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Drill faster, cheaper, more accurately.

ISEE Australian Chapter

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Improved Drilling Accuracy Results in Reduced Ore Dilution at Evolution, Cracow.

Ryan Stimpson

Head of Engineering, Minnovare

PRODUCTION™ OPTIMISER

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Company Background

About Minnovare

- Based in Perth, Western Australia
- Established in 2012 to commercialise the Azimuth Aligner drill rig alignment system.
- Leading Exploration drill-rig alignment system within mining and civil construction industries.
- National and international presence – spanning over 120 mine sites, across 8 countries.
- Offices in Canada and the United States.

Place a high value and emphasis on industry engagement and collaboration

- With mines
- Industry associations
- Other METs companies, and
- Mine planning software developers/providers

Through this, Minnovare has created an exciting product roadmap aimed at improving productivity within underground mining.

Mining Production Focus

Identifying a need within the industry

Collaboration with our mining clients highlighted the need for a **production drilling optimisation solution**, comprising;

Integrated hardware and software platforms,

Aimed at improving the efficiency and effectiveness of the drill and blast process.

Blast-hole deviation has been identified as a significant contributing factor behind sub-optimal blasts. The solution must therefore;

Minimise blast-hole deviation, and

Improve drill-data integrity, transfer, analysis and decision making on site. Leading to;

Optimal designs, charging and blasting, by;

Reducing dilution and associated costs (bogging, trucking, processing)
Reducing bridging in stopes (maximising stope recovery)
Reducing re-drills, down-time = increasing drilled meters per shift
Improving fragmentation size and consistency
Increasing ore recovery
In summary: Reducing costs and increasing productivity and profitability

What Factors Affect Blast-Hole Deviation?

Analysing the issue

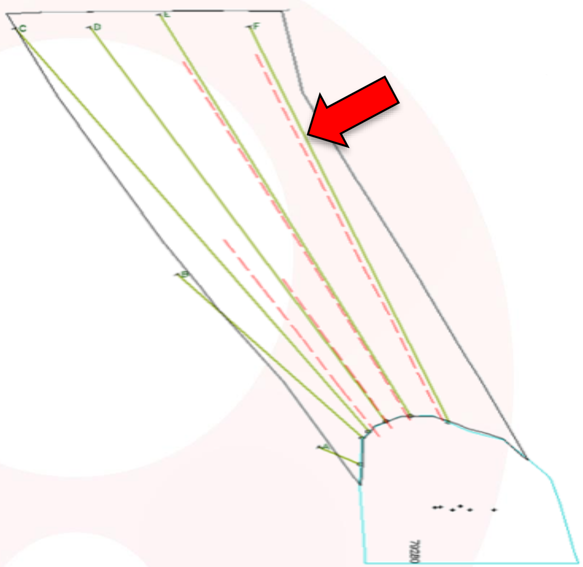
- It is widely accepted within the mining industry that blast-hole deviation occurs due to:
  - **In-hole deviation**
  - **Collar error**
  - **Alignment error**

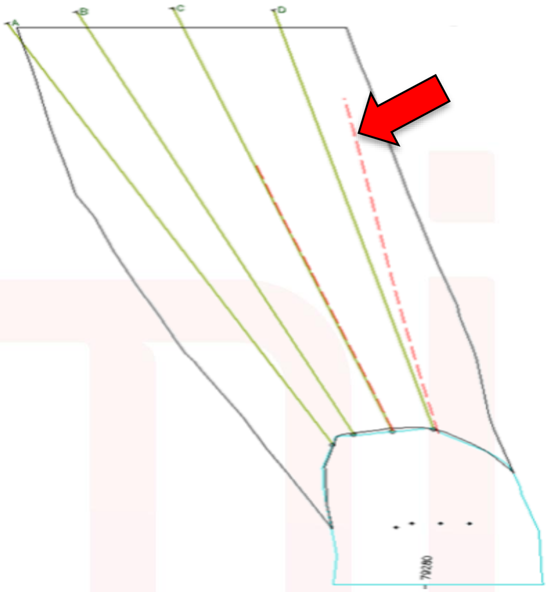
- There is a perception that in-hole deviation is the primary contributor, however testing conducted by Minnovare and our clients has proven that errors present **before** drilling commences, have the largest impact.

- These errors can be broken down further:
  - **Collar error:**
    - Collars incorrectly positioned – Inaccurate survey mark-up & operator error
    - Collar position moved - due to ground support, other obstructions or redrills
  - **Alignment error:**
    - Inaccurate survey mark-up
    - Limitations of OEM alignment systems and complex alignment processes
    - Operator error / diligence
    - Variation between equipment – e.g. wear and tear

What is the Impact of Collar & Alignment Error?

Distinguishing between the two





Collar Error

If the collar of a blast-hole is offset, and no change made to the planned dip and dump, the deviation at the toe of the hole will be a constant i.e. 150mm offset at the collar = 150mm offset at the toe.

**Assuming no additional in-hole deviation.*

Alignment Error

If the alignment of a blast-hole is incorrect at the collar of the hole, the error will increase proportional to the length of the blast-hole.

