Deep Mining 2012 — Y. Potvin (ed)

doi:10.36487/ACG_rep/1201_04_chinnasane

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

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Abstract

Mining in the 100/900 orebodies (OB) at Copper Cliff Mine in the Sudbury Basin has been associated with significant seismic activity. In September 2008, a 3.8 magnitude event occurred in the middle 100/900 OB and caused considerable damage to various excavations on multiple levels. Approximately 3,000 t of material were displaced in total and the damage was spread over a 300 m vertical block between 2700 and 3710 L. An analysis of the rockburst incident revealed that the previously installed support system was inadequate to withstand the impact of the dynamic load caused by the 3.8 Nuttli magnitude (Mn) seismic event. In view of this, a decision was taken to identify the areas prone to bursting, so that a burst-resistant support system could be employed, which would help minimise damage in the case of future occurrences. Accordingly, a rating system was developed to identify the areas that are prone to bursting conditions and Vale employed burst-resistant support system in all such identified areas.

After introducing the burst-resistant support system at Copper Cliff Mine, mining in the 100/900 OB was resumed. With the resumption of mining in the 100/900 OB, the Copper Cliff Mine started to experience an elevated seismic activity with a number of large seismic events ranging from 1.2 to 2.9 Mn events. Four stopes were mined out successfully without any significant damage after introducing the burst-resistant support system in the burst-prone areas at Copper Cliff Mine. This paper presents a case study which outlines the performance of the dynamic support system while mining the stopes that were located in the vicinity of highly burst-prone ground conditions.

1 Introduction

Copper Cliff Mine is located within the Copper Cliff Offset in the limits of City of Greater Sudbury, Ontario, Canada, as shown in Figure 1. The Copper Cliff Offset extends about eight kilometres south from the Sudbury Igneous Complex into the footwall rocks. Until 2008, Copper Cliff Mine operated as two separate mines i.e. North Mine and South Mine. In late 2008, South Mine was placed on 'care and maintenance' for an indefinite period. However, it was decided to merge North and South Mines to form "Copper Cliff Mine" as part of restructuring of Vale Nickel in 2009.

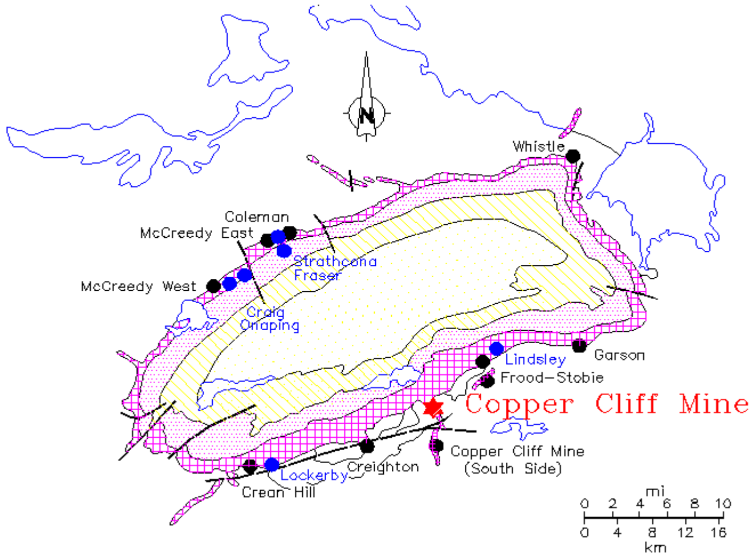

Figure 1 Location of Copper Cliff Mine in the Sudbury Basin of Vale Operations

2 Geology

There are quite a few major geological structures present at the Copper Cliff Mine. Different orebodies and the major geological structures across the Copper Cliff Mine are shown in Figure 2.

