Ameliorating the strainburst risk in a mechanised deep level gold mine: the South Deep experience

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Outline

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● Geology
● Destress Mining Method
  - Adaptations over time,
● Areas prone to Strainburst Risk,
● Strainburst Risk reduction,
  - Face pre-conditioning
  - Design, data collection, and quality assurance
  - Yield Pillars
  - Design, data collection, and quality assurance
● Outcomes and Conclusions
South Deep Mine

Location

- Located ~70km south-west of Johannesburg in the Witwatersrand basin,
- Deep level mine 2600m to 3400m below surface (Currently active 2600m-3000m)
- 37.3 Moz Reserve,
- Mine life on reserve to 2095 (78 years)

- Horizontal capital development requirements
- Total – 102.2 km
Geology

Local Geology

- South Deep is located in the Far West Rand Goldfield on the north-western rim of the Witwatersrand Basin.
- Lithology above the mining area consists of the Pretoria Group sandstones, overlying the Malmani Dolomite, and the Ventorsdorp lavas of which the Ventorsdorp Contact Reef (VCR) forms the base.
- Only the VCR and Upper Elsburg Formation beneath it are of economic importance on South Deep Gold Mine.
The thickness of the Elsburg reefs range from 5m thick in the west to 120m at the east. Depending on the grade distribution within the separate units, corridors can target different reef packages.
Mining Method

Destress Concept

- The mining method at South Deep uses the destress concept which relies on creating a zone of lower stress above and below the destress slot to allow LH stoping to occur in a reduced stress window.

- The window is actually smaller and the stress reduction is less than initially thought.

Low angle stress front < 15°
Mining Method

Low Profile Destress (LPS)

- There have been several destress layouts over time.
- The original corridor mining span was 240m wide, with 4 corridors,
- Low profile development with dimensions of 2.2mH x 5.0mW
- Crush pillars were 2mW x 10m long and were confined with backfill bags
- Support was installed conventionally
Mining Method

Low Profile Destress (LPS)

● There was a 17m vertical distance between destress cuts with a 25m overlap

● Each successive cut has to be developed into a high stress abutment

● Once the upper destress cut and 50% of the lower cut was complete long hole stoping was to begin

● Stoping was to use a primary-secondary extraction sequence with paste fill

● Issues with regards to convergence, pillar disintegration and support quality within the low profile destress slots were observed were seen as drivers as a need for a change in design
Mining Method

High Profile Destress (HPS)

- The new corridor mining span is 180m wide with 6 corridors, which has shown to reduce convergence when combined with the yield pillars.
- High profile development with a profile of 5.5mH x 5.0mW.
- Yield pillars are designed at 8mW x 20m long.
- Each successive cut still has to be developed into a high stress abutment.
- Stoping will use a centre out extraction sequence with paste fill on each cut.
- All support is mechanically installed and dynamically capable.
- Overall a better method with convergence reduced and rehabilitation reduced.
Strainburst Risk

Strainburst Prone Areas

- Potential strainburst risks areas were highlighted to be at the high stress faces and also within yield pillars if yielding did not fully occur,
- These locations are based on observations, historical data and confirmed by numerical models,
- Numerical modelling by Beck Engineering using finite element mesh (FE) construction and solved using a 3D non-linear continuum or discontinuum FE analysis package.
**Method: Face Preconditioning**

Detonation of the production and four face-perpendicular pre-conditioning holes were sequenced with 1 millisecond delays chronologically as follows;

1. Detonate face-perpendicular preconditioning holes below the grade line,
2. Detonate face-perpendicular preconditioning holes above the grade line,
3. Detonate the burn cut and then the rest of the production holes,
4. and lastly, alternate the positions of the face-perpendicular pre-conditioning holes after each blast.
Method: Face Preconditioning

Detonation of the production and face-perpendicular pre-conditioning holes were sequenced at 1 millisecond delays as follows:

1. Detonate face-perpendicular preconditioning below the grade line,
2. Detonate face-perpendicular preconditioning above the grade line,
3. Detonate the cut and then the rest of the production holes,
4. Alternate the position of the face-perpendicular pre-conditioning holes after each blast.
Strainburst Risk Reduction

