Geomechanics Strategies for Rockburst Management at Vale Inco Creighton Mine

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ABSTRACT: At Creighton Mine, magnitude events are a regular occurrence due to depth and major seismically-active structures. Over the last ten years, major advances have been made in research and development to develop strategies for the management of these major events. Today, the number of rockbursts has been drastically reduced at the mine and damage due to seismic events, when they occur, is often minimal. This paper describes the evolution and implementation of appropriate geomechanics strategies, designs, and practical ground control measures undertaken for the management of seismicity at Vale Inco’s Creighton Mine. A description of the research and development approach, implementation, and ground control strategy is provided for placement of enhanced support systems to manage the consequences of magnitude events at Creighton Mine. The approach ensures the safety of workers, stability of mine infrastructure, continuous access to ore and minimal downtime after large events.

1 INTRODUCTION

Monitoring of seismicity at Creighton Mine in the last two decades shows that the majority of seismicity occurs close to mining activity, mostly due to sudden mining induced stresses. A small fraction of the recorded seismicity, and significant events, occur tens to hundreds of meters away from mining, as a result of fault-slip along major seismically active shear zones (e.g., Plum Shear, Footwall Shear). These events are generally of large magnitude, pose substantial damage potential and can occur minutes, days or even weeks after production blasts.

At Creighton Mine, magnitude events are a regular occurrence due to the depth and major seismically-active structures. For more than ten years, major advances have been made in research and development in rock mechanics whereby the goal is to develop strategies for the management of the major events. Today, the number of rock bursts has been drastically reduced, and damage due to seismic events, when they occur, is often minimal.

The evolution and implementation of appropriate geomechanics strategies, designs, and practical ground control measures for the management of seismicity at Creighton Mine is described below. As well, the research and development approach, implementation, and ground control strategy for placement of enhanced support systems, to manage the consequences of magnitude events at Creighton deep, is reviewed. In the last two years, the implementation of a long term rock mechanics strategy, coupled with the day to day ground control recommendations have reduced the number of rock bursts and minimized the down time in the operation following any large magnitude event.
The structural geology and mining activities, especially the stope sequencing, play major roles in triggering rock bursts. Both regional and local mine geology with reference to structural geology play dominant roles in rock burst occurrences. Since stress changes cannot be avoided in mining, the redistribution and magnitudes of the stresses are managed through optimization of the mining sequencing and stope sizing. These aspects are briefly presented in the following sections.

2 GEOLOGY

2.1 Regional geology

The copper-nickel sulphide deposits in the Sudbury basin are part of the Paleoproterozoic Sudbury Structure that comprises the Sudbury Igneous Complex (SIC). The SIC forms an elliptical ring and is separated into North and South Ranges -- these differ with respect to the thickness of the norite and gabbro units, the character of the footwall rock and metamorphic history. The separation between the North and South Ranges occurs across a series of ductile shears at the southwestern and southeastern corners of the SIC. Creighton Mine is located at the southeastern corner of the SIC between the main mass norite and footwall rocks (Figure 1).

Figure 1: Geology Map of the Sudbury Basin showing the location of Vale Inco’s Creighton Mine

The discontinuous sublayer unit of the SIC is the usual host for the ore and comprises a series of mafic to ultramafic inclusions of varying size and frequency in a matrix of norite and sulphides. Orebodies generally have a high-grade footwall with a gradational lower-grade hangingwall.
The rocks of the Sudbury Structure are affected by five major fault sets:
1. Set 1 – these are major, south-dipping, curvilinear, reverse faults that cut through the Sudbury Basin in an ENE-NW direction, exiting from the basin at its southwest and southeast corners. These faults occurred between 1870 and 1700 Ma.
2. Set 2 – these are NNW-trending faults that cut the North Range of the Sudbury Basin. These are steeply dipping structures with a generally sinistral sense of displacement of up to 3,000 ft on the Fecunis Lake Fault. These faults crosscut the mineral deposits at the Coleman Mine.
3. Set 3 – these faults cut the SIC at a shallow angle on the East side of the Basin. These faults also have a sinistral sense of displacement of up to 2,000 ft.
4. Set 4 – these faults are part of the Murray fault system that consists of a number of east-west trending, steeply-dipping faults that cut the South Range of the Sudbury Basin. The displacement is right lateral. Fault sets 2, 3 and 4 all offset the northwest trending olivine diabase dykes.
5. Set 5 – these are a late-stage set of faults and fractures that are formed by the current tectonic stress field. The fractures are commonly infilled with low-temperature sulphides (galena, marcasite) and carbonate minerals. These faults and fractures commonly exhibit a low level of microseismic activity and are sometimes associated with poor ground conditions.