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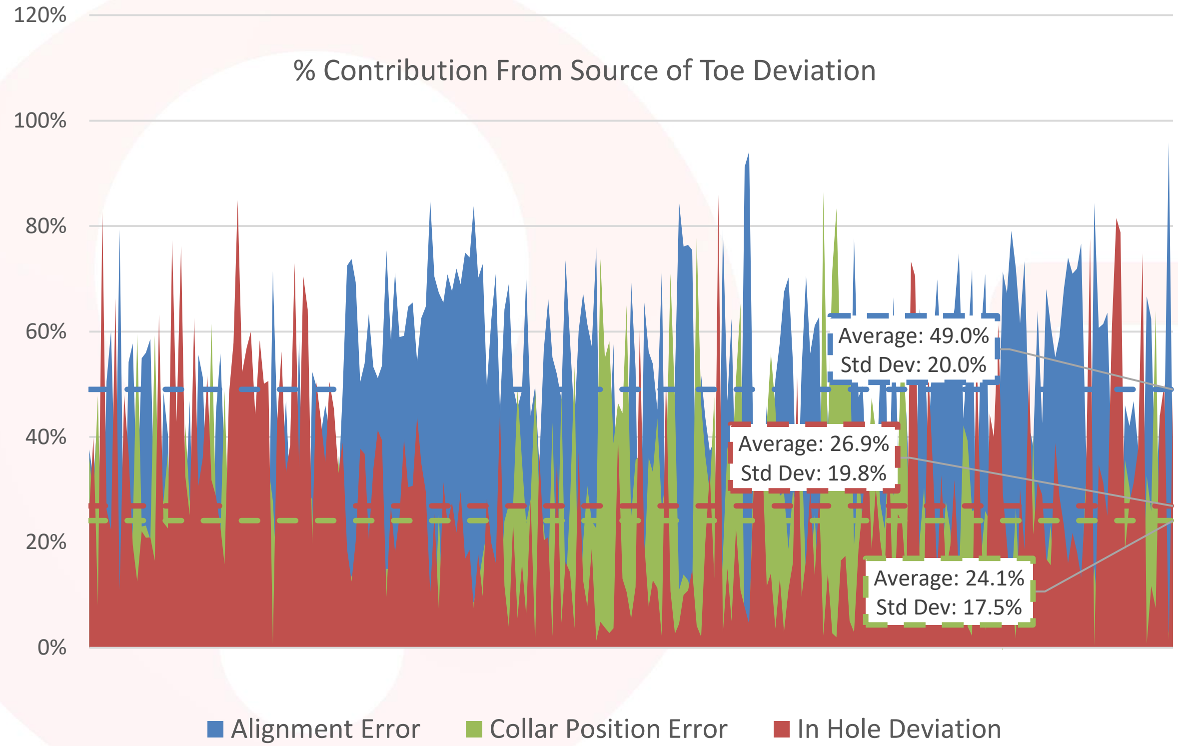
Analysis of Downhole Survey Data + Collar Pick-Ups

What impact does collar error, alignment error and in-hole deviation have on blast-hole deviation?



Over 250 hole surveys taken at 5 separate mine sites in Australia
All holes between 10-30m length (average length 22m)

A series of downhole survey results and survey collar pick-ups from a number of sites were analysed to determine what proportion of alignment error, collar error and in-hole deviation contributed to overall blast-hole deviation.

On average, the percentage of error were calculated as;

- **49.0% - Alignment**
- **26.9% - In-hole**
- **24.1% - Collar**

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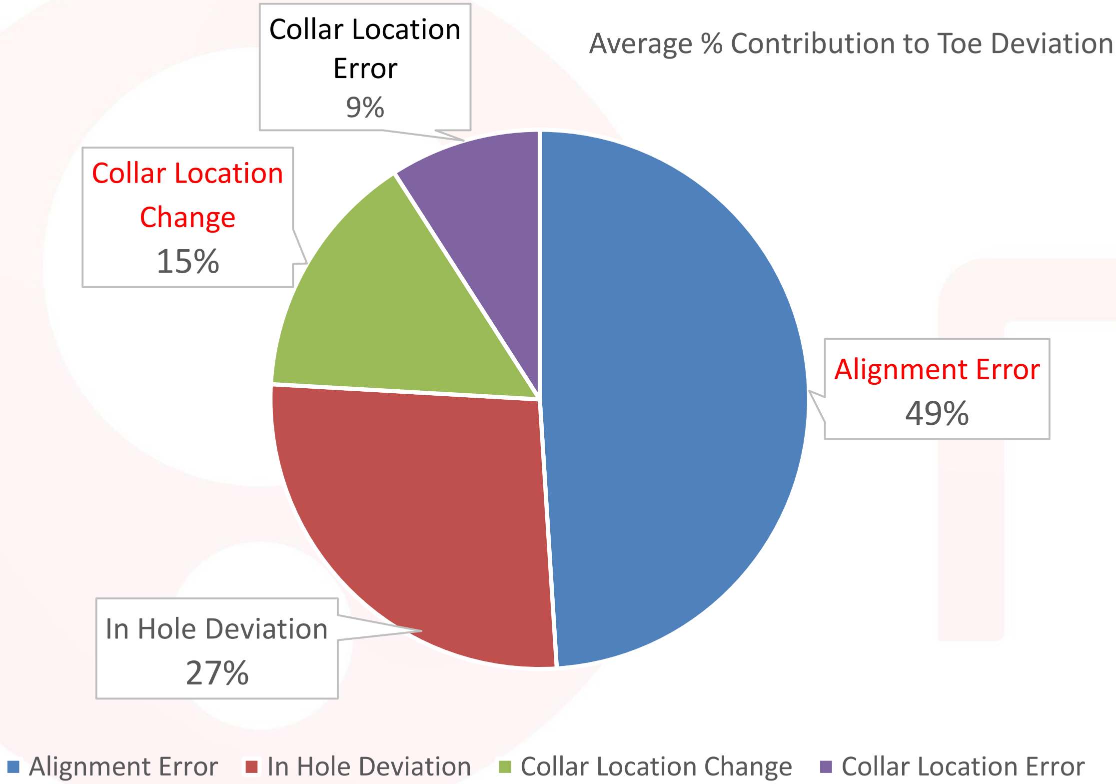
Further Analysis of Collar Error

