De-stress blasting strategy for mining in highly stressed sill pillars at Vale’s Sudbury mines – Two Case Studies

M. Yao, Principal Engineer - Rock Mechanics, Mining Technical Excellence Centre, Vale Base Metals.
A. Forsythe, Chief Ground Control Engineer, Mines Technical Support, Vale, Ontario Operations
D. R. Chinnasane, Sr. Ground Control Engineer, Copper Cliff Mine, Vale, Ontario Operations

Workplace Safety North’s Mining Health and Safety Conference, Sudbury, Canada – April 5-7, 2016
• What is a rockburst, what are the types?
• What are the factors contributing to rock bursting?
• What can we do to minimize the risk associated with the major seismic events?
• What is de-stressing and how does it work?
• Two case studies on de-stress blasting strategy for mining highly stressed sill pillars
  ▪ Sill pillar de-stressing in 153 orebody at Coleman mine
  ▪ Sill pillar de-stressing in the 100/900 orebody at Copper Cliff Mine
• Conclusions and recommendations for future work
What is rockburst and their types?

“A rockburst is defined as damage to an excavation that occurs in a sudden and violent manner and is associated with a seismic event”

1. Fault Slip Burst (Mn = 2.5 – 5.0)
   - Seismic wave shakes an opening
   - Movement along the contacts

2. Pillar Burst (Mn = 1.0 – 2.5)
   - Stress greater than rock strength
   - Crown/sill pillar bursts

3. Strain Burst (Mn = -0.2 – 1.0)
   - Slabbing of excavation
   - Typically in development drifts

(ACG, Australian, 2008)
What are the factors contributing to rock bursting?

- Geological Structures - faults and dykes
- Tectonic stresses
- *Mining induced stress*
- *Brittle rock store energy*
- *Mining induced ground movement*
Highly mining induced stress in sill pillars

Coleman Mine 163 Orebody – An Overview

Copper Cliff Mine 100/900 sill pillars
What can we do to minimize the risk associated with the major seismic events?

- **Strategic Control Measures:**
  - Design
  - Sequence

- **Tactical Control Measures:**
  - DE-STRESSING
  - Enhanced Support.
  - Reducing Personnel Exposure

- Monitoring and Communication, including re-entry protocol
What is de-stressing?

- De-stressing is a rock fracturing technique used in highly stressed ground – it is aimed at relieving the stresses and reducing the potential for a rockburst

  ✓ Release of stored strain energy
  ✓ Promote fracturing of the rockmass
  ✓ Shed stress away from sill pillars or promote controlled failure in pillars
How does de-stressing work?

De-stressing is a ground control technique, whereby explosives or other techniques are used to release the stored strain energy in a controlled manner by:

- Creating or extending a fracture zone around openings; or
- Shedding stress away from pillars or fracturing pillars that are likely to burst.
Case 1 – De-stressing sill pillars in 153 at Coleman mine
Case 1 – De-stressing sill pillars in 153 at Coleman mine

153 Orebody – An Overview
Ground Control challenges in the 153 OB
Mining Method and Related Seismic Risks
Increased Seismicity & Rockbursting with Sill Pillar Mining
Proximity of Major Infrastructure
• Sill pillar yielding can be unpredictable. Typically, a sill pillar in the narrower ore zones is expected to yield when the thickness is between 18’ – 27’.
153 OB (4550 Level)

1.5 MN Event @ 10:06 PM on Mar 02, 2014 (Pillar burst)

2.0 MN Event @ 12:49 PM on Mar 13, 2014 (Fault Slip)

2.7 MN Event @ 11:30 AM on Mar 22, 2014 (Pillar burst) (minor Fault Slip)

A 1.1 MN Event @ 12:08 PM on Mar 22, 2014.

Blasting in Block 1 bulk stope

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Northing</th>
<th>Easting</th>
<th>Depth</th>
<th>Location Num. Sensors</th>
<th>Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014-03-24</td>
<td>06:55:15.149</td>
<td>10139.78</td>
<td>15125.66</td>
<td>8645.95</td>
<td>32.69</td>
<td>-2.6</td>
</tr>
<tr>
<td>2014-03-24</td>
<td>06:37:50.594</td>
<td>10198.88</td>
<td>15919.66</td>
<td>8510.15</td>
<td>19.08</td>
<td>-2.1</td>
</tr>
</tbody>
</table>

March 2014
Rockburst damaged areas in the 4550L Block 2 - 2W heading, after the 2.7 MN event

