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New Afton Convergence Monitoring and Rehabilitation Planning in the B3 Footprint

Owre, S.
New Gold Inc., Kamloops, B.C., Canada
Tilley, E.
Equilibrium Mining, Vancouver, B.C., Canada
Kamp, C.
New Gold Inc., Kamloops, B.C., Canada

ABSTRACT: New Afton's B3 block cave footprint has been in steady state production since 2022. During mining, the production footprint is subject to changing stresses that have been observed to cause squeezing and convergence of the drift profile at drawpoints and extraction drives. This can present challenges to the mining operations in terms of drift stability and accessibility of the footprint for equipment. Robust geotechnical monitoring practices have been developed to address this. Convergence is monitored using periodic visual inspections, LiDAR scanning, and multi-point borehole extensometers. These geotechnical monitoring activities generate data that requires interpretation and review during rehabilitation planning. Geotechnical monitoring data is assessed before, during, and after rehabilitation to understand the effectiveness of rehabilitation activities. This paper discusses two practical examples of New Afton's convergence monitoring and rehabilitation practices in the B3 footprint with the objective of documenting the importance of timely and well-planned rehabilitation in achieving safe and efficient production.

1. INTRODUCTION TO NEW AFTON

The New Afton Mine is a block caving operation, located approximately 10 kilometers outside of Kamloops and 350 kilometers northeast of Vancouver in British Columbia. The copper-gold orebody is situated on the Stk'emlupsemc te Secwépemc territory, within the unceded traditional lands of the Secwépemc nation.

In 2021 and 2022, New Afton completed its first two Block Caves on Lift 1, the West and East Caves, which mined over 24.5 MT and 23.7 MT respectively. Currently, New Afton successfully initiated and is monitoring steady state caving of a third cave (B3) beginning in January 2022 with 8.8 MT (probable tonnes). Production involves milling over 8,000 tonnes per operating day from the B3 cave. Footprint development and drawbell blasting is ongoing at a fourth cave (C-Zone), which comprises 29.5 MT (probable tonnes). These mining areas are shown in Figure 1.

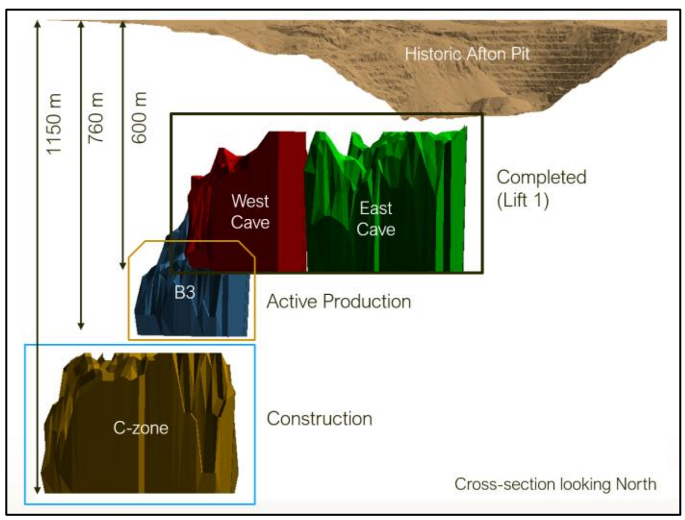

Figure 1. Layout of New Afton Workings.

2. B3 FOOTPRINT CONSTRUCTION

The B3 production footprint has a small and narrow geometry. It is approximately 125 m wide by 225 m long. There is a total of 65 drawbells and 111 drawpoints accessed via 4 extraction drives, as shown in Figure 2. Design production drift dimensions are 4.5 m wide by 4.3 m high for the extraction drives and drawbells.

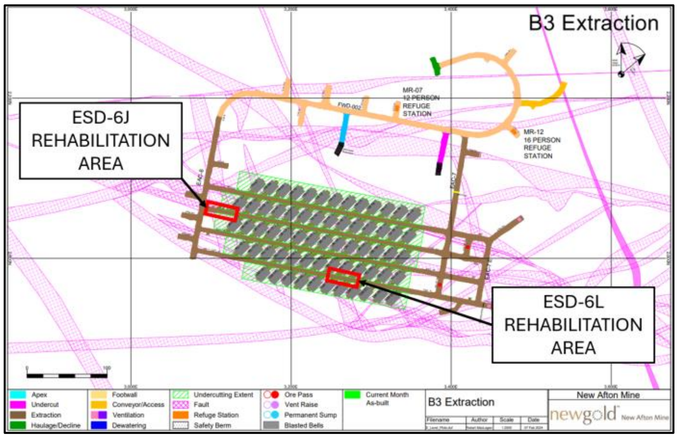

Figure 2. Layout of B3 extraction level with example areas of rehabilitation highlighted.