Data indicates that the majority of collar error is due to a **change of collar location**



By highlighting the proportion of holes with >150mm collar error, we were able to highlight occurrences where the operator had "offset" the collar position due to an obstruction or redrill.

This highlighted that alignment error and collar "offset" error (collar location change) contributed up to **64%** of overall blast-hole deviation.

Does this important data always make its way back to Engineering?

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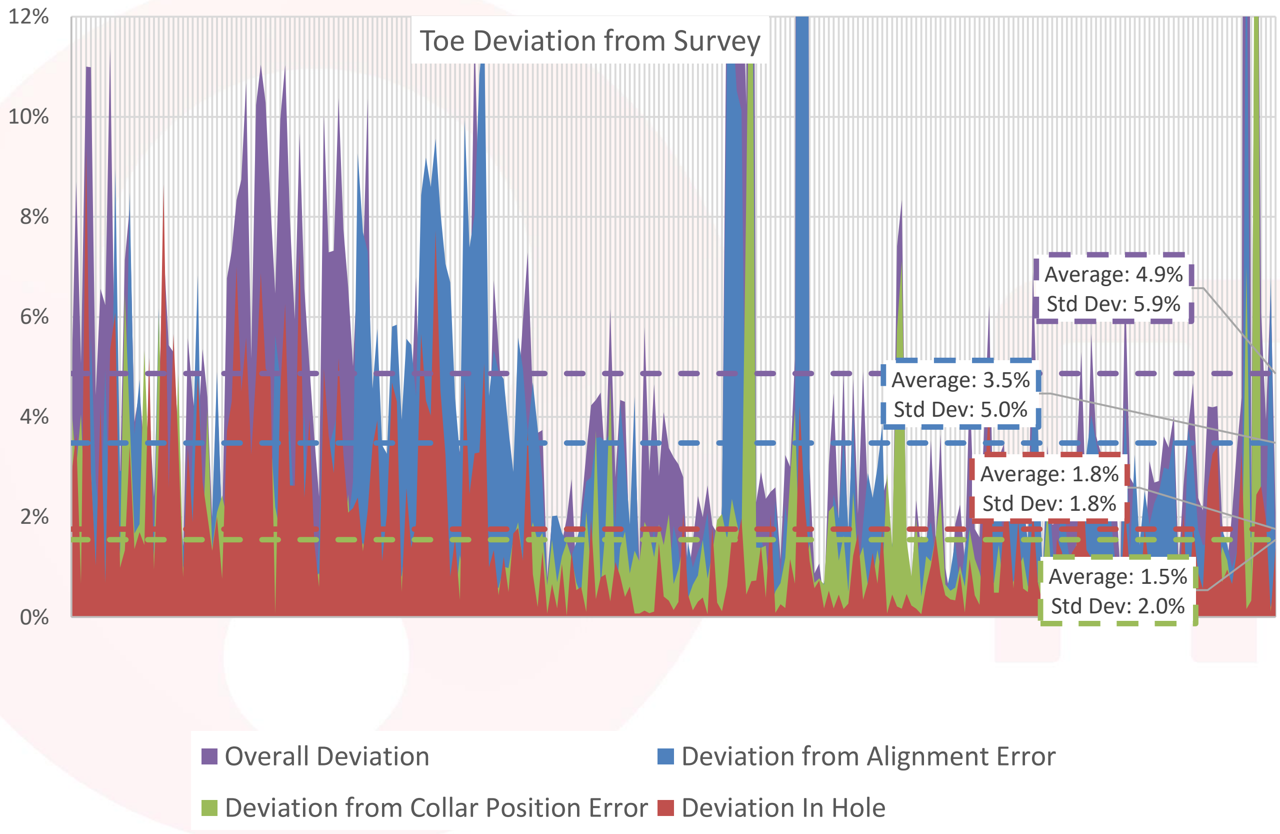
Overall Deviation

And the contributors again



Average overall deviation 4.9%

Average alignment error 3.5%

Average from collar position 1.5%

Average in hole deviation 1.8%

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Issues with Incumbent OEM Alignment Systems

Integrated (rig) systems

Multiple Tolerances:

- How well the laser lines are marked?
- How well the rig is aligned to the laser lines?
- How well the rig is levelled?
- Multiple sensor calibration
- All wear and 'slack' throughout the rig affects accuracy

System is Unreliable:

- Sensors can break
- Calibration drifts
- Drillers use handheld clinometers to confirm system accuracy
- Many wires that can be damaged by rock falls

Alignment quality/accuracy is surveyor, drill rig *and* driller dependent

On to Evolution Cracow

The perfect development collaboration partner

Cracow Overview:

500km north-west of Brisbane, Queensland.

