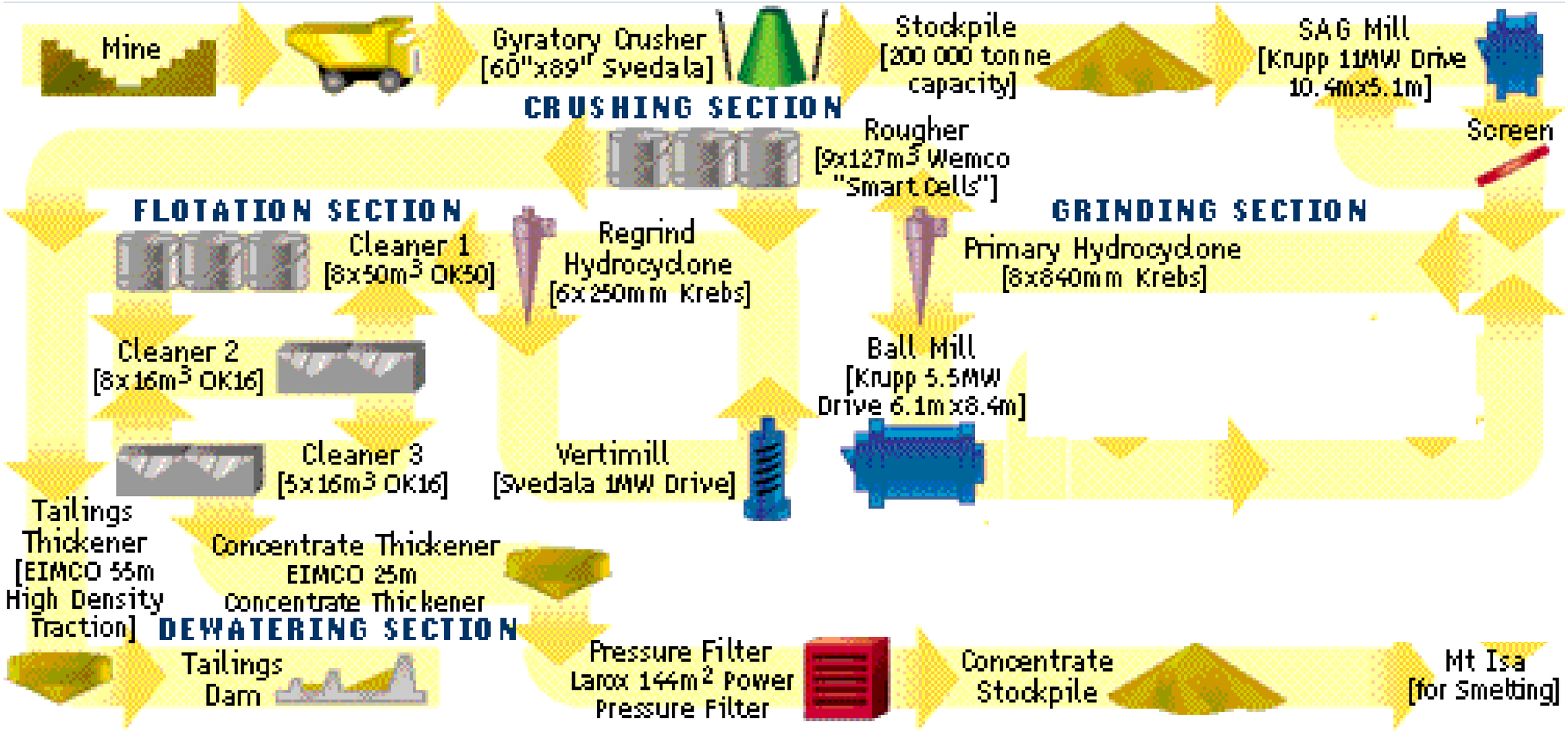
The MagoMill®



Ernest Henry case study - location



Ernest Henry case study – Flow sheet



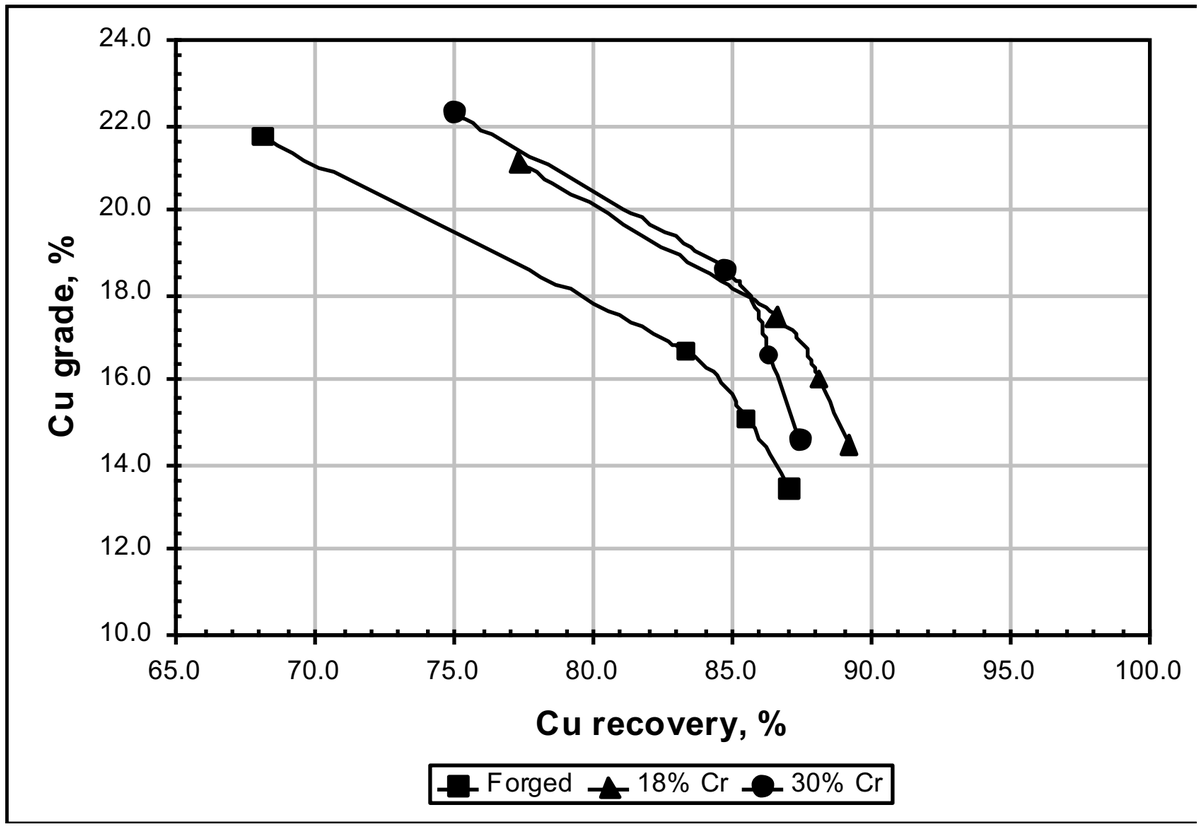
Ernest Henry case study – Project history

- 2002-2004: Ian Wark Research Institute conducted tests on site with the MagoMill®, but encountered problems with copper activated pyrite.
- September 2004: A SAG mill feed sample tested successfully.