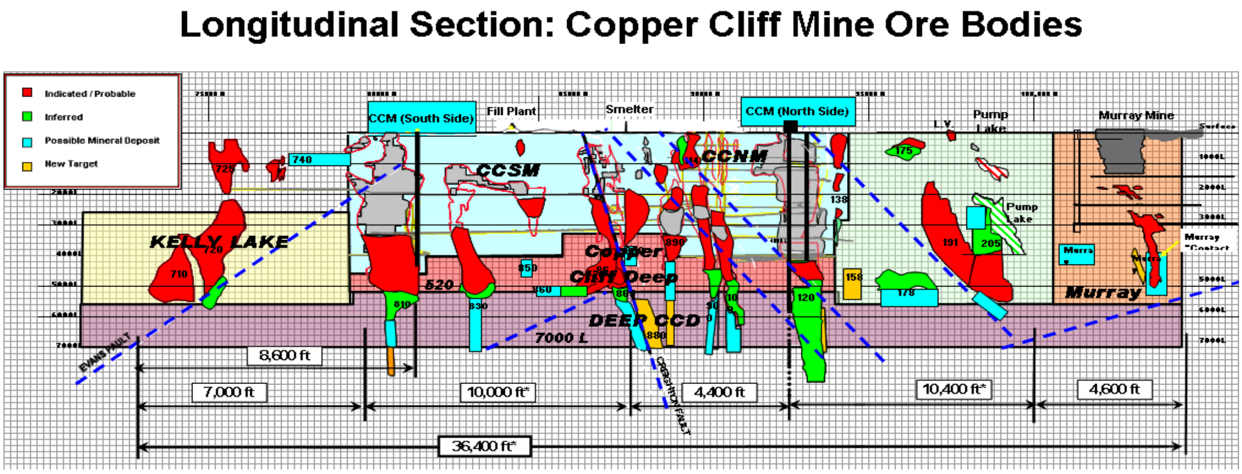

Figure 2 Long-section showing different orebodies and the major geological structures at Copper Cliff Mine

Of all the major geological structures present at Copper Cliff Mine, only two structures need a mention in this paper, as these structures are known to be seismically active (Yao et al., 2009). The details of these two structures are given here and are shown in Figure 3.

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

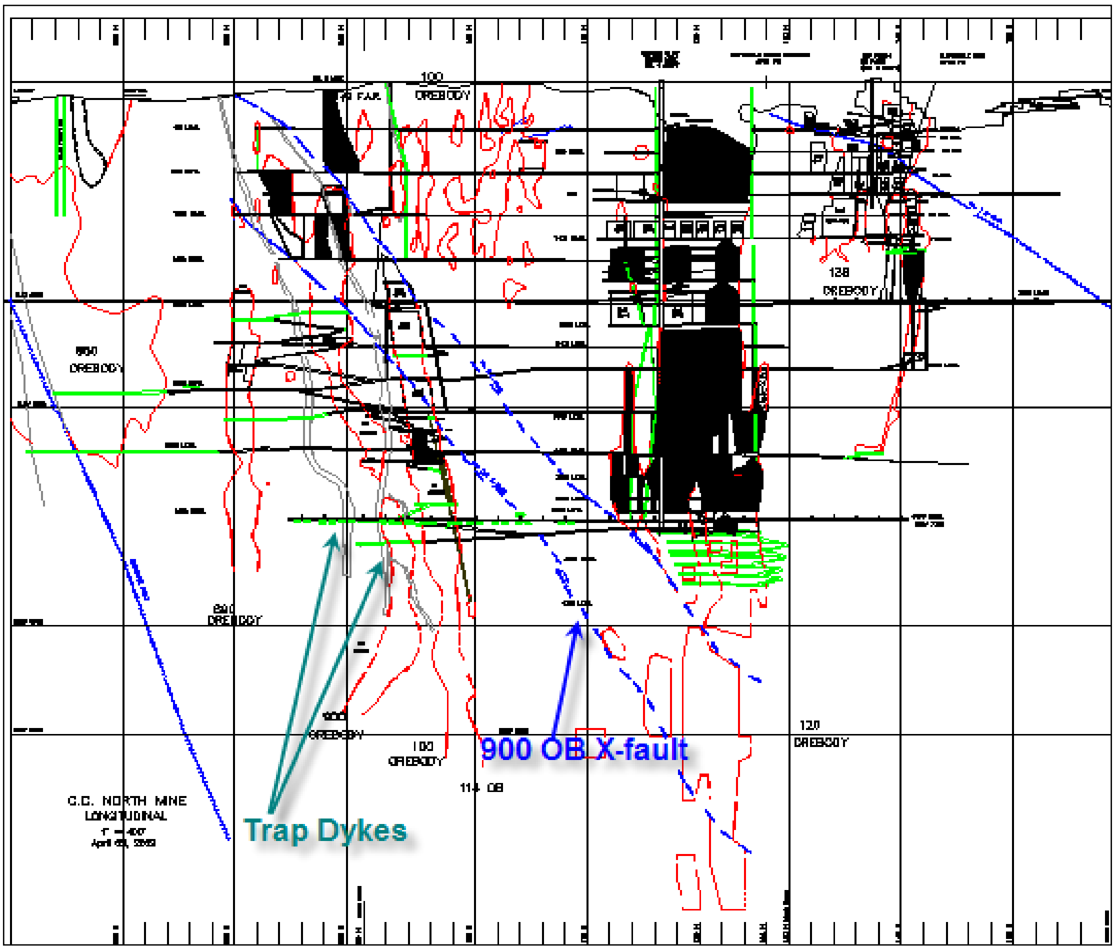

Figure 3 Location of 900 OB X-Fault and Trap Dykes with reference to 100 and 900 orebodies

3 Rockburst history at Copper Cliff Mine

The rockbursts/seismic events that have occurred since 1998 have been reviewed with a view to get a general idea as to which orebodies are more burst-prone. To avoid confusion between rockbursts and seismic events, the following explanation is provided. If an event results in sudden displacement of material associated with violent failure of the excavations including damage to the installed ground support system then the incident is called a rockburst. On the other hand, if an event does not associate with any material displacement and no damage occurred to the installed ground support system, then it is called only a seismic event. 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 orebodies and the remaining five incidents (almost 13%) took place in the 120 and 880 orebodies. The distribution of all the rockbursts and significant seismic events (> 2.0 Mn) over the last 13 years is shown in Figure 4.