Narrow vein, long-hole stoping operation

Ore reserves as at 31 Dec 2017: 1.48Mt @ 5.14g/t gold for 245koz gold

Improved Drilling Accuracy Results in Reduced Ore Dilution at Evolution, Cracow.

Phil Jones, Technical Services Superintendent, Cracow Gold Mine, Evolution Mining
&
Minnovare

Abstract

During a period of six months in FY2018, a series of trials were conducted to compare drilling accuracy using two different methodologies and the subsequent impact this had on ore dilution. Testing was conducted at Cracow underground gold mine in Queensland, Australia. The drill rig's existing alignment process was compared to a new technology system with the following observations:

- Using the existing alignment process only 20% of holes surveyed recorded toe points within the +/-300mm (11.8in) tolerance blast-hole deviation.
- The new technology was proven to limit rig alignment error, reducing average blast-hole deviation and increasing the number of holes drilled within tolerance by 160%.

The increased accuracy reduced stope dilution by reducing over-break of subgrade ore:
- Stopes drilled using the new technology recorded 62.6% less average dilution.
- This contributed to an overall reduction in dilution for the full year (FY18) of 5 percentage points compared to FY17 - from 22% to 17% (a net decrease of 22.7%).

A cost-benefit analysis extrapolated from the trials stipulates that if the new technology were in use for a full 12 months, when applied to FY17 full year data, a 10 percentage point reduction in dilution would represent a net 45.4% decrease, and would result in AUD8.2M (USD5.9) additional ore recovered, with AUD4.5M (USD3.2M) less spent on wasted cost of haulage and processing of diluted ore. As a result, return per tonne would increase 22%, from AUD87 (USD63) to AUD106 (USD77.1).

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Full whitepaper available in print and online
www.minnovare.com

Co-Authored by Phil Jones, Evolution Mining.

Geology: Gold mineralisation is hosted in steeply dipping low sulphidation epithermal veins.

Discrete lodes (often associated stockwork veining); varying percentages of quartz, carbonate and adularia.

Mining currently being conducted in the Killarney, Griffin, Baz, Kilkenny, Coronation, Imperial and Empire orebodies.

Methods: Modified Avoca. Primary method of extraction at Cracow.

Bottom up method working on top of backfilled (rockfill) stopes. 20m (65ft) sublevel spacing (floor to floor).

Average stope dimensions 15m (49ft) high and 20m (65ft) along strike.

Evolution Cracow

Historical issues with production drill-hole deviation

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Deviation identified as an issue for some time. Inaccurate drilling has resulted in a number of issues with the stopes;

- Excessive dilution
- Rework due to bridges (downtime)
- Exacerbated in recent years due to the decreasing width of orebodies being mined
- Different causes of deviation (rig setup, at collar, in-hole) – misconceptions.

Attributed to a number of factors;

- Ageing fleet of drills employed on site (1 x Simba 1257 drill, 1 x Simba S7 drill) and associated issues with the digital inclinometers
- Poor ground conditions resulting in hole wander
- Inexperienced (recently hired) operators
- Perceived production pressure (achieve meterage targets at the expense of drill accuracy)
- Due to a high gold price, narrow width orebodies coming online as the operation progressed (further exacerbating deviation)

Evolution Cracow

Historical issues with production drill-hole deviation – **previous studies**

A drill hole deviation study was undertaken in late 2016/early 2017 ;

- 250 holes (collars and breakthroughs) across various orebodies. Average hole length 15m.
- 26% of all holes surveyed deviated greater than 400mm (15.7in) at the toe
- Drillers not routinely checking breakthroughs;
  - Not following procedure, or,
  - No access at the base of the hole due to open stopes or backfilling
- Setup issues on collars, both in terms of angle and offset distance from walls

Feedback from drillers was that they had **little confidence in the onboard digital inclinometer.**

- Drillers were relying mostly on hand-clinometers to check the angle of each hole
- Resulted in a **high level of frustration for the drillers** who were often rushing to get on and off the rig – **safety issues.**

Production Optimiser™ - System Summary

A hardware/software system that adds value throughout the drill and blast process

MINNOVARE™ CORE

Minnovare's online drill data hub. Integrates with mine planning software:

Ensures *"what is being drilled is what was designed"*

Drill & Blast Software

DIGI PLAN™

DIGI PLOD™

Digitised drill plans and plods

Accurate, reliable drill data capture, transfer and visualisation between Engineering and Drill Operators

Can be retrofitted to **ALL** types of long-hole production rigs, regardless of age.

OPTI™ BOX

Rig integrated alignment sensor

Rig levelling and alignment to laser lines <u>non-critical</u>

Independent of onboard (rig) 'clino' systems

PRODUCTION™ OPTIMISER

- **Automatically recalculates new dip/ dump should the original hole collar location move**

SMART™ COLLAR

Integration with Drill & Blast Software

How it works - Overview

- Export ring designs directly from Drill & Blast software
- CSV and image file via USB (Phase2 is Wifi transfer)
- Load files to CORE Mobile Interface
- Driller works Digi-Plan / Digi-Plod
- Captured drill data imported back into Drill & Blast software at end of shift

Ensuring "what is drilled is what is designed"

Evolution Cracow

The Minnovare Study

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Conducted over roughly 6 months between Jun 2017 and Dec 2017 (within FY2018)

Aim: Rig alignment accuracy and its impact on blast-hole deviation, and subsequent impact on dilution and productivity, at Cracow.