- April 2005: Confirmation study on new SAG feed sample.
- April 2006: Further confirmation study on new SAG feed sample.
- April 2008: Pilot plant trial.
- November 2009: Plant trail commences.
- March 2012: Low pH trials

Ernest Henry case study – Laboratory testing

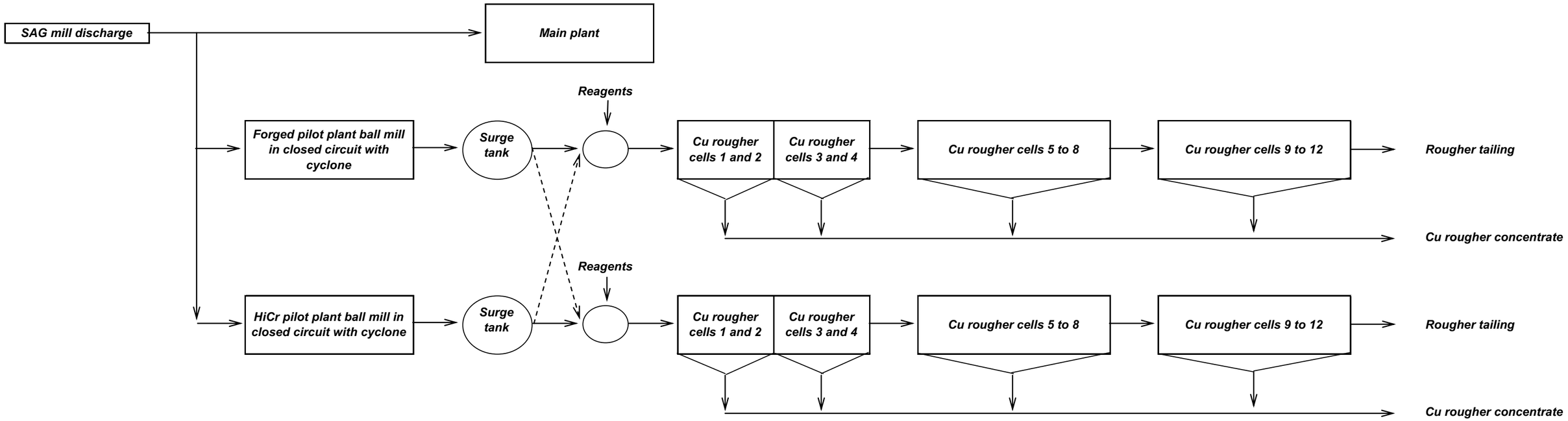
Media	pH	Eh, mV (SHE)	DO, ppm	EDTA, %	
				Fe	Cu
Forged	10.9	-23	0.0	1.6	0.08
18% Cr	10.9	93	0.4	0.2	0.10
30% Cr	10.9	110	0.6	0.2	0.09