Of all the rockbursts, the 3.8 Mn event that occurred on 11 September 2008 in the 100/900 orebodies following a crown blast is considered to be significant as it caused considerable damage to underground excavations on multiple levels. Although the location of the major event was on 3050 L in the 100 orebody, the damage was extended across nearly a 300 m vertical block starting from 2700 L to 3710 L. Approximately, 3,000 t of material was displaced in total 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. Basically, 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 damage locations was incapable of taking the impact of dynamic loading caused by the 3.8 Mn event.

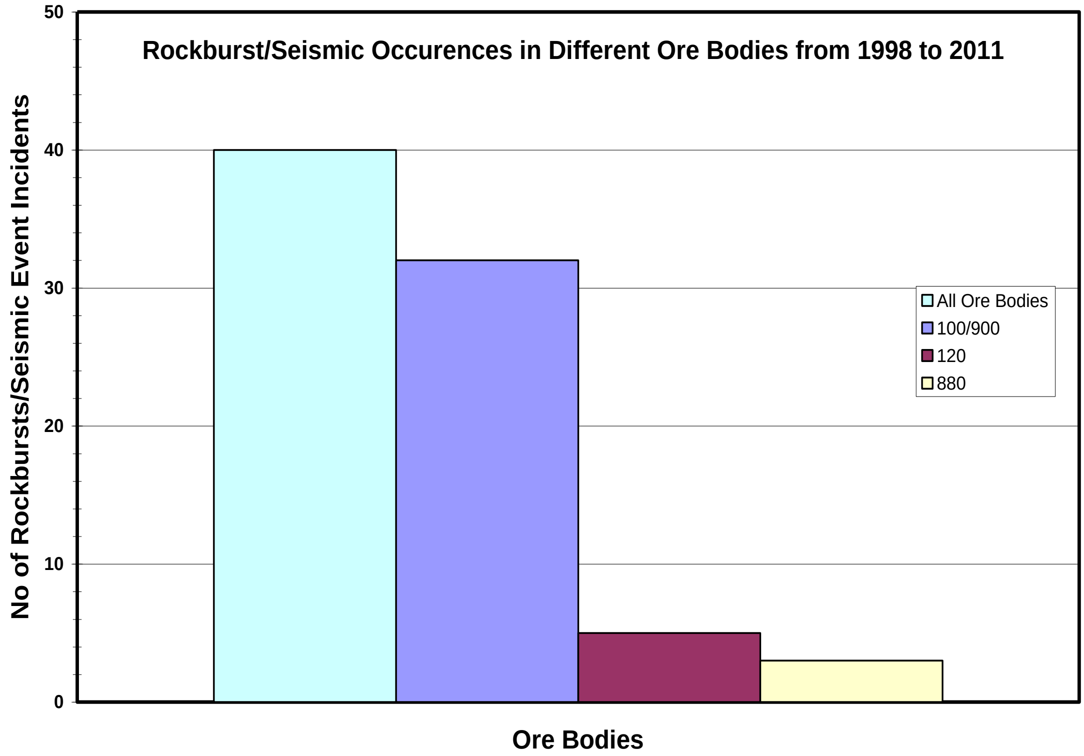

Figure 4 Distribution of rockbursts/seismic events across different orebodies at Copper Cliff Mine

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.

4 Why the ground in 100 and 900 orebodies is more burst-prone

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 orebodies (Yao et al., 2009). The rationale for this kind of thinking could be better explained with the help of layout shown in Figure 5 as follows:

- 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 of this, 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 L to 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 5, 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 orebodies, the Trap Dyke is loaded up, which can then lead to significant seismic events/rockbursts.

The 3.8 Mn event on 11 September 2008 was considered to be a result of mining of 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 5.