The rocks of the Sudbury Structure are cross-cut by two major dyke swarms:
1. A system of quartz diabase dykes striking east-west along the southern margin of the Sudbury Basin. These dykes vary in thickness from a few inches up to several hundred feet and are commonly referred to as “trap dykes”. The quartz diabase dykes cross-cut several mineral deposits at Creighton Mine.
2. A system of olivine diabase dykes, commonly referred to as the “Sudbury Swarm” that strike northwest-southeast and are steeply dipping. These dykes are dated at about 1235 Ma.

2.2 Local and structural geology

Creighton Mine is located within the Creighton embayment on the outer rim of the South Range of the SIC (Figure 1). The Creighton embayment also includes two smaller satellite embayments to the west called the Gertrude and Gertrude West embayments. The Creighton Fault, which strikes N70°E and dips 85°N, truncates a small, near-surface, portion of the Creighton embayment at its southern margin. Four main geological units are present:

1. Members of the Main Mass of the SIC. Towards the base of the main SIC, overlying the embayment, the basal norite may contain a small percentage of inclusions and disseminated sulphide.
2. Sublayer norite, which is the common host for the ore and consists of inclusions of varying composition, size and frequency of occurrence set in a matrix of norite and sulphide.
3. A short, variably mineralized, quartz diorite offset dyke. Mineralization is spatially associated with the dyke, but the dyke itself is usually barren.
4. Footwall rocks comprising Paleoproterozoic Creighton granite that intrudes lower Huronian metavolcanics and metasediments.

Creighton Mine comprises 15 orebodies of which the majority of the higher grade mineralization in the Main, West, 117, 118, 128, 125, 126, 401 orebodies have been depleted. Remaining reserves and resources at Creighton Mine are concentrated in the 3 Shaft remnants, Deep 400 Orebody, Up-dip 402 Orebody, and 403 Orebody remnants and the recently discovered 649 Orebody.

Mineralization is contained within a north-west plunging embayment of norite in the footwall. Within the embayment, mineralization is controlled by two troughs or indentations into the footwall region. The majority of orebodies are located along a northwest plunging trough
(Creighton 400 trough) that follows the general geometry of the main Creighton Embayment, while the remainder are located along a near orthogonal trough (Gertrude 402 trough) plunging north east at 40 degrees. Figure 2 shows the composite geology section of Creighton Mine.

![Composite geology section of Creighton Mine](image)

At depth, the Creighton’s main ore zone strikes roughly east-west (E-W) and dips steeply to the north. Along strike, the bulk of the remaining ore extends about 150 m with an average thickness of 100 m. At a depth of 7530 feet (2295 m) the ore zone extends about 250 m in the E-W direction with an average thickness of 50 m. In addition, there are several ore zones located in the hangingwall and footwall of the main orebody at depth.

### 2.3 Characteristics of major rock units and the stress tensor at Creighton Mine

The mining zone at Creighton can be characterized as footwall granite-gabbro domain, massive sulphide ore zone domain and hangingwall norite domain (Figure 2). Other ore zones, such as the 461 orebody, are embedded in the footwall granite-gabbro domain.

Structural analyses identified mostly two subvertical joint sets and one low angle to flat lying joint set in the footwall domain. The joint set orientation in the hangingwall norite domain is different with three high-angle to subvertical joint sets and a low angle joint set. There are four joint sets in the ore domain with three subvertical joint sets and one low angle to flat lying joint set. Table 1 shows the summary of intact rock properties from all three rock domains at Creighton Mine.

Systematic logging and mapping has been carried out over the last few years to identify major joint sets and structures. Core logging data is processed using procedures developed internally by Vale Inco. The derived results are regularly reviewed to identify the distribution of the rock mass quality and location of major structures for design purposes (e.g. stope design, support design, location of major infrastructure). Table 1 is the average geomechanics properties of major units at Creighton Mine.
Table 1. Average geomechanics properties of major units at Creighton Mine.

