# Performance of dynamic support system in highly burst-prone ground conditions at Vale's Copper Cliff Mine – a case study

**by D. Reddy Chinnasane, Dr Mike Yao, David Landry and P. Paradis-Sokoloski, Vale Canada Ltd., Canada**

## Introduction

Copper Cliff Mine is located within the Copper Cliff Offset in the limits of the City of Greater Sudbury, Ontario, Canada (Figure 1). The Copper Cliff Offset extends about 8 km south from the Sudbury Igneous Complex into the footwall rocks.

## Geology

Of all the major geological structures present at Copper Cliff Mine, two structures are known to be seismically active (Yao et al. 2009), (Figure 2):

1. The 900 orebody (OB) cross fault, which strikes east–west and dips at about 55° towards north.
2. The Quartz Diabase Dyke (trap) located between 100 and 900 OBs striking east–west and dipping steeply towards north.

## Rockburst history at Copper Cliff Mine

A review of the rockburst/seismic event history over the past 13 years at Copper Cliff Mine revealed that there were approximately 40 rockburst/significant seismic event incidents in total that occurred in four different orebodies. Of all these incidents, 35 of them (roughly 87%) occurred within the 100/900 OBs, and the remaining five incidents (almost 13%) took place in the 120 and 880 OBs.

Of all the rockbursts, the 3.8 Mn event that occurred on 11 September 2008 in the 100/900 OBs following a crown blast was considered to be the most significant. Although the location of the major event was on 3050 L in the 100 OB the damage was extended across nearly a 300 m vertical block starting from 2700 to 3710 L. Approximately 3,000 t of material were displaced at five locations on different levels. The damage was mostly associated with either the trap dykes and/or 900 X-fault. The support system at the damage locations mainly consisted of resin grouted rebars, and mechanically anchored bolts in the back, and anchored mechanical bolts on the walls to 1.5 m above the floor installed through #6 gauge welded wire mesh. At some locations, shotcrete and cable bolts were used as a secondary support system. The installed ground support system was too stiff in nature and it did not provide much yielding capability. Accordingly, the support system that was employed at the damaged locations was incapable of taking the impact of dynamic loading caused by the 3.8 Mn event.

It should be noted that a central blasting system was used and the Copper Cliff Mine re-entry protocol after major seismic events was followed. No personnel injuries occurred due to these events.

It has been concluded that the trap dyke and the 900 OB X-fault are major contributing factors for elevated seismicity in the 100 and 900 OBs (Yao et al. 2009). The rationale for this kind of thinking could be better explained with the help of the layout shown in Figure 3:

- Since all the stopes along the 900 OB X-fault were mined out on the mining front between 3500 and 3050 L, the natural confinement that the orebody provided to the fault plane was taken out. As a result, a major displacement might have occurred along the fault-plane and caused the 3.8 Mn event after taking the crown blast in the 94561 stope between 3050 to

This article has been reproduced from the Australian Centre for Geomechanics December 2013 Newsletter.

3200 L on 11 September 2008. By all means, the crown blast could have triggered the slip and caused the large magnitude event.

- As it can be seen in Figure 3, there is a trap dyke between 100 and 900 OB, which is very strong material and highly brittle in nature. As mining progressed in the 100 and 900 OB, the trap dyke is loaded up, which can lead to significant seismic events/rockbursts.

The 3.8 Mn event on 11 September 2008 was considered to be a result of mining the 94561 stope between 3050 and 3200 L. The location of the stope in relation to the major geological structures, i.e. trap dyke and 900 X-fault is shown in Figure 3.

Since large magnitude events are associated with damage to underground excavations and the installed ground support systems, mining in the

burst-prone ground conditions pose a greater challenge both in terms of safety and production. The 3.8 Mn rockburst triggered a series of rockbursts within the limits of the 100/900 OBs and caused damage at multiple locations on different levels. In order to rehabilitate all the damaged areas, considerable time and resources were spent, and production was significantly impacted.

## Introduction of burst-resistant support system in burst-prone ground conditions

A system was introduced in all the burst-prone areas at Copper Cliff Mine, with a view to minimise or completely eliminate the damage to the installed ground support and/or the underground excavations in the event of future occurrences. A rating system was developed to identify the burst−prone areas (Yao et al. 2009).

## Burst-resistant support elements used in burst-prone ground conditions at Copper Cliff Mine

Based on the guidelines outlined in the 'Canadian Rockburst Support Handbook' (Kaiser et al. 1996), the following ground support elements were identified and used in the burst-prone ground conditions at Copper Cliff Mine.

For walls: 1.95 m long FS-46 split sets on a 1.2 × 0.75 m pattern with #4 gauge welded wire mesh, followed by a minimum 76 mm thick pass of plain shotcrete, and then 2.3 m long modified cone bolts on a 1.2 × 1.8 m pattern with #0 gauge mesh straps. The wall bolting was usually extended to the floor level.