Method: Face Preconditioning
Strainburst Risk Reduction

Method: Face Preconditioning

- During investigations between the 4 hole and 5 hole trials the following attributes were investigated:
- Hole depths and diameter post firing,
  - There was less hole length after blasting in the 5 hole pattern indicating better mining advance,
  - The post blast hole diameter was larger in the 5 hole pattern than the 4 hole pattern
Strainburst Risk Reduction

Method: Face Preconditioning

- Rockmass fracturing:
  - More intense fracturing in the 5 hole pattern than the 4 hole pattern

- Hangingwall profiles:
  - The data obtained from the hanging wall indicated a smoother hanging wall using the 5 hole pattern and intermediate to minor fracturing on the hanging wall were observed using the 4 hole pattern
Method: Face Preconditioning

- Face advance:
  - The 5 hole pattern showed better face advance than the 4 hole pattern:
  - The higher intensity of face fracturing resulted in easier scaling and barring down providing a higher advance rate
  - 5 hole advance rate was generally 0.5m better than the 4 hole pattern
Strainburst Risk Reduction

Quantification: BH Camera

- After preconditioning holes were fired, several boreholes were drilled into the face to determine how well preconditioning worked.
- The amount of fractures per meter are counted and a borehole fracture log is created for each borehole viewed,
- Logs indicate other fractures, borehole breakout, hole closure, etc.
- The amount of fractures per meter are counted and the fracture count is converted to a face burst risk rating.

<table>
<thead>
<tr>
<th>Fracture Frequency/meter</th>
<th>Risk Profile</th>
<th>Color Coding</th>
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<tr>
<td>&lt;5</td>
<td>High strainburst risk, rockmass not fractured/yielded</td>
<td>Red</td>
</tr>
<tr>
<td>5-10</td>
<td>Ff/m between 5 - 10: Medium strainburst risk, rockmass beginning to fracture/yield</td>
<td>Orange</td>
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<td>10-20</td>
<td>Low strainburst risk, rockmass has fractured/yielded</td>
<td>Blue</td>
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<td>Very low strainburst risk, rockmass highly fractured/yielded</td>
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Strainburst Risk Reduction

Method: Face Preconditioning

The borehole fracture frequency data was used to determine the face burst risk per meter for each blast hole.

4 hole pattern results
- 48.6% very low risk,
- 23.0% low risk,
- 23% Medium risk,
- 5.4% high risk

5 hole pattern results
- 79.1% very low risk,
- 12.4% low risk,
- 8.1 Medium risk,
- 0.4% high risk

This indicated that a higher majority of mining faces were prone to rockburst when using the 4 hole pattern than when using the 5 hole pattern.
Strainburst Risk Reduction

**Methods: Ground Penetrating Radar (GPR)**

- A decision was made to reduce the number of people from the face during quantification of preconditioning effectiveness
- South Deep use the Reutech Sub-Surface Profiler (SSP) to investigate the effectiveness of preconditioning the faces
- The intended application was to investigate the effectiveness of both face preconditioning patterns
Strainburst Risk Reduction

Quantification: Ground Penetrating Radar (GPR)

- GPR images from four pattern produced weak reflections within 1m to 3m ahead the face, which indicate that there were less changes in material properties and least number of discontinuities.
- Beyond that, the rock mass ahead of the face is not consistently fractured across the full width and may therefore be more prone to face bursting.
Strainburst Risk Reduction

Methods: Ground Penetrating Radar (GPR)

- GPR images from the five face-perpendicular pre-conditioning practice produced a significant difference in the nature of fracturing ahead of pre-conditioned faces as compared to four face-perpendicular pre-conditioning practice.
- Consistent fracturing is much further ahead of the face (5m-7m) indicating less potential for face bursting.
Strainburst Risk Reduction

Methods: Ground Penetrating Radar (GPR)

- More recent results of GPR
Strainburst Risk Reduction

Results: Face Preconditioning

- South Deep now only use the 5 hole pattern for pre-conditioning for the following reasons:
  - It produces deep fracturing away from the face rather than in other areas and reduces risk of face bursting.
  - This transfers stresses away from the production face and thus improves conditions and reduces face bursting risk.
  - This in turn improves the hangingwall and sidewall fracturing (less shallow dipping fractures), it also reduces fracturing over hangingwalls and improves face conditions (i.e. less sockets and better face shape).
  - The extended fracturing ahead of the face induced by five face-perpendicular pre-conditioning reduced the seismicity, rockburst incidences, accidents and injuries resulting from rockburst and falls of ground.
Since site changed to HPS, an observational method based on numerical modelling results has been used to ensure pillars that will crush or yield.