~ 5 tons of material displacement from the lower wall

~ 1 ton of material displacement from the face on the H/W side
2.7 MN Pillar Burst Event on Mar 22, 2014 resulted in Floor Heave in 4550L Block 2 – 2W, Cut 16 UCF
4550L – De-stressing Drift in H/W of Block 2 - 2W

Blast Data

- 83 Rings; 3.5” diameter holes
- 166 holes; 2 holes per ring
- ~ 54,000 lbs of explosives (emulsion)
- 15ms delay between each hole – each hole on its own delay
- Blast duration 2.4 seconds
- 420 lbs per delay (maximum)

Drilling & Blast design reviewed by ITASCA and approved by Vale.
153 OB - 4550L De-stressing Blast – Drilling Layout

4550L – Block 2 Sill Pillar

Average hole length = 70 ft.
With the exception of damage to auxiliary ventilation infrastructure, the blast did not cause significant damage to mine workings.
Stress Shedding after the de-stressing Blast

Increased Seismicity above and below Destress Blast Area

Section View Looking N-E
Field Instrumentation Results – Stress Cell

**Stress Change (MPa)**

- **1.0 MN @ 12:13 PM on July 20, 2015**
- **1.3 MN event @ 9:48 PM on July 23, 2015**
- **1.9 MN event at 7:35 AM on Oct 2, 2015**
  - **GSC = 2.1 MN**
- **2.0 MN event @ 7:33 PM on Sept 24, 2015**
- **2.3 MN event @ 1:38 PM on Sept 15, 2015**
- **4550L Destress Blast at 6:46 AM on May 18, 2015**
- **1.1 MN event at 9:07 AM on Nov 16, 2015**
- **1.3 MN event at 8:56 AM on Nov 23, 2015**

- **Resumed blasting/mining in 4550L Block 2 - 2W Cut 16 UCF on June 23, 2015**
- **Damaged Stress cell cable and Datalogger lost 110V Supply (June 6th - 24th, 2015); fixed connections and relocated datalogger**
Effectiveness of the 153 OB - 4550L Block 2 de-stressing Blast

• The 153 OB 45550L Block 2 De-stress Blast was effective in reducing the high stress conditions and number of the larger magnitude (> 2.0 MN) events in the 4550L Block 2 Sill Pillar.

• 2W - Cut 16 was completed with neither injuries nor major interruptions to production.

• There was measured stress re-distribution and migration of seismic events to sill pillars above and below the 4550 Level.

• Field instrumentation installed in F/W Drift on the west end of 2W showed significant stress increase in the west abutment of 4550L during mining of 2W - Cut 16.

• Mining of Cut 15 Underhand Cut & Fill is in progress.
Case 2 – De-stressing sill pillars in 100/900 at Copper Cliff Mine
Case 2 – De-stressing sill pillars in 100/900 at Copper Cliff Mine

- Bottom-up mining method has been in practice in different ore bodies at Copper Cliff Mine.

- As the mining approaches the sill pillar position, the mining-induced stresses concentrate in the sill pillar zones and often result in bursting problems.

- Crown blasts in the stopes within the sill pillar areas in 100/900 have always been associated with major magnitude seismic events.
  - 3.8 Mn event on Sep 11, 2008, and
  - 3.0 Mn event on Oct 8, 2014
Damage Following the 3.0 Mn Event on October 8, 2014

Damage in the 9510 sill after a crown blast in the adjacent stope
De-stressing blast – Phase 1 (3550-3500L and 3550-3710 L)

Blast Data
- 4.5” diameter holes
- 9537 ft of drilling for phase-1
- ~ 52,000 lbs of explosives (emulsion)
- 18 ms delay between each hole – each hole on its own delay
- 500 lbs per delay (maximum)

Drill & Blast design was carried out by ITASCA and reviewed/approved by Vale
The blast lasted approximately for 6 seconds and triggered the vibration monitoring sensors as 2.1 mm/s in Copper Cliff (the blast was designed for a maximum of 6 mm/s).

No major seismic activity occurred following the blast.

The preliminary review of the stress cell measurements indicate stress drop in all the stress cells.
Field Instrumentation Results – Stress change due to de-stress blast and mining of the 9631 stope in the crown pillar area
Instrumentation Results - stress drop associated with major de-stressing blast

Stress Cell Monitoring Data After Destress Blast in the 100/900 OB

Destress blast on Sep 21, 2015
There were no major magnitude seismic events until the crown blast in the stope.