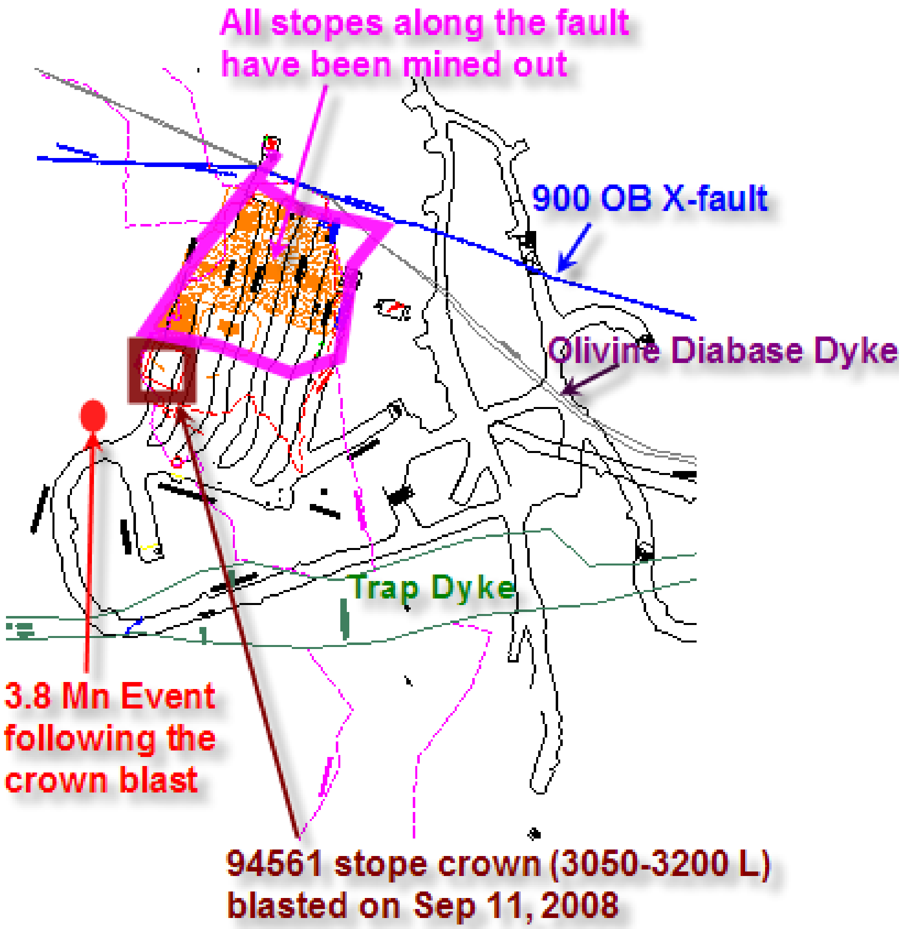

Figure 5 Layout showing the location of Trap Dyke and 900 X-fault in relation to mining on 3200 L

Since large magnitude events were associated with the damage to the underground excavations and the installed ground support systems, mining in the burst-prone ground conditions poses a greater challenge both in terms of safety and production. There are both direct and indirect costs associated with major rockbursts. For instance, the 3.8 Mn rockburst triggered a series of rockbursts within the limits of the 100/900 orebodies 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.

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

As mentioned previously, the installed ground support system at Copper Cliff Mine did not have much yielding capability, which could have been the reason why there was widespread damage following the 3.8 Mn seismic event. Based on this experience, it was decided to introduce the burst-resistant support system in all 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).

Before defining the appropriate characteristics of support systems employed in burst-prone ground, and trying to match these with the characteristics actually available in support elements, it is important to understand the role of each element in a support system. Figure 6 shows a simplified view of three primary support functions:

- to reinforce the rock mass

- to retain the broken rock
- and to securely hold the retaining elements in place (McCreath and Kaiser, 1992).

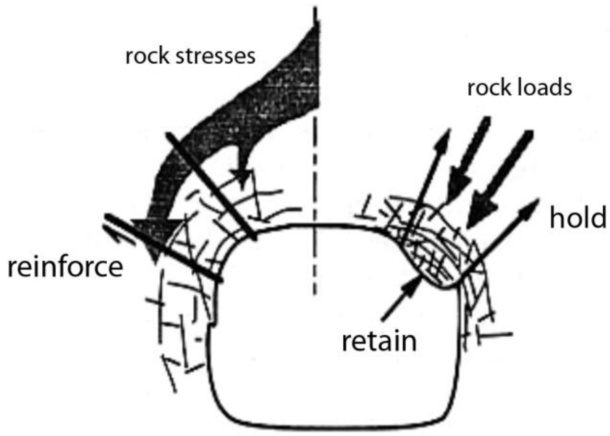

Figure 6 Three primary functions of support elements (McCreath and Kaiser, 1992)

The reinforcing, retaining, and holding functions will be required in various proportions under rockburst conditions depending on the specific damage mechanisms and severity involved in a particular situation. An appropriate support system must, however, be able to survive the displacements associated with the rockburst and remain functional after the rockburst to hold and retain any broken rock. Under situations that involve violent rock ejection the support must also be able to absorb kinetic energy in the ejected material (Kaiser et al., 1996).

5.1 Characteristics of support elements in burst-prone ground

In burst-prone ground, the desired properties of individual elements or support systems depend on the anticipated severity of damage inflicted by a rockburst and on the intended role of the support, which is related to the underlying damage mechanism involved. Initially, a stiff and strong support is advantageous to reinforce the rock and to prevent loosening or weakening of the rock mass near the opening. However, if rockburst damage of major severity is anticipated, the rock mass should not only be reinforced to control the bulking process, but the holding elements must be ductile and able to yield (Kaiser et al., 1996). By definition, a yielding support system has enhanced load-time distribution properties when subjected to large displacements, while providing resistance to the movement (Gaudreau et al., 2004). Typical characteristics of different support elements are shown in Table 1.