The principal host rock for the New Afton deposit comprises crystalline and polymictic fragmental volcanics belonging to the Triassic Nicola Formation and lesser monolithic intrusive breccias. These rocks have been altered and mineralized by a monzonite intrusive consisting of a fault controlled elongated stock and related dyke swarm.

From drillcore logging and testing, the rock across B3 footprint has a median RMR value of 68. In comparison, the faults at New Afton mine have a typical RMR value of 43. The faults vary in characteristics but are typically heavily altered and sheared. Both the alteration and the shearing negatively affect rock mass competency and strength. These poorer quality faults are present in both of the example locations presented.

At the B3 footprint the principal in situ stress is oriented north-south, with an approximate magnitude of 30 MPa. During the undercutting process and later stages of cave mining the extraction level footprint is subject to changes in stress. Squeezing and convergence may be observed within drawpoints and extraction drives depending on the local geological conditions, geometry of the footprint, and excavation geometry. At New Afton, the convergence of a tunnel is typically highest at fault zones and other areas of weak or altered rock. Other contributing factors for squeezing can include stress concentrations associated with the cave geometry, overbroken excavations, and draw control.

A robust ground support system was installed during development and construction of the level. This consists of the following:

First Pass During Development:

- 75 to 100 mm thickness, 54mm length fibre, fibre-reinforced shotcrete
- 2 m x 3 m, 6 mm thickness welded wire mesh with 76 mm square openings
- 2.4 m length D-Bolts or MD-bolts at approximately 1.1 m bolt spacing

Second Pass Long-Term Support:

- 6 m or 9 m long 17.8 mm diameter cablebolts at 1.3 by 1.5 m spacing
- Two rows of RS32SS self drilling hollowbar anchors approximately 0.5 m and 1.5 m above the sill
- Three rows of cable slings (also known as pillar wrapping) using 15.2 mm diameter cablebolts

Additionally, floors are poured with concrete within the extraction level. This helps provide some resistance to floor heave, reduces slimes generation from tramming, and helps to maximize equipment utilization and efficiency. A final spray of 30-50mm of fibre-reinforced shotcrete, referred to as a spray to cover, is applied from sill to 3 m height to armour the underlaying ground support from equipment impact and to also assist with surficial support pressure. An example of a fully supported B3 extraction level drawpoint is presented in Figure 3, without the shotcrete spray to cover on the walls.

Figure 3. An example of ground support in the B3 extraction level, short and long support are installed including pillar wrapping. A drawpoint steelset is standing ready to be sprayed in with shotcrete.

3. CONVERGENCE MONITORING STRATEGY

The three main components of convergence monitoring for the B3 footprint are visual monitoring, convergence scanning, and MPBX data interpretation. There are a variety of strengths and weaknesses in terms of spatial coverage, data resolution, and continuity of readings with each of these monitoring techniques, but together they form a robust system. The following paragraphs provide a brief explanation of each of these monitoring activities.

Weekly geotechnical inspections are carried out on the B3 extraction level. Photographs, notes, and observing the level in person help reconcile and understand what the data from other monitoring systems are showing. Damage mapping is completed where visible features such as cracking are tracked and updated if there are changes between inspections, noting the length and aperture of cracks, any bulging or movement, and any other signs of damage. Each new observation is tracked chronologically to record the history of damage progression and rehabilitation activities completed in a given area.

The geotechnical team also uses a high-precision handheld Geoslam LiDAR scanner to monitor convergence. Scans are taken of the individual extraction drives and compared to scans of the same area at a prior date. Scans are visualized through Maptek's Point Studio software and referenced and aligned back to a previous scan. This can be the most recent previous scan or could be another archived scan. The choice depends on what the aim of the scan comparison is and if construction activities have impacted the data quality. The accuracy of the scanner is up to 6 mm under ideal conditions. Scans that are compared are typically spaced at several months apart from each other in order to observe multiple centimeters of convergence.

For a proper comparison, the walls, back, and floor need to be in a similar state to the previous scan in order to detect meaningful convergence. For example, if the baseline scan was taken prior to the protective shotcrete layer application or the floor pour, both of these surfaces could show high convergence rates that are related to construction activities and not actual ground movement. Similarly, areas that are eroded by equipment impact on the extraction level can obfuscate indications of convergence from the scanning data. This is where the visual inspections and photographs can assist with interpretation of the data.