Rigs: Floating-boom mounted Atlas Copco 1257 and S7 long-hole rigs

All trials were conducted drilling holes of approx. diameter 64mm (2.5in), and average hole length of 15m (49.2ft).

Phase 1: Drilling a number of holes on several rings **using the existing rig alignment process** to conduct all rig setups.

Alignment error calculated by measuring the actual dip and dump of the drill rod with a survey instrument *prior* to drilling commencing, and hole breakthrough locations.

Phase 2: Drilling a total of 61 holes across several rings in a single stope using the **Production Optimiser system**. Breakthrough locations of Phase 2 to provide a comparative dataset aligning the rig using the new technology.

Evolution Cracow

The Minnovare Study

Evolution MINING

Phase 3: Using the Production Optimiser system for all holes drilled over a six-month period.

Comparing the performance of these stopes to previously drilled stopes, using the existing process.

Resulting in a detailed stope performance study:

28 stopes selected, representing approximately 20% of the total tonnes mined for FY18.

- 11 stopes using the existing alignment process, 17 stopes using the Production Optimiser
- All stopes close proximity, same ground conditions
- All stopes were narrow vein making them most susceptible to the impact of blast-hole deviation

The results as follows…

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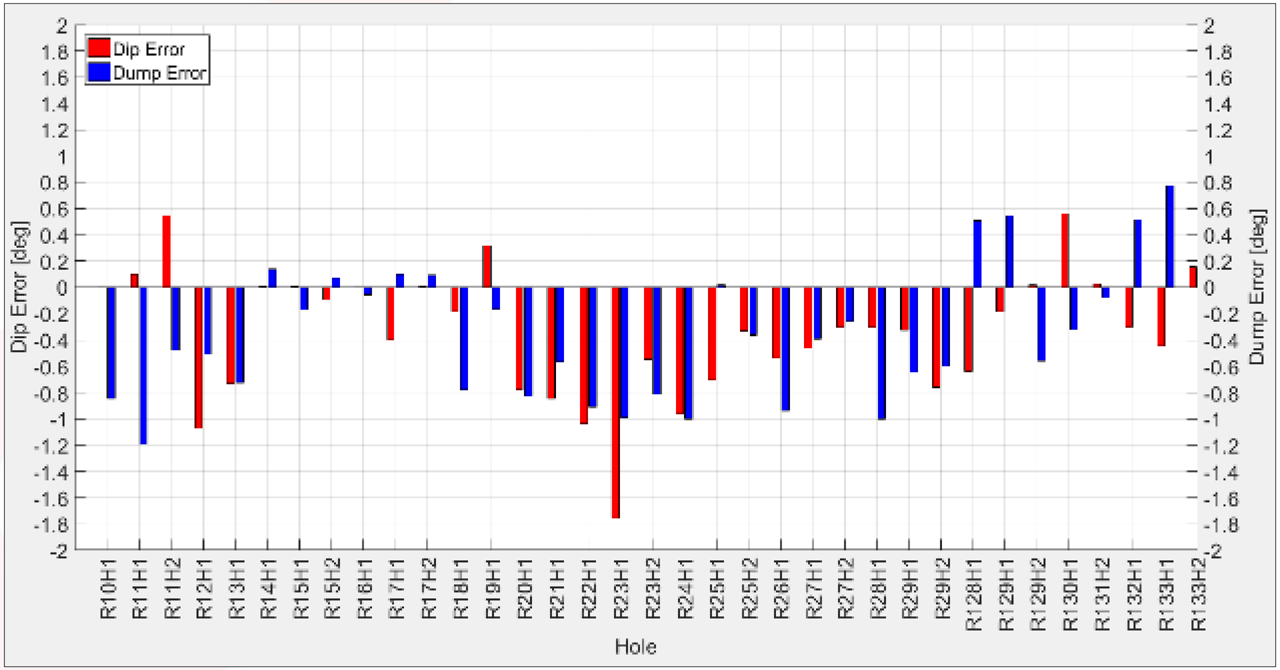
Evolution Cracow

The Minnovare Study – Summary of Results: **Phase 1**

Using the existing alignment process;

Only 20% of holes surveyed recorded toe points within +/-300mm (11.8in) tolerance



Showing dip and dump error at setup using the existing process.