Table 1 Characteristics of typical support elements (Kaiser et al., 1996)

Support Characteristics	Support Functions		
	Reinforcing	Retaining	Holding
Stiff	Grouted rebar	Shotcrete	Grouted rebar
Soft	–	Welded wire mesh	Long mechanical bolt
Strong	Cable bolt	Reinforced shotcrete	Cable bolt
Weak	Thin rebar	#9 gauge mesh	Split set
Brittle	Grouted rebar	Plain shotcrete	Grouted rebar
Yield	Cone bolt	Chain-link mesh	Yielding swellex

5.2 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 x 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 x 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 mainly 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 7.

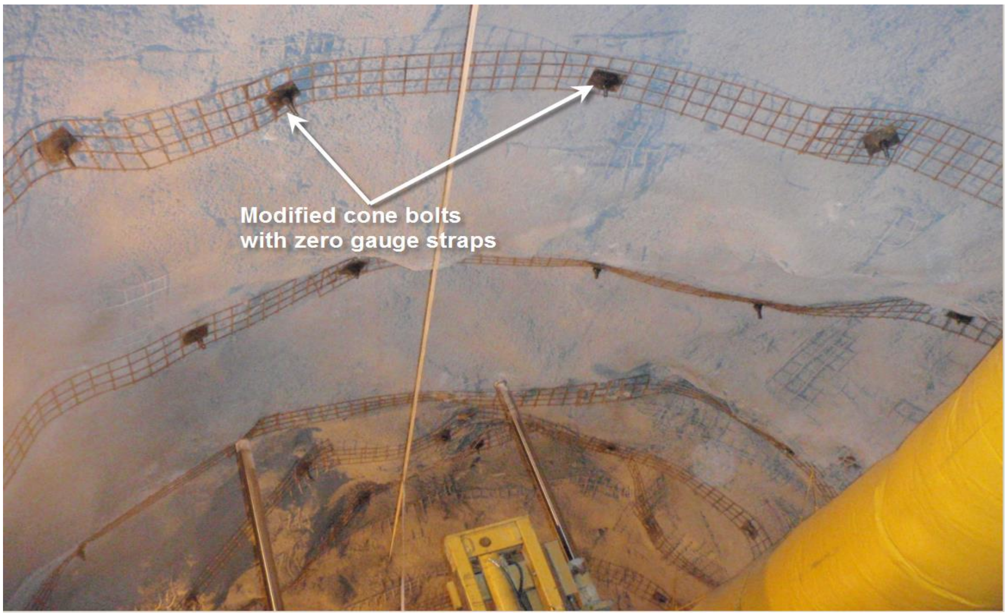

Figure 7 Final product of burst-resistant (dynamic) support system used in one of the drill sills at Copper Cliff Mine

Energy absorption capacity and load–displacement characteristics of various ground support elements (Kaiser et al., 1996) that were used as rock-burst resistant support system at Vale’s Copper Cliff Mine are given in Table 2.

Table 2 Energy absorption and load-displacement characteristics of support elements (Kaiser et al., 1996)

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 x mesh	< mesh	3–5 x mesh*

* at displacements below 100–150 mm

Based on the above energy absorption values, the total energy absorption capacity that was employed in burst-prone ground conditions at Copper Cliff Mine was calculated anywhere between 20 kJ and 48 kJ per square metre. The required energy absorption capacity was determined based on 3.8 Mn event and the observed damage levels at Copper Cliff Mine following the steps outlined in the "Canadian Rockburst Support Handbook" (Kaiser et al., 1996). The steps that were followed in the design of burst-resistant support system are given below.

- Step 1: to determine the ground motion level in terms of Peak Particular Velocity (PPV) for a known rockburst.
- Step 2: to calculate the total kinetic energy of any ejected blocks of rock, i.e. the demand on the support. The total energy can be determined using Et = ½ m ve 2 + q m g d (Kaiser et al., 1996).
- Step 3: to determine the energy absorption capacity provided by different ground support elements.
- Step 4: to ensure the factor of safety (FOS), i.e. support capacity (from Step 3)/demand (from Step 2) is between 1.3 and 1.5.

At some locations the shotcrete was excluded from the burst-resistant support system, so the energy absorption capacity that could be achieved with the combination of resin grouted rebars, FS-46 split sets, #4 gauge screen and modified cone bolts along with #0 gauge straps would be anywhere between 11 kJ and 30 kJ per square meter.

6 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. The stopes that were mined out in the vicinity of Trap Dyke these were the i.e. burst-prone ground conditions in the 100 and 900 orebodies and are shown in Figure 8.