Ernest Henry case study – Laboratory testing



Test	Recovery, %		Dilutent grade			
	Cu	Au	Au, ppm	Mo, ppm	IS, %	NSG, %
Forged	85.6	65.7	5.4	1436	18.3	38.4
18% Cr	88.8	70.4	5.2	1552	14.4	42.3
30% Cr	87.2	65.3	5.5	1528	7.6	49.1

Ernest Henry case study – Pilot plant testing



Ernest Henry case study – Pilot plant testing

Media	Parameters				
	pH	Eh, mV (SHE)	DO, ppm	EDTA, %	
				Fe	Cu
Forged 18% Cr	10.3 10.1	-83 54	0.03 0.02	0.05 0.03	0.1 0.1

Ernest Henry case study – Pilot plant testing

Statistical analysis of the 65 surveys of the pilot plant indicated:

- 2.8±1.8 % increase in Cu recovery (>99 % confidence)
- 1.3±0.8 % increase in Cu grade (>95 % confidence)
- 3.4±2.2 % increase in Au recovery (>99 % confidence)

Ernest Henry case study – Independent review

The laboratory and pilot plant studies were reviewed by the JKMRC. This independent analysis was beneficial to both companies as it:

- Provided confidence to the Ernest Henry Mine that the work completed by Magotteaux was of a high standard, with the results and analysis were in good order; and
- Provided Magotteaux with valuable positive feedback regarding its technical approach and analysis methods.

Ernest Henry case study – Plant trial

- Do nothing.
- Convert the ball mill to high chrome grinding media:
  - Dump and replace with an initial charge of high chrome
    - Realise benefits earlier
    - On/off trial
    - Logistical nightmare for a mill of this size
    - Media delivery at end of year
  - Purge by top-up
    - Nominally 8 months to purge the mill
    - Compare before and after
    - Supply earlier

Ernest Henry case study – Plant trial

Dumping a mill without a hatch!!!!!

Ernest Henry case study – Plant trial

- Collect both pulp chemical and metallurgical data:
  - Pulp chemistry surveys of the grinding/flotation circuit were collected on a daily basis for nominally three weeks before and after the conversion; and
  - The shift inventory samples for at least three months before and after the conversion were used to evaluate metallurgical performance.
- The statistical methods used to analyse the data were:
  - t-test analysis;
  - Comparison of regression lines; and
  - Multiple variable regression analysis.

Ernest Henry case study – Plant trial

Parameter	pH		Eh, mV (SHE)		DO, ppm		EDTA Fe, %	
	FS	HC	FS	HC	FS	HC	FS	HC
Average value	11.4	11.1	66	95	0.8	1.1	0.35	0.06
# of samples	26	26	22	25	22	26	26	26
Confidence level, %	>99		>99		86		>99	
Difference	-0.3±0.1		29±16		0.3±0.4		-0.29±0.09	