To get visual proof that pillars are yielding SD have been using a borehole camera for ~18 months.

Holes are drilled every cut on both sides of the pillar at gradeline (1.5m above floor).

Borehole monitoring takes place as soon as possible after borehole is drilled.

The camera records the amount of fracturing and closure.
Strainburst Risk Reduction

**Methods: Borehole camera**

- Snapshots taken from the borehole videos of regular HPS pillars to compare:
Strainburst Risk Reduction

Quantification: Borehole camera

- The amount of fractures per meter are counted and a borehole fracture log is created for each borehole viewed,
- Logs indicate other fractures, borehole breakout, hole closure, etc.
- The amount of fractures per meter are counted and the fracture count is converted to a rock burst risk rating.

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Method: Borehole camera

• To date borehole camera monitoring has been successful with pillars found to fracture throughout the whole 6m (and now 8m) pillar width from the once the pillar nose is isolated.

• Although results indicate 8m rib pillars are yielding, borehole monitoring will continue to act as a quality assurance tool,

• Any areas within the pillars found not to have yielded to at least 5-10 fractures per meter (after 7 days of pillar formation) is investigated and may require post conditioning.
Strainburst Risk Reduction

Quantification: Ground Penetrating Radar

- Eight boreholes were drilled around the pillar with the purpose of analyzing fracture frequency.
- Boreholes were at 1.5m above floor and indicated the pillar was fractured throughout.
- GPR scanner was then conducted in both sides of the pillar.
- Scanner was below support line (~1m from floor).

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Strainburst Risk Reduction

Quantification: Ground Penetrating Radar

- GPR scan of pillar shows at least 3m of intense fracturing into the pillar along the long axis of the pillar and 2m in from each end.
- It also indicates that the pillar core is not fractured which is different from the borehole camera logs.
- The difference is thought to be due to the differing heights of the readings.
Strainburst Risk Reduction

Theory: GPR Pillar Section

- The scenario below is believed to be what is happening within the pillar.
- The solid sections at the top and base of the pillar have been seen before with a fractured core.
Ameliorating Strainburst Risk

Results

- The design changes undertaken at South Deep from LPS with crush pillars to HPS with yielding pillars have been effective in providing a safer working environment by allowing effective mechanized support installation.
- With the use of borehole monitoring within pillars in conjunction with observations and numerical modelling, South Deep have progressively moved to larger pillars that still yield but also have a post peak strength that is reducing closure and providing a safer long term work environment.
- Borehole monitoring of the pillars quickly identifies areas of potential strainburst which can be further monitored or destressed.
- After the two design trials it has been found that a 5-hole pre-conditioning pattern drilled ahead of the development faces in the high stress abutments has significantly reduced the potential for strainbursting with only 1 incident occurring in the last 12 months.
- The effectiveness of pre-conditioning has been done using borehole monitoring, but has now moved to GPR to reduce the number of people at the face.
Conclusions

- Mining at deep levels or in areas of high stress will always expose people/equipment to areas of potential strainbursting.
- South Deep shown that through a combination of techniques that strainburst risk can be reduced. The techniques employed at South Deep include:
  - Design changes using observational methods, based on calibrated numerical models. The ongoing optimisation of yield pillars has been very successful using this approach.
  - Pre-conditioning ahead of the high stress faces. Two methods trialled and vigorously interrogated with the best method now used in every development end
  - Continuous monitoring, using the best available methods from low-tech borehole monitoring to high-tech ground penetrating radars.
  - A response plan to be carried out if required fracturing within pillars or ahead of the face has not been achieved.
Thank you to the following

- Gold Fields’ South Deep Mine management
- Fhatuwani Sengani. The majority of the work outlined today will be used in his Masters Project
- South Deep Rock Engineering department for data collection