Scans are taken on a routine basis, with the frequency of scans tailored to the observed convergence rate. Typically, on the B3 footprint this would involve scans being taken every 1-2 months and at greater frequency as low as two weeks if convergence rates are high (>2 mm per day). The movement within New Afton extraction levels typically starts at a relatively slow pace and then can increase in convergence rate if not addressed in a reasonable time frame (Kamp, 2022).

A total of 54 Multi-Point Borehole Extensometers (MPBXs) were installed in the B3 extraction level. MPBXs measure the strain between evenly spaced nodes along the length of the instrument. For the B3 cave, each MPBX instrument is 8 m long and contains six of these nodes spaced at 1.3 m intervals with a 254 mm potentiometer head. Each MPBX is connected to a Newtrax wireless transmitting node that relays the data to a junction box that relays the information to an online web interface for real-time interpretation. The B3 MPBXs are configured to take readings 8 times per day. They are installed in arrays of three instruments with one in the north wall, one in the back, and one in the south wall, the locations of these arrays are as shown in Figure 4.

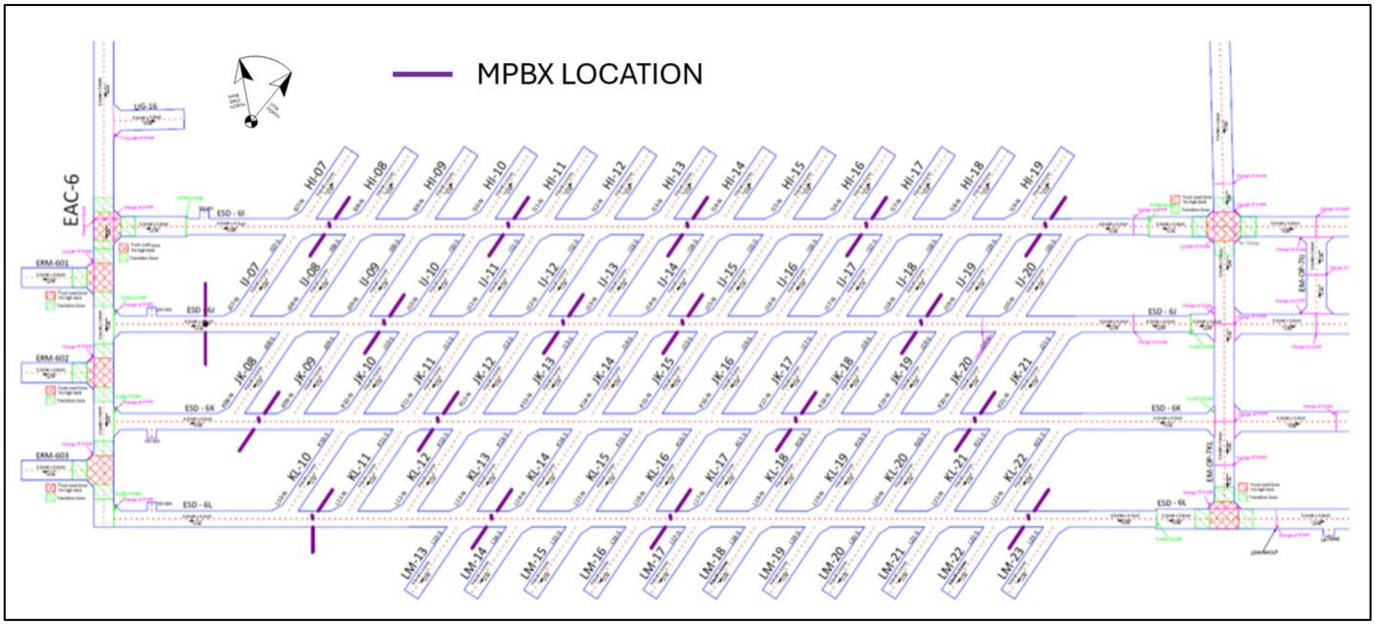

Figure 4. MPBX locations with the B3 Footprint.

4. EXAMPLE #1: ESD-6J ENTRANCE

Extraction drive ESD-6J serves as an access to extract ore from the B3 production footprint into a remuck where it is hauled away by 45 tonne trucks. The entrance area of ESD-6J is situated on the outer edge of the caving footprint, and throughout the stages of the caving process it has experienced varying levels of mining induced stresses.