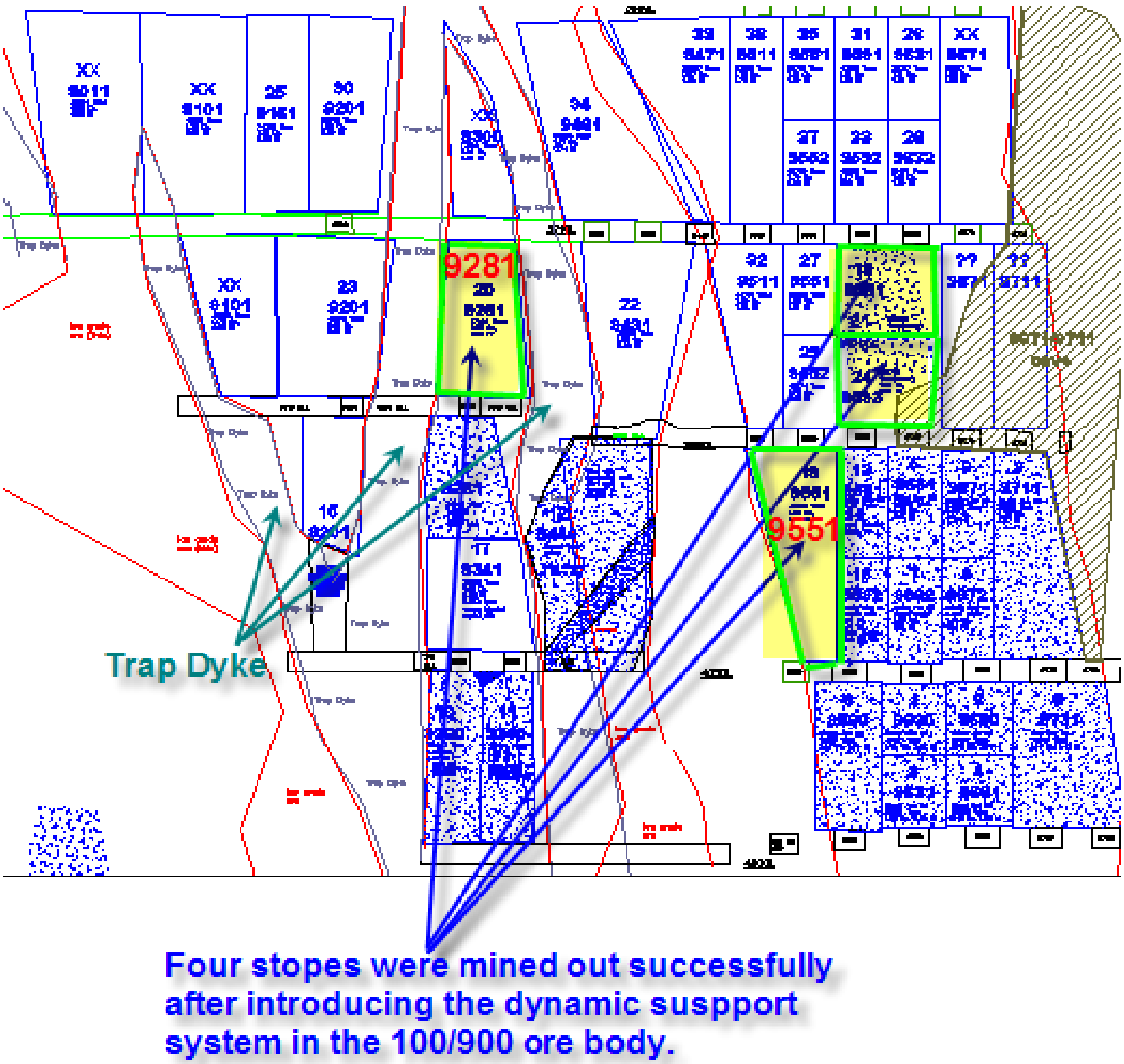

Figure 8 Long-section of the stopes mined after the 3.8 Mn event in the vicinity of Trap Dyke in the 100/900 OB at Copper Cliff Mine

With the resumption of mining in the 100/900 OB, Copper Cliff Mine once again started to experience an elevated seismic activity, particularly while mining the stopes surrounding the Trap Dyke. Seven seismic events/rockbursts, ranging from 1.2 to 2.9 Mn, occurred while mining the 9551 and 9281 stopes. As it can be seen in Figure 8, these stopes are located in the vicinity of Trap Dyke, especially the 9281 stope being sandwiched between two forks of the Trap Dyke. Out of the seven seismic events, six of them occurred while mining the 9281 stope between 3710 and 3880 L. The chronology of the seismic events/rockbursts that occurred while mining the stopes in the vicinity of Trap Dyke is given in Table 3.

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 whatsoever 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 adequate energy absorption capacity to withstand the impact of 2.9 Mn event. As mentioned in the "Canadian Rockburst Support Handbook", the support must not only be able to survive a single seismic event or the main seismic event causing the largest ground motions, but it must also retain its integrity and support functionality after the initial seismic event, so that it can continue to provide effective support for aftershocks or subsequent seismic activity (Kaiser et al., 1996).