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The Minnovare Study – Summary of Results: **Phase 1**

Using the existing alignment process;

80% of holes were outside of the +/-300 mm tolerance at toe point/breakthrough (average was +/-450 mm)

Of those, on average 47% of the inaccuracy was attributable to (rig) setup error at the collar

Hole	Predicted Toe Offset mm (in)	Surveyed Toe Offset mm (in)	Surveyed Toe Deviation	Offset Due to Setup	Toe Offset with Setup Error Removed mm (in)
R10H1	146 (5.7)	507 (19.9)	3.4%	29%	361 (12.4)
R11H1	246 (9.6)	329 (12.9)	2.2%	75%	84 (3.3)
R11H2	89 (3.5)	620 (24.4)	4.1%	14%	531 (20.9)
R12H1	325 (12.7)	660 (25.9)	4.4%	49%	334 (13.1)
R13H1	309 (12.1)	565 (22.2)	3.8%	55%	256 (10)
R14H1	179 (7)	406 (15.9)	2.7%	44%	228 (8.9)
R15H1	119 (4.6)	429 (16.8)	2.9%	28%	310 (12.2)
R16H1	118 (4.6)	447 (17.5)	3.0%	26%	329 (12.9
R17H1	166 (6.5)	192 (7.5)	1.3%	87%	26 (1)
R18H1	352 (13.8)	424 (16.8)	2.8%	83%	73 (2.8)

Sample of the hole survey data, showing error due to setup.

Evolution Cracow

The Minnovare Study – Summary of Results: **Phase 2**

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Using the Production Optimiser;

48% of holes were outside of the +/-300 mm tolerance at toe point/breakthrough (average was +/-317 mm)

The Production Optimiser improved number of holes drilled to within tolerance by 32% (percentage points)

R66_1	302 (11.8)	2.0%
R66_2	499 (19.6)	3.3%
R66_3	514 (20.2)	3.4%
R67_1	62 (2.4)	0.4%
R67_2	530 (20.8)	3.5%
R67_3	184 (7.2)	1.2%
R68_2	274 (10.7)	1.8%
R68_3	161 (6.3)	1.1%
R54_2	258 (10.1)	1.7%
Average:	**317 (12.4)**	**2.1%**

Sample of the hole survey data, showing reduced overall deviation due to reduced setup error.

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The Minnovare Study – Summary of Results. **Phase 3** (over 6 months)

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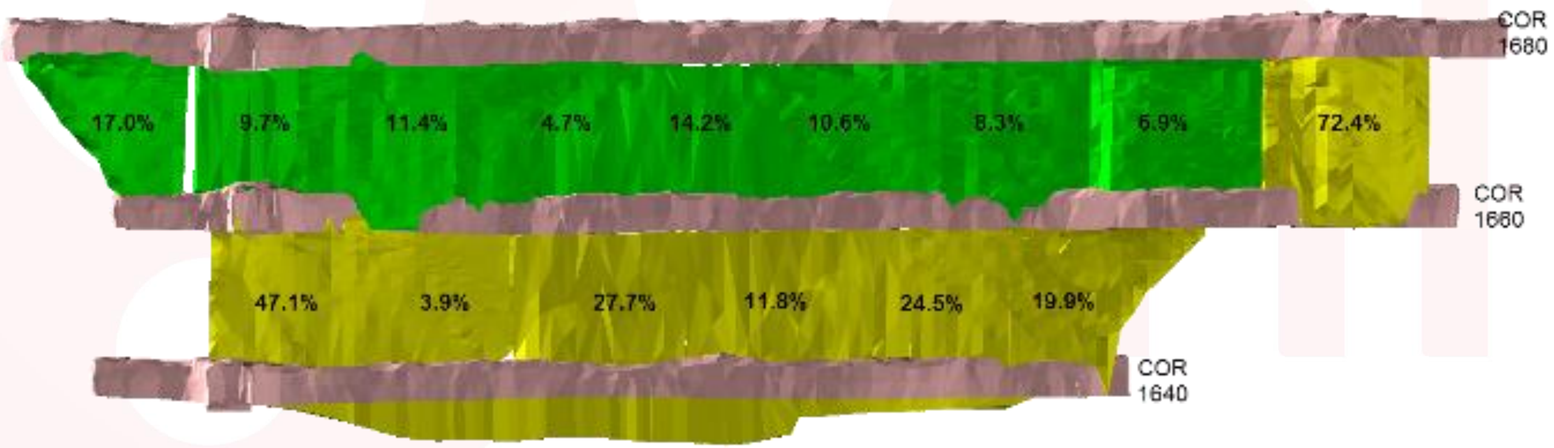
The increased accuracy reduced stope dilution by reducing over-break of subgrade ore:

28 stopes drilled in total. 17 using the Production Optimiser, 11 using the existing process.

Stopes drilled using the Production Optimiser, recorded **62.6% less average dilution** **(11.7% compared to 29.8%).**

Contributing to an overall reduction in dilution for the full year (FY18) of **22.7%** **(22% in FY17 down to 17% in FY18).**



Coronation ore body, lower long section - showing stope over-break percentage.
Stopes in Green Drilled with the Production Optimiser show reduced dilution, and greater consistency.