For the back: 2.4 m resin rebars on a 1.2 × 0.75 m pattern with #4 gauge welded wire mesh, followed by a minimum 76 mm thick pass of plain shotcrete, and then 2.3 m long modified cone bolts on a 1.2 × 1.8 m pattern with #0 gauge mesh straps. In addition, 6.3 m long twin cable bolts were used in a ramp, where the depth of failure was almost 5.1 m from the seismic events. The purpose of the cable bolts was to reinforce the rock mass as well as hold the broken rock mass by anchoring them in the solid ground.

The burst-resistant support system that was employed in burst-prone ground conditions at Copper Cliff Mine is shown in Figure 4.

Energy absorption capacity and load-displacement characteristics of various ground support elements that were used as rockburst resistant support system at Vale's Copper Cliff Mine are given in Table 1.

**Table 1 Energy absorption and load-displacement characteristics of support**

| Description | Peak load (kN) | Displacement limit (mm) | Energy absorption (kJ) |
|---|---|---|---|
| 19 mm resin-grouted rebar | 120–170 | 10–30 | 1–4 |
| 46 mm split set bolt (FS-46) | 90–140 | 80–200 | 5–15 |
| 16 mm modified cone bolt | 50–100 | 100–200 | 10–25 |
| 16 mm cable bolt | 160–240 | 20–40 | 2–6 |
| #4 gauge welded wire mesh | 34–42 | 150–225 | 3–6 per $m^2$ |
| Shotcrete and welded wire mesh | 2 × mesh | < mesh | 3–5 × mesh* |

** at displacements below 100–150 mm.*

Based on the above energy absorption values, the total energy absorption capacity that was employed in the burst-prone ground conditions at Copper Cliff Mine was calculated anywhere between 20 and 48 kJ per $m^2$. The required energy absorption capacity was determined based on the 3.8 Mn event.

## Performance of dynamic support system

After introducing the burst-resistant system at Copper Cliff Mine, mining in the 100/900 OB was resumed. Four stopes were mined out successfully without any significant damage.

With the resumption of mining in the 100/900 OB, Copper Cliff Mine once again started to experience elevated seismic activity, particularly while mining the stopes surrounding the trap dyke. Several seismic events/rockbursts, ranging from 1.2 to 2.9 Mn, occurred while mining the 9551 and 9281 stopes. The chronology of the seismic events/rockbursts that occurred while mining the stopes in the vicinity of the trap dyke is given in Table 2.

**Table 2 Seismic events/rockbursts occurred while mining the stopes in the vicinity of trap dyke in 100/900 OB**

| Date | Magnitude (Nuttli) | Orebody | Level (stope) | Remarks |
|---|---|---|---|---|
| 18 February 2009 | 2.9 | 100 | 3710–3880 (9551) | No damage to the mine openings |
| 30 September 2010 | 1.9 | 900 | 3710–3880 (9281) | No damage to the mine openings, but 80–100 t of trap dyke material was sloughed into the open stope |
| 2 October 2010 | 1.6 | 900 | 3710–3880 (9281) | No damage to the mine openings |
| 4 October 2010 | 1.4 | 900 | 3710–3880 (9281) | No damage to the mine openings |
| 4 October 2010 | 1.2 | 900 | 3710–3880 (9281) | No damage to the mine openings |
| 5 October 2010 | 1.9 | 900 | 3710–3880 (9281) | Some minor surface cracks in the shotcrete |
| 15 October 2010 | 2.3 | 900 | 3710–3880 (9281) | Minor damage to the installed ground support system and some floor heaving |

It was interesting to observe that there was no damage, after the 2.9 Mn event that occurred on 18 February 2009, while mining the 9551 stope. In fact, the event was located within 20–30 m from the top and bottom sills, respectively. This has demonstrated that the rockburst resistant support system that was installed after the large 3.8 Mn event had sufficient energy absorption capacity to withstand the impact of a 2.9 Mn event.

While mining the 9281 stope, the installed burst-resistant support system was repeatedly subjected to seismic event impacts and showed some signs of negligible damage. Although it is difficult to assess the impact of previous seismic events in a quantitative manner, the ground control engineer identifies whether there are signs of support yielding based on their observations, and/or field instrumentation monitoring, if any. If so, it may be prudent to install extra support in an effort to compensate for any potential loss in the safety margin (Kaiser et al., 1996).

Although the support system was subjected to repeated seismic loading, the burst-resistant support system showed its first sign of damage only after the 2.3 Mn seismic event (see Table 2 for the order of events). However, the level of damage was very insignificant (Figure 5).

## Conclusions

Even though many seismic events occurred in the 100/900 OBs while mining in the burst-prone ground conditions, no significant damage was associated with such events after introducing the burst-resistant support system at Copper Cliff Mine. It was evident from the underground observations that a well designed dynamic support system will cope very well in the event of large and repeated seismic events, by sustaining the impact of dynamic loading with no, or negligible damage to the underground excavations and/or the installed ground support system. Four stopes were mined out successfully without any significant damage after introducing the burst-resistant support system in the areas at Copper Cliff Mine.

Please contact the ACG for the full paper that was published in the Deep Mining 2012 Seminar proceedings.