While mining the 9281 stope, the installed burst-resistant support system was repeatedly subjected to the impact of seismic events and as a result it showed some signs of negligible damage. Although it is difficult to assess the impact of previous seismic events in a quantitative manner in the field, the ground control engineer determines whether there are signs of support yielding based on their observations, and/or filed instrumentation monitoring if any. If so, it may be prudent to install extra support in an effort to compensate for any potential loss in safety margin (Kaiser et al., 1996). For instance, the induced stress level in the 9281 stope was observed to be relatively high when mining started in the stope. The reason could be due to fact that this stope was sandwiched between two limbs of Trap Dyke. The squeezing of an 'in the hole' (ITH) drill holes while mining was in progress in the 9281 stope can be seen in Figure 9.

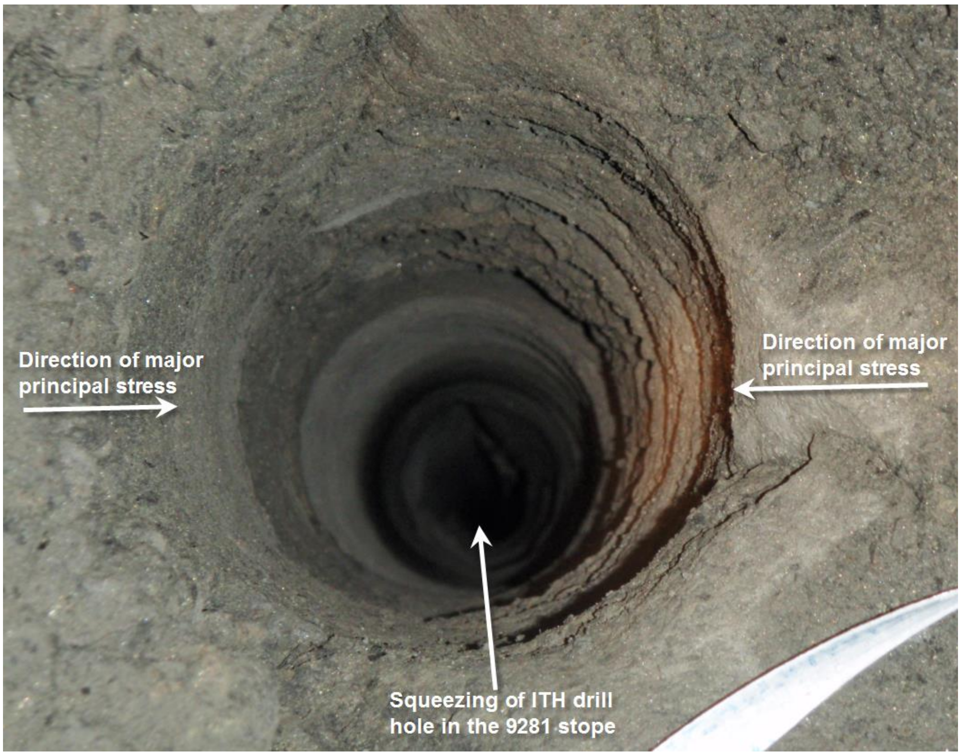

Figure 9 An ITH hole subjected to squeezing and shifting due to high induced stress level in the 9281 stope

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 3 for the order of events). However, the level of damage was very insignificant and it can be seen in Figure 10 and Figure 11 respectively.

Figure 10 Minor cracking and bulging of the support system following a 2.3 Mn event in 9280 top sill