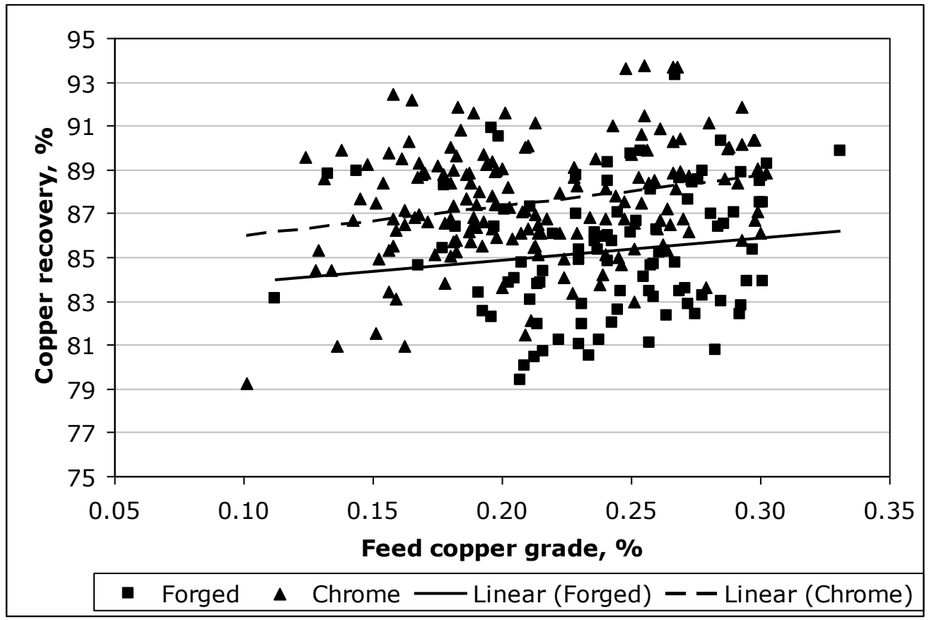
Ernest Henry case study – Plant trial

- The analysis commenced with an examination of the feed data to determine if a valid comparison could be made by investigating variations in :
  - Particle size distribution;
  - Throughput; and
  - Feed grade.
- Tools used for the initial comparisons were:
  - Time series plots; and
  - “Cusum” plots.

Ernest Henry case study – Plant trial

The t-test analysis suggested the copper recovery improved by 2.2±0.6 percent (with greater than 99 percent confidence).

The comparison of regression lines indicated a copper recovery improvement of 2.4±0.8 percent (with greater than 99 percent confidence).



Multiple variable regression analysis showed an improvement of 2.0±0.7 percent copper recovery (with greater than 99 percent confidence).

Ernest Henry case study – Conclusions

After 8 years of laboratory and pilot plant testing, numerous metallurgical superintendents, and a positive review of our work by the JKMRC a plant trial was conducted.

The plant trial results were of the same order of magnitude as those observed in the laboratory and pilot plant.

But, out work was not complete . . . we had noted in our laboratory testing that when using high chrome grinding media we could reduce the pH. In March 2012 another plant trial was conducted showing that it was possible to operate at a lower pH.

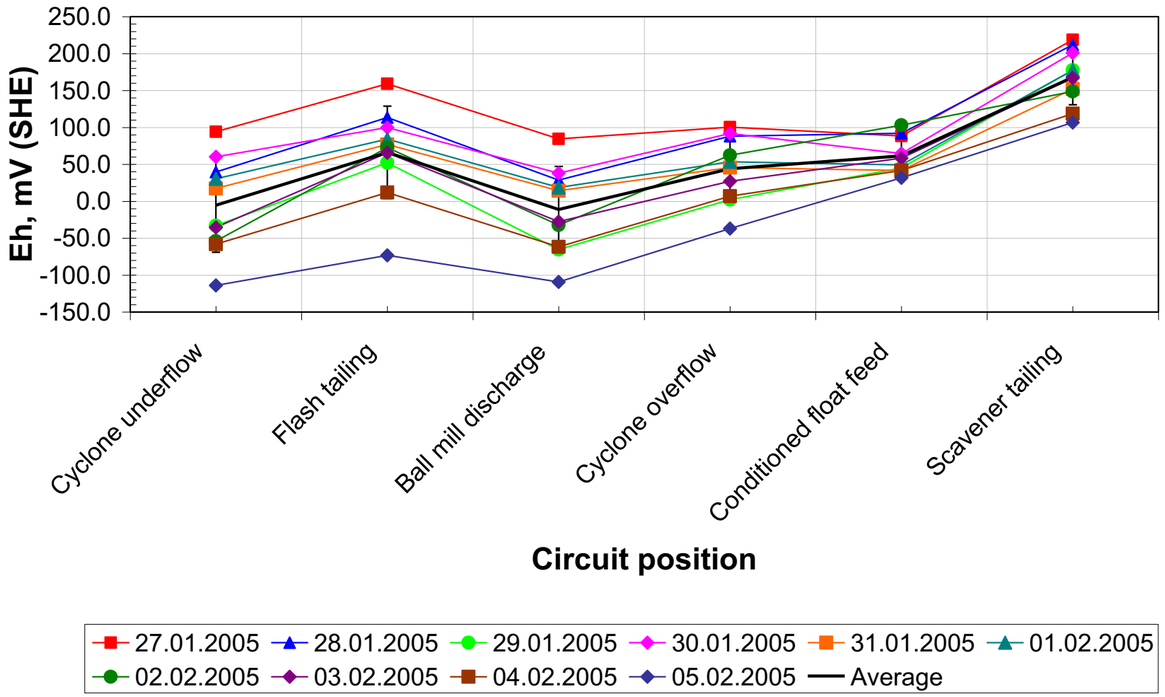
Today Ernest Henry Mine operates their rougher circuit at natural pH and still runs with high chrome grinding media.