<table>
<thead>
<tr>
<th>Domain</th>
<th>Density (Kg/m$^3$)</th>
<th>UCS (MPa)</th>
<th>Young Modulus (GPa)</th>
<th>Poisson ratio ($\nu$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granite</td>
<td>2600</td>
<td>240</td>
<td>60</td>
<td>0.26</td>
</tr>
<tr>
<td>Norite</td>
<td>2850</td>
<td>190</td>
<td>78</td>
<td>0.28</td>
</tr>
<tr>
<td>Ore</td>
<td>3600</td>
<td>130</td>
<td>68</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Geology mapping shows that Creighton Mine is characterized by several late-stage faults, locally termed shears. The structures consist of foliated material and tend to contain a large proportion of biotite mica that is, for most part, healed. Depending on structure, shear zones vary in thickness from a few centimeters to tens of meters. Figure 3 identifies the late-stage shear zones at a depth of 7680 feet (2304 m).

Creighton Mine’s pre-mining far-field stress regime used in rock mechanics studies is derived from far-field stress measurements taken in the mid to late 1980’s. In the absence of more recent measurements, the stress tensor used for numerical stress/strain modeling is derived from selected data from earlier measurements. In the Sudbury Basin, the vertical stress is the minimum principal stress. However, in some of the data sets, the vertical stress was found to be erroneously recorded as near horizontal and was not consistently increased with depth. These data sets were eliminated from the database, and Figure 4 presents the best linear fit to the selected data, i.e. after eliminating the erroneous measurements.
3 MINING ACTIVITY

#9 Shaft is the only shaft still in service to deliver all of the supplies and personnel for Creighton Mine’s production. The lowest access level from #9 Shaft is 7000 feet (2135 m). Creighton Mine has adopted an incremental strategy to reach ore at increasing depths below 7000 Level (2135 m). Access to orebodies below this level is via a haulage ramp system. Levels are generally driven at 130 feet (40 m) intervals for the 400 orebody and 85 feet (26 m) intervals for the 461 orebody.

Mining activity has been on-going at Creighton Mine for more than 100 years using a combination of shafts, winzes and ramps to access its various ore zones. Over the years, a number of mining methods have been used including shrinkage, block caving, cut and fill, vertical crater retreat and slot-and-slash mining. Presently, the mining method at Creighton Mine (in the deep portion of the mine) consists mainly of vertical retreat and slot-and-slash bulk mining with limited uppers mining of small hangingwall ore zones.

Presently, the main production areas are:

- Division 4: Bulk mining in the 402 Orebody between 3700 Level (1130 m) and 5400 Level (1645 m) with bottom-up, center-out mining.
- Division 5: Pillar recovery (remnants) between 5400 Level (1645 m) and 6600 Level (2010 m).
- Division 6: Bulk mining at depth, below 6400 Level (1950 m). This mining area is known as Creighton Deep.

Creighton Deep plays a leading role, financially, by generating the highest tonnage, grades and revenues per tonne in the mine. Its importance will increase as ore reserves are depleted in the upper parts of the mine. At depth, the ore is typically mined using a slot-slash mining method with a pillarless, top-down and center-out mining sequence for the main 400 Orebody.

The sand fill system uses mill tailings delivered to the Creighton sand plant. The sand plant consists of two 300 tons storage tanks each with its own mixing tank and a capacity to produce 200 tons per hour. The underground delivery system consists of a series of boreholes between surface and 7000 Level (2135 m) and 4-inch sand fill pipes on the levels and down short boreholes to deliver the sand fill from 7000 Level to all mined stopes. Currently, the sand fill is distributed to the lowest mining level at 7810 feet (2380 m) with plans to incrementally extend the feed to lower levels as mining extends to depth.

4 SEISMICITY / ROCKBURTS HISTORY

Historically, the first recorded seismic events and rock bursts at Creighton Mine started in the 1930’s, predominantly in crown pillars and sill pillars at a depth of 2300 feet (700 m). Years later, as mining progressed to depth, seismicity began to occur in single development headings (i.e. strain bursts) at a depth of 4000 feet (1200 m) and in sill accesses following production blasts at a depth of 6600 feet (2000 m). Most rock bursts in sills accesses occurred with the day to day mining activity and have typically been the result of sill and crown pillar mining (pillar bursts) whereas most strain bursts have been associated with geological structures.