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The Minnovare Study – Summary of Results. **Phase 3**

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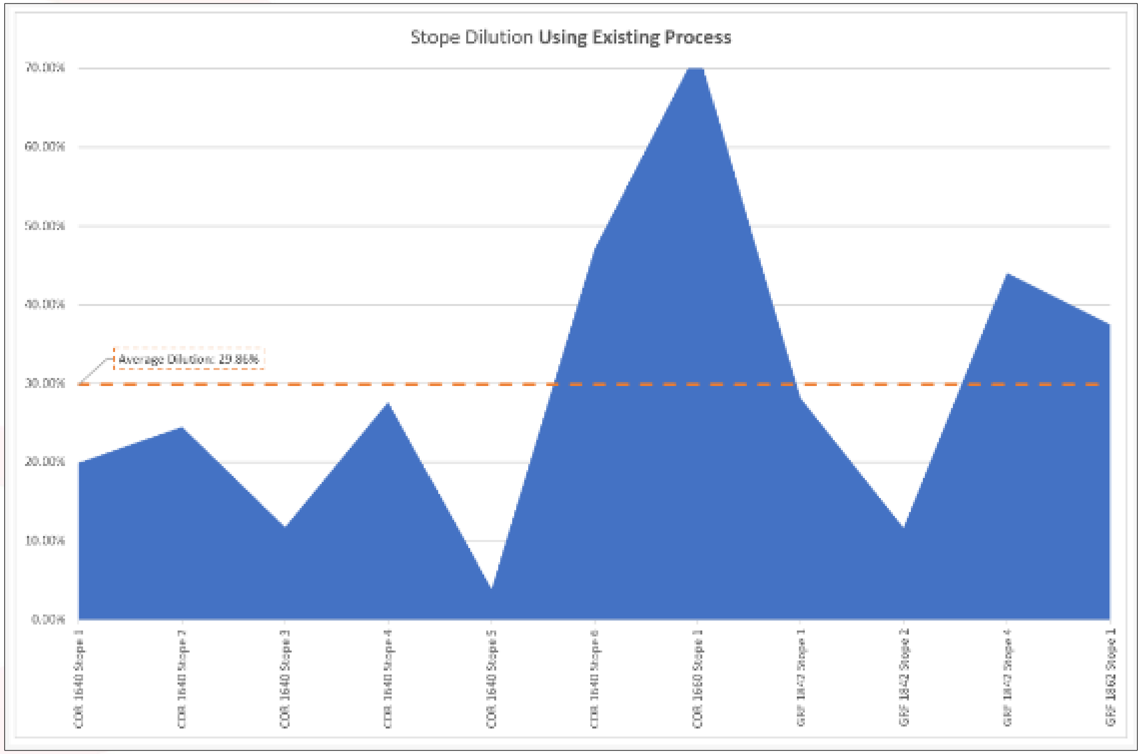
Stopes drilled using the existing process;



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The Minnovare Study – Summary of Results. **Phase 3**

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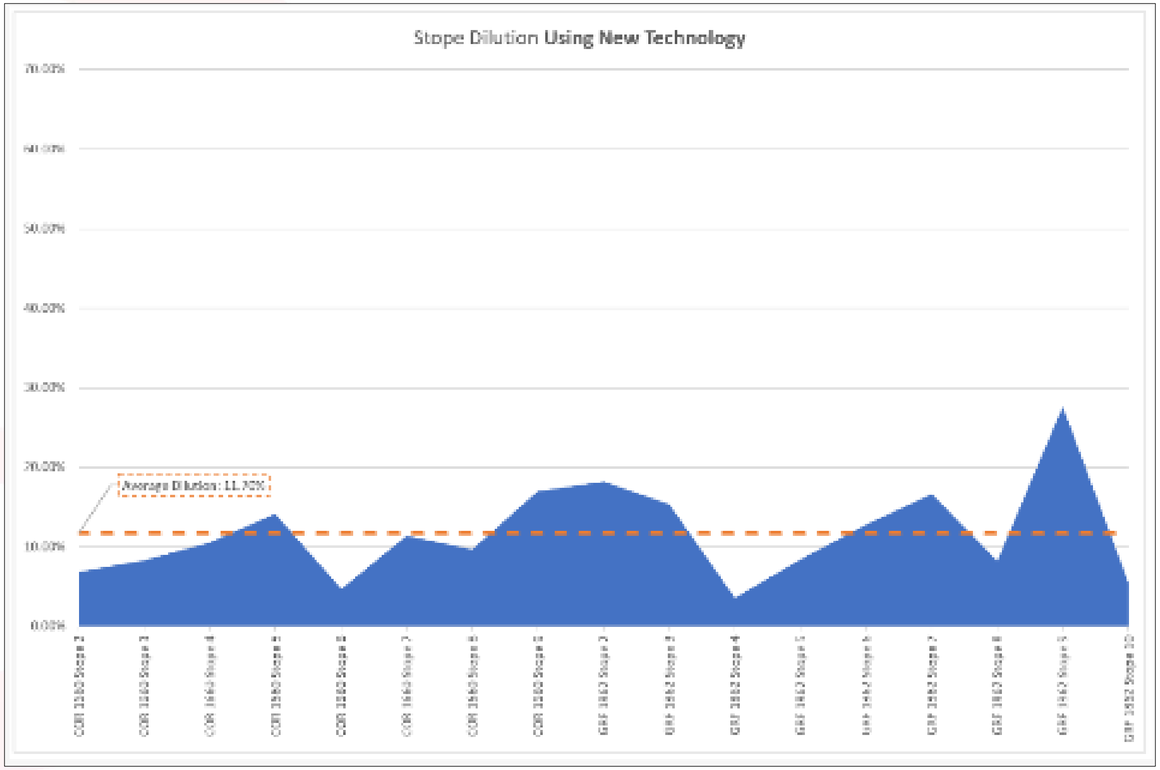
Stopes drilled using the Production Optimiser;



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The Minnovare Study – Summary of Results

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A cost-benefit analysis from the trials, stipulates:

If the Production Optimiser were in use for a full 12 months, when applied to Cracow's FY17 full year data;

A **10 percentage point reduction in dilution** (double that achieved during the six month phase 3 trial), would represent;

AUD$8.2M additional ore recovered, with

AUD$4.5M less spent on cost of dilution - wasted cost of bogging, hauling and processing of diluted ore.