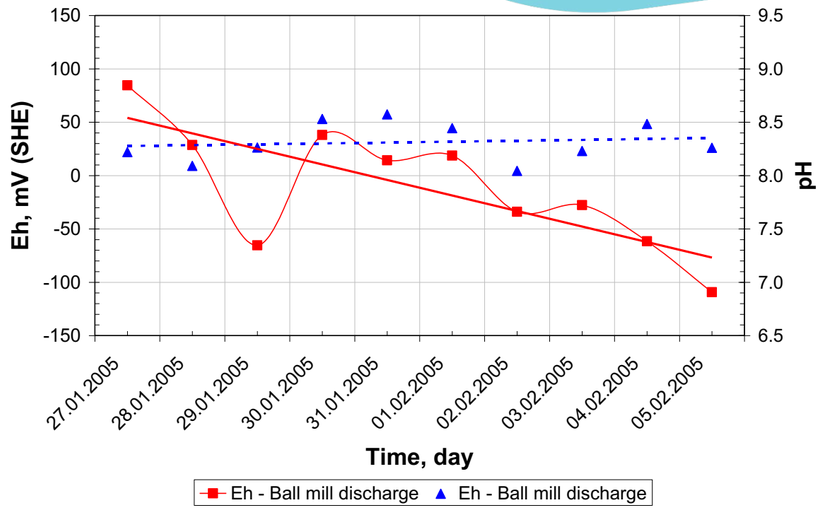
And . . . there were times a Jim's Mowing franchise looked very enticing!

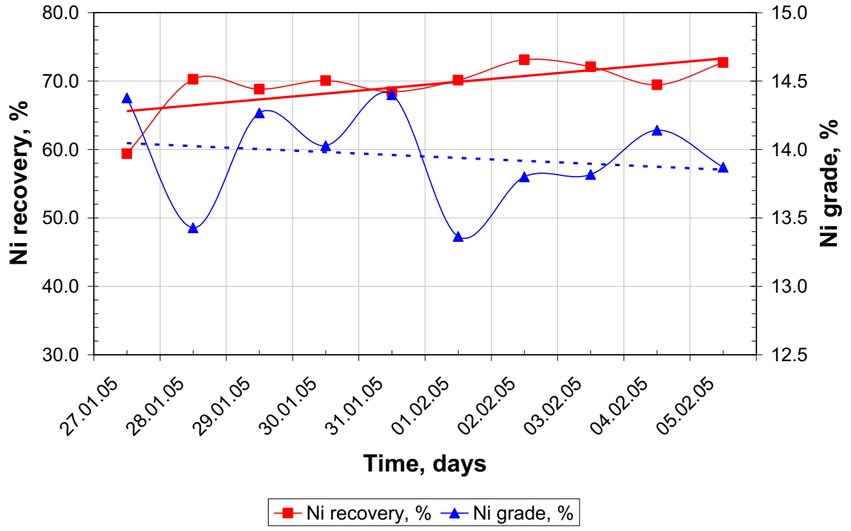
Pulp chemistry, is it useful?

This story goes back to the early 2000's . . . and it's another journey with many potholes on the road to success . . .

Does the pulp chemistry change?

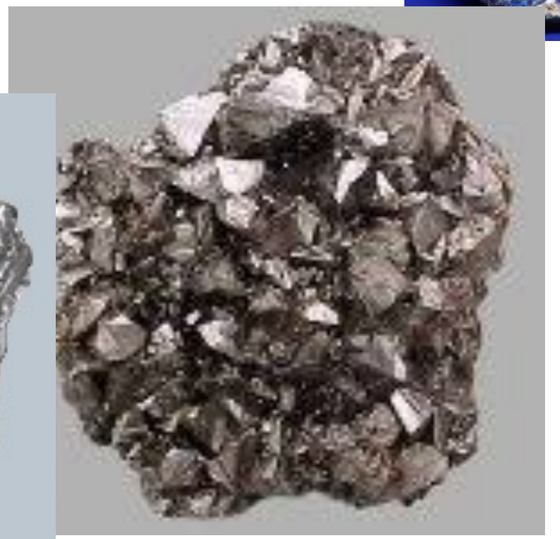






Why does the pulp chemistry change?

Mineral	Rest potential, V
Pyrite	0.66
Chalcopyrite	0.56
Sphalerite	0.46
Galena	0.40
Forged steel	-0.20



Pulp chemistry observations

If we look beyond grinding chemistry typically we observe that as the pyrite in the ore increases:

- The Eh becomes more reducing
- The dissolved oxygen decreases; and
- The oxygen demand increases.

These changes generally lead to lower concentrate grades and lower recoveries.