On July 6, 1984, a Nuttli Magnitude (mN) 4.0 rock burst occurred 500 feet (150 m) into the hangingwall of the 125 Orebody between 3200 and 3400 Levels (1000 m). This major event was then followed by a series of events ranging in magnitude of mN 2.1 and 2.4 – these events occurred in the footwall of the main orebody between 3200 and 3800 levels and in the vicinity of #5 Shaft.

A few years later, on May 25, 1998, a mN 3.9 rockburst occurred deep in the hangingwall of the 400 orebody at a depth of 7200 feet (2200 m). The event was then followed by a number of relatively large magnitude events, the largest being mN 2.1. The seismicity migrated upward and
into the footwall, leading to a $m_N$ 3.5 at a depth of 6800 feet (2070 m) in the footwall near the fresh air raises. This event occurred approximately 12 hours after the main event. The analysis of the seismic data following the $m_N$ 3.9 and other footwall events indicated that they were due to fault-slip movement along a hangingwall structure and along other structures in the footwall, as identified by cumulative plots of microseismic data.

On November 29, 2006, a major seismic event of $m_N$ 4.1 occurred in the hangingwall of the 400 Orebody at a depth of 7200 feet (2200 m). This event was most likely due to a slip along a shear zone located deep in the hangingwall, at a distance of more than 500 feet (150 m) from the mine workings. This major event was followed fifteen minutes later by a $m_N$ 3.3 event in the footwall at a depth of 7680 feet (2340 m). Similar to the May 1998 event, it is postulated that the $m_N$ 4.1 event was the result of a lock-up/release mechanism with mining-induced confinement followed by a reduction in the normal or confining stress on the NE trending late-stage shear zone.

On June 15, 2007, a major seismic event of $m_N$ 3.0 occurred in the footwall of the 400 Orebody at a depth of 7200 feet (2200 m). This event was also a fault slip event along a seismically active fault (i.e. Plum Shear) located in the footwall of the 400 Orebody. This event is the most undesirable and damaging due to the fact that the event was located in the footwall and the mine’s main ramp and most of the mine’s infrastructure is located in the footwall.

In summary, the rock bursts at Creighton Mine in the 1990’s occurred predominantly in crown/sill pillars (pillar bursts) and in development headings when seismically-active structures were intersected by or were in the vicinity of active development headings. In early to mid-2000’s, rock bursts occurred mainly in development headings (strain bursts) and occurred in association with the mining of the 1290 Orebody, the Footwall Plum Orebody and 461 Orebody.

5 GEOMECHANICS STRATEGIES AT CREIGHTON MINE

5.1 Microseismic System

The first microseismic system at Creighton Mine was a 16-channel MP 250 installed in 1980. This was later expanded to monitor increased seismicity with depth. In 1988, the system was converted into a 12-bit full waveform system as developed by Queen’s University Seismology Department. This system employed the MP250’s accelerometer array already in operation underground, but it allowed for correct first-arrival picking and magnitude evaluation. In 1999, the seismic system was replaced with a 16-bit Hyperion system developed by the Engineering Seismology Group (ESG).

Currently, Creighton Mine operates a Hyperion system that monitors a mine-wide underground array with a capacity of 104 channels. The system covers the mining area from 3540 to 7940 Levels (1080 to 2420 m). One 64-channel transceiver is located at #8 Shaft on 6400 Level (1950 m), one 24-channel transceiver is located on 7680 Level (2340 m), and a 16-channel transceiver is located on 4000 Level (1220 m) to cover the 402 orebody. The system is configured as two sub-arrays and has 8 channels for expansion.

The sensor array consists of uniaxial accelerometers with a sensitivity of 30 V/g and a frequency range of 50 to 5000 Hz and triaxial accelerometers with sensitivity of 0.3 and 0.5 V/g and a frequency range of 3 to 8000 Hz. Although this array can locate any seismic event within the mine, the magnitude estimates are limited to events between $m_N$ -2 and 1. To estimate larger magnitude events, the mine operates three triaxial 4.5 Hz geophones recorded by a 24-bit Paladin system (Strong Motion System), also developed by ESG.