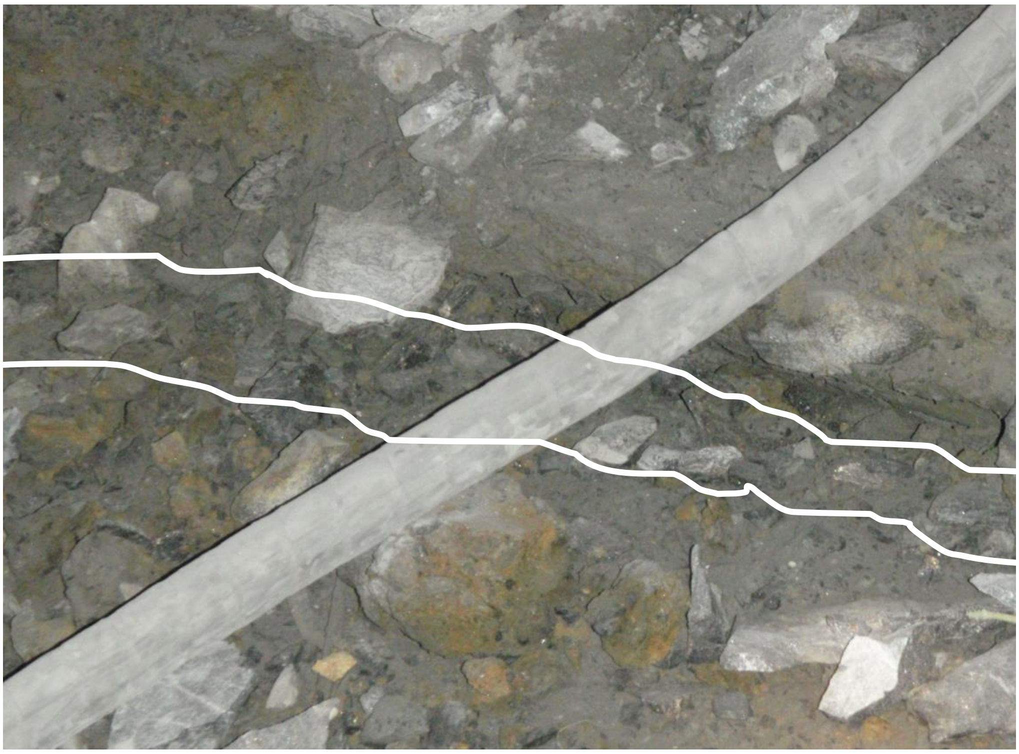

Figure 11 Floor heaving (5 cm) following a 2.3 Mn event in 9280 top sill

The "Canadian Rockburst Support Handbook" provides a reference (Figure 12) to the anticipated floor heave in a highly stressed ground caused by a remote seismic event. Since the conditions in the 9280 sill can be considered to be highly stressed due to presence of Trap Dyke on both sides of the stope, it would be worthwhile to compare the actual floor heave caused by the 2.3 Mn event. The source location of the 2.3 Mn event was found to be approximately 50 m away from the damage location. Based on the chart shown in Figure 12, the anticipated floor heaving could be more than 0.1 m for the 2.3 Mn event. However, in reality there was only about 0.05 m of floor heave, even though the floor was not supported. This could be attributed due to the fact that the dynamic loading caused by 2.3 Mn event was better managed by the burst-resistant support system and thereby reduction in the floor heaving due to impact of the 2.3 Mn event.

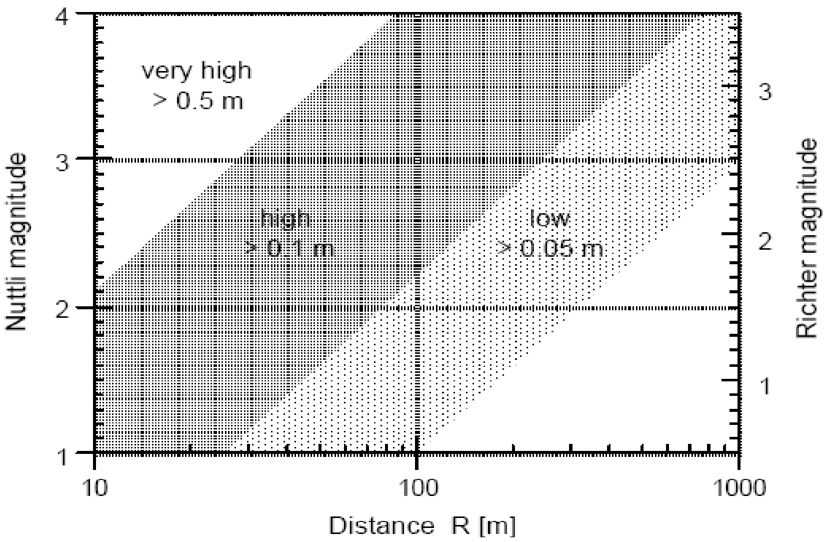

Figure 12 Anticipated floor heave caused by a remote seismic event in typical conditions (Kaiser et al., 1996)

7 Conclusions

Even though, many seismic events occurred in 100/900 orebodies 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.

Acknowledgements

The authors would like to express their thanks to Samantha Espley, Steve Runnalls, Jim Willan and Alex Henderson for granting the permission to publish this paper. Also, encouragement received from Wayne Cassidy and central rock mechanics group at Vale's Sudbury Operations is greatly appreciated.

References

Gaudreau, D., Aubertin, M. and Simon, R. (2004) Performance of tendon support systems submitted to dynamic loading, in Proceedings Fifth International Symposium on Ground Support, Ground Support in Mining and Underground Construction, E. Villaescusa and Y. Potvin (eds), 28–30 September 2004, Perth, Australia, Australian Centre for Geomechanics, Perth, pp. 299–312.

Kaiser, P.K., McCreath, D.R. and Tannant, D.D. (1996) Canadian Rockburst Support Handbook, Geomechanics Research Centre, MIRARCO Sudbury, Ontario, Canada.

McCreath, D.R. and Kaiser, P.K. (1992) Evaluation of current support practices in burst-prone ground and preliminary guidelines for Canadian hardrock mines, in Proceedings International Symposium on Rock Support in Mining and Underground Construction, A.A. Balkema, Rotterdam, pp. 611–619.

Yao, M., Chinnasane, D.R. and Harding, D. (2009) Mitigation Plans for Mining in Highly Burst-Prone Conditions at Vale Inco Copper Cliff North Mine, ROCKENG09: Proceedings of the 3rd CANUS Rock Mechanics Symposium, Toronto, May 2009, M. Diederichs and G. Grasselli (eds).