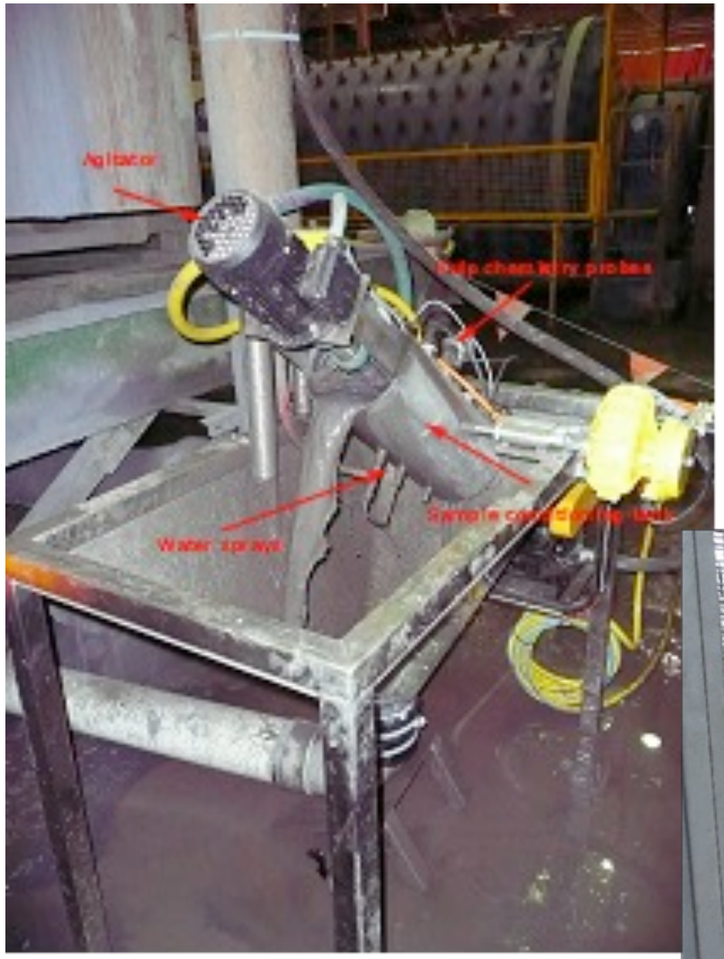
How do we measure the pulp chemistry change?

Generally, pulp chemistry measurements are made by a metallurgical technician using laboratory meters and probes.

This data gives the metallurgist a point in time, which can be used to diagnose problems in the plant or recognise changes.

But, it is not normally completed on a routine or continuous basis.

What if we could measure pulp chemistry on-line?



Manual measurements do not provide continuous reading of the pulp chemistry, so MagoPulp® (aka PCM® (pulp chemistry monitor) was developed in 2008. This instrument has been refined with time to make it more robust, but it is able to measure the pulp chemistry continuously, on-line and in real time.

Initial plant trials

The concept was initially tested at Perilya Broken Hill, and proved the concept.

Further trials were conducted at Terramin's Angas Mine, Phu Kham, Cadia and Prominent Hill

It became obvious that:

- The instrument required lots of love and attention; and
- The data was not presented in a useable way.

Improved design

Data overload

A day's worth of data generates a spreadsheet with 217 columns and 86,400 rows!

Timestamp	Stream 1 Oxygen Demand	Stream 1 Dissolved Oxygen	Stream 1 Dissolved Oxygen Array	Stream 1 pH	Stream 1 Eh	Stream 1 Temperature	Spare	Stream 2 Oxygen Demand	Stream 2 Dissolved Oxygen	Stream 2 Dissolved Oxygen Array	Stream 2 pH	Stream 2 Eh	Stream 2 Temperature
	PCM-OX-DEM-1.PV	PCM-OX-DIS-1.PV	PCM-OX-ARR-1.PV	PCM-PH-1.PV	PCM-EH-1.PV	PCM-TEMP-1.PV	Spare	PCM-OX-DEM-2.PV	PCM-OX-DIS-2.PV	PCM-OX-ARR-2.PV	PCM-PH-2.PV	PCM-EH-2.PV	PCM-TEMP-2.PV
1/05/2017 5:00:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:01:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:02:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:03:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:04:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:05:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:06:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:07:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:08:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:09:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:10:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:11:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:12:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:13:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:14:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:15:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:16:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:17:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:18:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:19:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:20:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:21:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:22:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:23:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:24:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:25:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:26:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:27:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:28:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:29:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:30:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:31:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:32:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:33:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:34:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:35:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:36:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:37:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:38:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:39:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:40:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:41:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:42:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:43:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:44:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962
1/05/2017 5:45:00	2.527153015	6.150000095	6.679999828	12	-88	32.70000076	Tag not found	0	7.909999847	7.909999847	10.64999962	-17.29999924	27.39999962