5.2 Destress Blasting

Rockmass damage mechanisms are typically tied to high stresses and the presence of geological structures. Due to well-designed and well-executed destress blasting practices at Creighton Mine, strain bursts and stress-related issues are minimized in development headings.
5.3 Introduction of enhanced support

Enhanced support consists of a combination of MCB® cone bolts with zero-gauge straps or the use of shotcrete arches. These two support systems have proven to be very effective in burst-prone conditions and around seismically-active geological structures, especially when installed during development or at the early stage of mining.

Over the last decade, the ground support system for Creighton Deep has continuously improved based on trials and analyses of the ground response and stress levels. Primary support systems have been improved with the development and implementation of the 46 mm friction sets (FS46®) for wall bolting and Swellex® bolts when mining under or beside sand fill. The use of Swellex and Super-Swellex bolts for development under sandfill has improved the development efficiency by reducing the cycle time and improving the overall stability of the top sills (driven under sandfill).

Below a depth of 7000 feet (2135 m) top sills are developed underneath or within previously mined and backfilled zones. The ground is supported with a first layer of shotcrete, followed by a layer of split set bolts and screen, and finished with a second layer of shotcrete. The development is done in short 6-foot (1.8 m) rounds.

With the exception of development in damaged ground (under sandfill), all deep development at Creighton follows a strict perimeter and destress blasting design to reduce the number of strain bursts in the development headings. Furthermore, an enhanced method for cutting intersections below 7680 feet (2340 m) was implemented in 2006 to reduce the risk of instability. Depending on the geometry of the opening, certain rules are applied with respect to (i) the way in which the intersection is excavated and (ii) the timing of installation of secondary or enhanced support. For example, in areas where secondary support (cablebolts) or enhanced support (cone bolts with zero-gauge straps) is required, the support is to be installed when driving the development. This is generally done prior to driving any secondary cross-cuts or approximately every four rounds. Delayed installation of cone bolts and straps causes various challenges over time; this main challenge is the difficulty experienced in installing bolts due to ground deterioration from high in-situ stresses.

5.4 Mining Sequence

Numerical modelling is an integral part of the long-term and short range planning at the mines. Modelling software used at Creighton Mine includes three-dimensional elastic packages (Examine-3D® (RocScience, 2009), MAP3D® (Wiles, 2009) and the Itasca finite element codes (3DEC®, FLAC-3D®). Structural analysis software such as DIPS® (RocScience, 2009) is also used on regular basis for design purposes.

MAP3D® has been used at Vale Inco since it was developed and later marketed in the 1990’s. The program is quick and easy to use, and it is a valuable tool for the Ground Control Engineer to use for mine planning and stope sequence designs. The mine’s stope model is easily updated to include new mining areas and the results can be quickly assessed using years of empirical data.

Figure 5 presents a three dimensional view of the Creighton Deep MAP3D model showing the top-down, center out mining for the main 400 Orebody. In Figure 5, light coloured stopes represent the mined-out stopes (top and bottom centre) while darker colours indicate unmined stopes and these also represent the top-down centre-out mining sequence.

5.5 Hazard map project

Seismic hazard maps were researched by Vale Inco and introduced to Creighton Mine in 2008. This tool allows the engineer to strategically identify locations where enhanced support systems are required for ground stability. As per Section 5.3, enhanced support systems are expensive and cannot be installed throughout the entire operation. The tool is used to identify potential areas of elevated seismic hazard and thus identifying the locations where enhanced support systems must be installed to reduce excavation damage, downtime in the operation and loss of ore reserves as a result of the seismicity.
The Seismic Excavation Hazard Map (SEHM) project is the result of a collaboration between researchers at MIRARCO’s Geomechanics Research Centre and Vale Inco. The work was conducted using scientific visualization techniques in the Laurentian University’s Virtual Reality Laboratory. Fundamentally, the hazard maps are derived from seismic and microseismic data routinely collected by the mine. From a geomechanical viewpoint, the following three seismic hazard factors are identified (Kaiser et al., 2005 and Vasak et al., 2004, 2006):

1. **Microseismic (MS) Density**: MS activity is evidence of rock mass degradation with a potential fall of ground as a hazard. MS density effect is cumulative and the damage caused is irreversible and therefore is classified as a long-term or permanent hazard. This is generally a local gravity-driven (ground-fall) risk to excavations, equipment and personnel.