Based on cost per tonne of $130, return per tonne would **increase 22%, from AUD$87 to AUD$106.**

Particularly telling was the impact the Production Optimiser had on planned vs actual return on stopes.

The accuracy of the system reduced the **average return variance to +/-1% down from +/-15%**

What does greater accuracy and reliability in stope performance mean for mine and blast design?

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The impact at Cracow

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Feedback from engineering and drillers has been positive

At Cracow, budget dilution has been **lowered to 10% in FY19 (half that of FY2018).**

Allowing for higher grade mill throughput and a reduction in costs

Cost per tonne already down for FY19;

Mining FY19 YTD: $64.27/t ($68.33/t FY18)

Milling FY19 YTD: $36.84/t ($39.24/t FY18)

Admin FY19 YTD: $21.13/t ($21.99/t FY18)

All-in FY19 YTD: $122.24/t ($129.56/t FY18) 5.7%

Increase in stope productivity - **circa 20% increase in annual recovery**

A faster overall stope cycle time and reduction in overall mine life – **a higher net present value (NPV) for the asset**

Where to From Here?

Implications for mine design at Cracow

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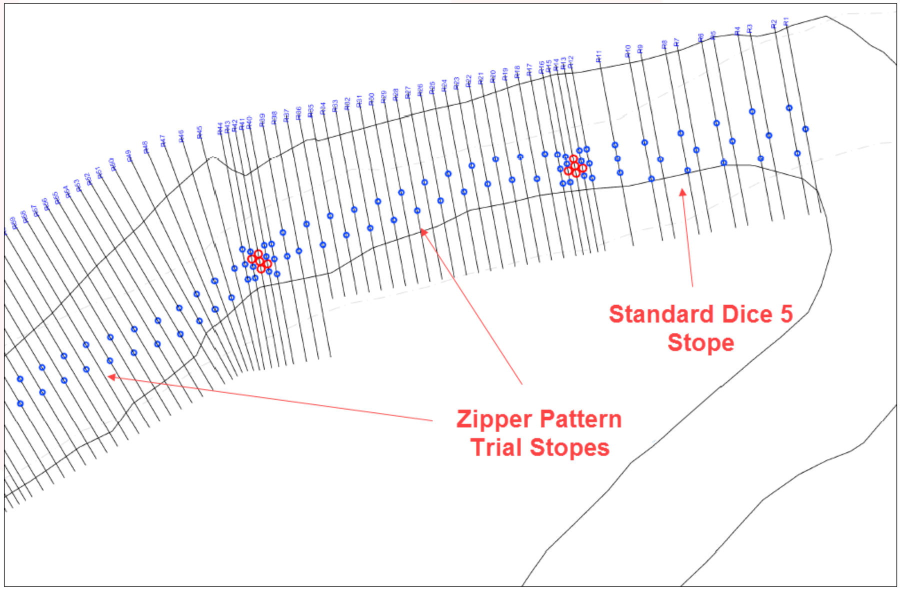
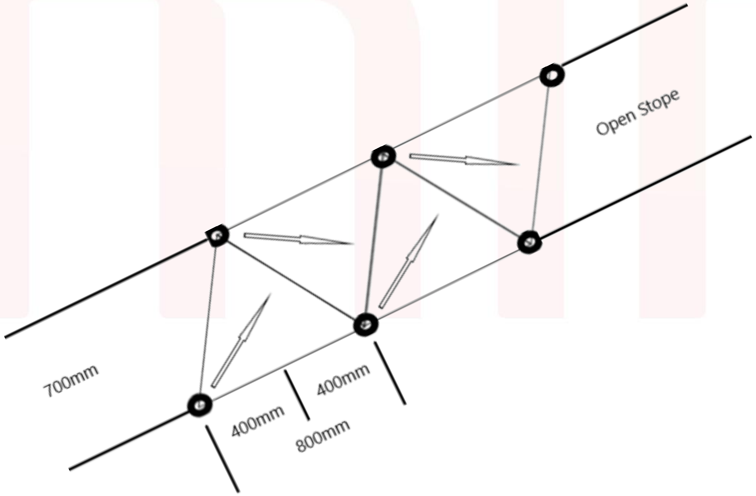
Reverse firing stopes now being considered – less dilution/bogging, but relies on high drilling accuracy

'Zipper' blasting pattern trial is currently being undertaken.

- Effective in very narrow ore bodies, deeper areas (<1m)
- Replaces the conventional 'Dice-5' pattern, reducing stope firing width and resulting dilution





Where to From Here?

Implications and future work

Production Optimiser facilitates future opportunities in mine design.

- Greater reliability/accuracy for blast and explosives engineers
- Greater reliability/accuracy and flexibility in mine and pattern design for mine engineers
  - Facilitating big data capture throughout the drilling process;
  - Bringing accurate, reliable drill-data back into Drill & Blast software where it can be further utilised

Thank you.
Questions?

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