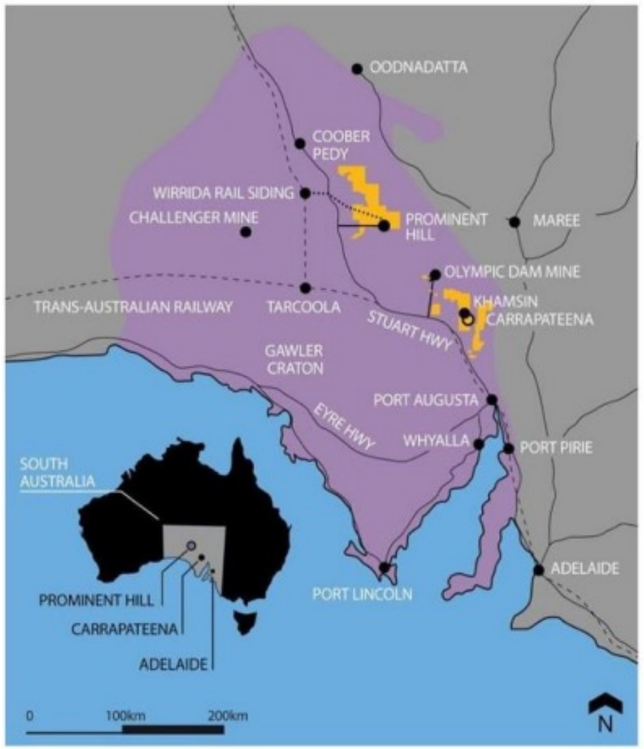
Using the data

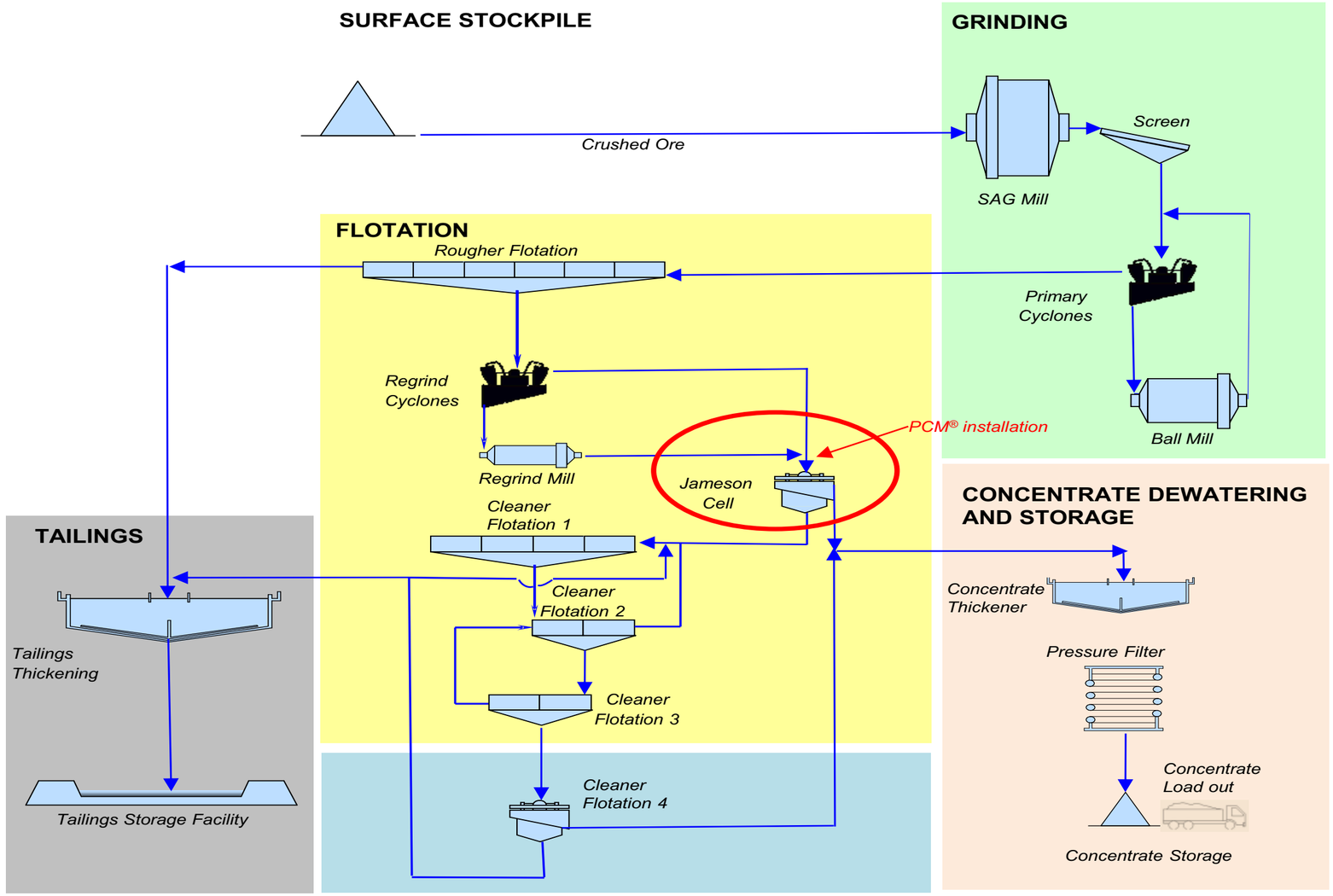
It quickly became apparent that this was not trivial so we have moved from Excel to using MATLAB® by MathWorks®, which provides greater flexibility in the models available and significantly reduced the analysis time.