2. **Seismically Active Planes (SAP)**: Both the presence and number of active planes pose a hazard. This is a short to medium-term hazard.
   
   a. Active planes have a potential to slip and thus may cause major events (mining-induced tremors).
   b. The presence of more than one active plane increases the potential of wedge formation, thus increasing the fall-of-ground hazard.
   c. Both gravity and seismic energy release may lead to local rock burst risk to excavations, equipment and personnel.

3. **Dynamic Stress Loading**: Large seismic events (tremors, earthquakes) can induce nearby dynamic loading resulting in severe damage to excavations. Dynamic stress loading is a short-term hazard and damage can be in the form of block ejection, rock mass bulking or shakedown.

As part of the Ontario government’s Productivity Enhancement and Risk Management for Underground Construction and Mining (PERM) initiative, a project to translate the research into a useful seismic hazard tool that utilizes the latest virtual reality and scientific visualization technology was recently successfully completed. Vale Inco’s Creighton Mine has installed and opened its own virtual reality room. The system hosts ParaviewGeo (paraviewgeo.mirarco.org) as the immersive, multidimensional visualization platform since the SEHM tool was developed specifically for that open source platform. The seismic hazards are calculated for the rock mass volume but can be represented in terms of iso-surface contours, or more traditionally as plans...
and sections (Figure 6 and Figure 7) or the data can be projected onto any other geometric object such as geological structures (e.g. faults), mine stopes or drifts (also shown in the Figure 6). A simple range of colours from cool (blue) to hot (red) colour is the scale that represents the hazard level from low to high.

Figure 6. ParaviewGeo visualization of a Seismic Hazard Map projected on drifts at a depth of 7680 feet (2400 m.).

Figure 7. ParaviewGeo visualization of a Seismic Hazard Map on section and projected on drifts, showing integrated geology and stope information.
Seismic Excavation Hazard Maps at Creighton Mine will be an integral part of the geotechnical review process for both strategic and tactical approaches for mine design as the mine progresses to greater depths.

5.6 Geomechanics strategy and rock bursts

At Creighton Mine in 2007-2009, the number of rock bursts has been decreasing in terms of frequency and the average tonnage of material displaced per event. This decrease in the number of rock bursts in the last two years is mostly due to a number of initiatives. These initiatives can be summarized as follow:

- Extensive detailed numerical modeling for a number of ore zones (e.g. Plum Orebody, and mining sequence change) followed by a number of recommendations.
- Testing and introduction of enhanced support (i.e. super swellex and straps) in ore sills and intersections developed under cemented sandfill.
- Implementation of stope de-stressing in high stress areas (e.g. 461 Orebody).
- Regular use of the hazard map to identify high stresses and seismically active areas.
- Strategic and timely placement of enhanced support.
- Timely filling of stopes in the deep parts of the mine and filling of critical unused openings in close proximity of the seismically active structures (e.g. 7200 truck loop near the main ramp).
- Change of the development procedure when intersecting major seismically-active shear zones.

All these late initiatives have reduced the number of rock bursts and have minimized the down times in the mine as a result of major magnitude events. Today, the damage after magnitude events is often minor or insignificant. Figure 8 is the number and moving average of reportable rock bursts per year at Creighton Mine between 1996 and 2008. This graph shows the significant decrease in the number of rock bursts in 2008.

Figure 8. Number of reportable rock bursts (moving average) per year at Creighton Mine between 1996 and 2008.
6 CONCLUSION

The geology of Creighton Mine is complex whereby several discrete geologic structures intersect the major rock units. As well, this mine has been in operation for over a century and the extraction has reached maturity, literally leaving a significant void underground from surface to 7810 level. The combination of the complex geology with discrete geological structures, a large mined-out volume and the increasing mining depth is challenging in terms of designing and mining in a way that effectively manages the inevitable seismicity.

To date, through strategic planning, in combination with research, Creighton Mine has successfully managed the difficult mining conditions. This is evident from the reduction in the number magnitude events occurring each year, in the limited amount of damage that has occurred to the mine infrastructure, and in the continued safety and protection of equipment and underground personnel.

Scientific visualization techniques in the Laurentian University’s Virtual Reality Laboratory have enabled a better understand of the behavior of seismic and microseismic activities in the complex mining environment. This understanding has made it possible to develop seismic hazard maps as an aid in strategically identifying locations where enhanced support systems are required and in locating the future mine infrastructure. This, combined with sound ground control practices, has enabled Creighton Mine to effectively manage the occurrence and consequences of seismic events.

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