Significant stress increase was observed immediately after the crown blast.
Instrumentation Results – stress data post crown blast in the 9631 stope (3550-3710L)

- Significant stress increase was observed associated with the major seismic events.
- Stress is dropping after the intensive seismicity associated with the crown blast.
Stress Shedding Following Crown Blast in the 9631 stope (Jan 5, 2016 - Mar 11, 2016)

Mn 2.0 event @ 8:17 a.m on Jan 6, 2016
Mn 2.2 event @ 11:22 a.m on Mar 10, 2016
Mn 1.3 event @ 9:11 p.m on Mar 11, 2016
Mn 2.3 event @ 6:51 p.m on Jan 6, 2016
Mn 1.8 event @ 6:07 p.m on Jan 9, 2016
Mn 1.7 event @ 4:55 p.m on Jan 27, 2016
Performance of burst-resistant support system

Burst-resistant support in 100/900 OB consists of a combination of:

- D-Bolts/Super Swellex/MD Bolts
- FS-46 split sets on walls
- #4 gauge and 0 gauge straps

- The burst-resistant support system performed very well despite the abnormal seismicity associated with a crown blast (very negligible damage).
- Minor shake-down of material from the back of the 9550 sill following 2.2 Mn event on March 10, 2016.
Effectiveness of Phase 1 De-stressing Blast in 100/900 OB

- The stress cell data confirmed nominal stress drop at all the instrument locations immediately following the major de-stress blast.
  - Stress drop was observed to be more significant in the direction of major principal stress i.e. East-West as compared to North-South direction.

- After taking the crown blast of stope 9631 HW, a significant stress increase was observed at a small distance (2-3 x-cuts) from the stope being mined on South side of the stope. However, on North side there was no major stress change as the area has been de-stressed.

- Significant number of magnitude seismic events occurred within a small distance (2-3 x-cuts) on South side following the crown blast.

- The stress dropped after the intensive seismicity associated with the crown blast, which indicates the sill pillars were yielding.

- Despite significant seismic activity, there was very minor damage to the excavations. The burst-resistant support system held-up as designed.
Conclusions and recommendations for future work

**Conclusions:**

- Successful implementation and execution of these two de-stress blasts in highly stressed sill pillars have provided useful experience for the industry. This knowledge will be applied to future large-scale de-stressing programs at Vale’s Ontario operations.

- Stress drop/reduction was evident immediately following the major de-stress blast. However, the magnitude of the stress drop was limited to 6.4 MPa.

- The de-stress blast was effective in (1) reducing high stress conditions in the immediate vicinity of the blast and (2) reducing the magnitude of seismic events in the sill pillars.

- Stress redistribution, away from the de-stressed stopes, was evident. This is important for designing any large scale de-stress program whereby risk of triggering seismicity in other areas of a mine must be considered.

- Despite significant seismic activity in the sill pillars, there was very minor damage occurred as the burst-resistant support system help-up as designed.

- The mine services and infrastructure need to be protected prior to the de-stress blasts.
Conclusions and recommendations for future work

**Recommendations for Future Work:**

- Vale is making a great effort to further understand and improve current de-stressing techniques while investigating new tools to reduce the risk associated with seismicity in burst-prone ground conditions. Current research projects include:
  - Drift de-stressing:
    - working with Queen’s University to evaluate and improve drift de-stress designs through field trials and numerical modelling.
  - Stope/large scale de-stressing/pre-conditioning:
    - working with McGill University to evaluate and improve the stope de-stress design by calibrating the numerical models based on instrumentation data collected.
    - working with MIRARCO through UDMN to investigate hydraulic preconditioning technology, commonly used in the oil and gas industry, to pre-condition potentially burst-prone ground.
- Effectiveness of de-stress blasts will be continuously monitored and evaluated as future mining progresses in the concerned areas.
- Pillarless mining is a lower risk approach of mining in highly-stressed ground conditions; this method of extraction is recommended as the best option for minimizing rockburst risks associated with sill pillar recovery.
Acknowledgements:

The authors would like to thank Samantha Espley, Director, Vale Ontario Operations and Andre Lauzon, Director, Vale Base Metals, for granting the permission to present this information. Technical and operational input, along with the collaboration in developing these de-stress programs at Coleman and Copper Cliff Mines, are greatly appreciated.
VALE
For a world with new values.