By examining the process and think about what parameters influence the behaviour of valuable and gangue minerals typical variables using in our algorithms are:

- Throughput
- Particle size
- Feed grade
- Collector addition
- Air
- Level
- Pulp chemistry

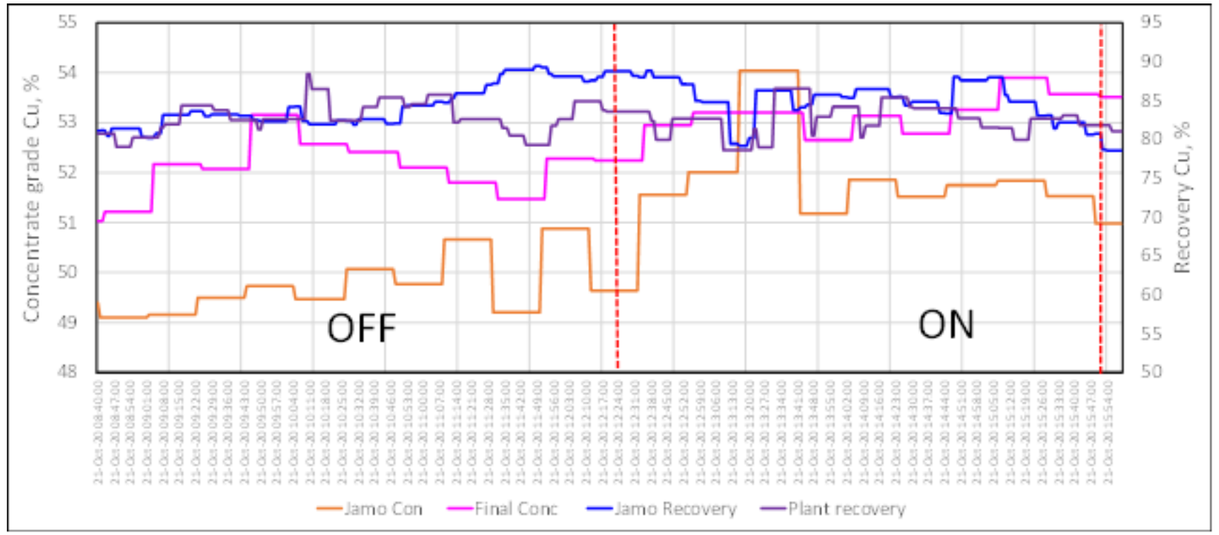
Prominent Hill . . . TAKE 2!





Prominent Hill . . . TAKE 2!

- Based on a knowledge of the process and what the parameters measured mean an application was developed that describes concentrate grade and recovery.
- Using this application it is possible to input either as target concentrate grade or recovery, and for the pulp chemistry readings for a given time adjust the collector, air and level in the flotation cell to maximise the recovery or concentrate grade.
- A short ON/OFF trial at OZ Minerals' Prominent Hill Mine demonstrated that the App was able to increase the final copper concentrate grade by 0.85 percent with no loss in copper recovery compared with the operators running the plant.



	Change	confidence interval
Cu grade, %	0.85	**±0.41**
Cu recovery, %	**No difference**	**No difference**

That was in 2019 . . .

- Prominent Hill agreed to an extended plant trial, expected to start in 2020.
- Replaced old MagoPulp with a new unit (after three years of operation) at the beginning of 2020.
- COVID
- No site access to install new unit.
- Communication issues between MagoPulp and site.
- New OSA and level control installed on Jameson Cell.
- Personnel changes.
- New owners (i.e. Oz becomes part of BHP).
- Communication issues (MagoPulp's PLC removed due to cyber security fears).
- Relocation.

Have we given up?

- Perhaps surprisingly, site are still very interested, so the project is still alive.
- The latest news . . . we are relocating MagoPulp, and once installed we need to collect new data, retrain the algorithms then start the extended plant trial . . .
- We are conducting plant trials at Dugald River and Batu Hijau in addition to the work at Prominent Hill.

Closing remarks . . .

- Over the past 21 years with Magotteaux we have conducted over 100 plant trials evaluating the impact of grinding chemistry on flotation and leach performance.
- Has it been easy? No, but it has been fun, frustrating, challenging, exciting and rewarding.
- It has given me some very valuable insights into people and how they run their plants, and when coupled with the technical knowledge it has been an excellent learning experience.
- Have I been driven to investigate a Jim's Mowing franchise? No . . . but perhaps I need serious psychological help!

- Good experimental technique, tenacity, credibility, honesty and a supercharged dose of humour help.