The location of interest is presented in Figure 5. This is followed by a summary of the convergence monitoring observations and rehabilitation activities at this area.

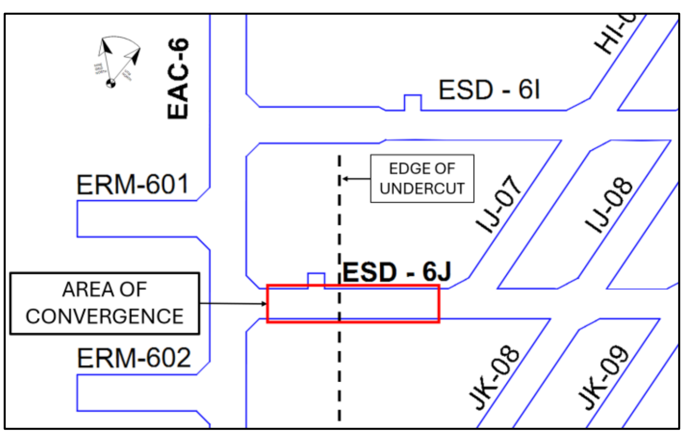

Figure 5. Highlighted location of ESD-6J convergence and subsequent rehabilitation. The approximate edge of the undercut level is indicated.

In October of 2019, ESD-6J was developed. Face mapping confirmed the presence of steeply dipping faults comprised of heterogeneous, highly altered, and highly sheared material. These faults and their orientations are shown in Figure 6. The transition from EAC-6 into ESD-6J had an irregular development profile, with the largest amount of overbreak in the back. In January of 2021 prefabricated rebar cages were secured to the back using 47mm splitsets loaded with #7 forged head resin rebar (known as hybrid bolts). The rebar cages were then sprayed into place to reduce drift size and increase support pressure.

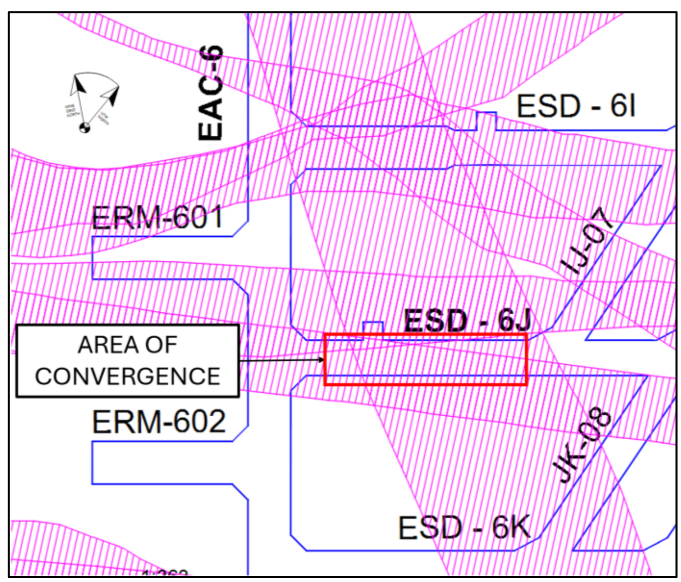

Figure 6. Highlighted location of ESD-6J convergence. Overlaid are fault projections originally obtained from drillhole data and refined with face mapping data. Each hatched area is an individual fault. In the area of convergence two faults run parallel with ESD-6J drive direction and one runs perpendicular to the drive. The combined shearing, alteration, and joint infilling of the three faults has weakened the entrance of the extraction drive more than if only a single fault were present.

To further increase surficial support pressure, a single steel lattice arch from sill to sill was installed in March 2021 using hybrid bolts and a spray to cover. The arch was field fit to the location that would fit the steel as close as possible to the existing walls to limit the amount of shotcrete required for load transfer to the steel. This lattice arch has resisted deformation in the entrance of the drive and is continuing to perform up to and including February 2024, with periodic scaling and respraying of flaking shotcrete due to convergence and equipment impacts.

During April of 2021 the initial undercut slots were blasted above the ESD-6J entrance, reorienting and redistributing stresses at the extraction level below.

The first indications of convergence in ESD-6J towards IJ-07 drawbell were recorded January 2022 based on visual inspections and convergence scanning. Movement was mostly in the back of the drive, with the walls showing minimal convergence through scanning. The northern shoulder of the drive showed some signs of shearing and some movement in the scans. MPBX measurements also supported this. The convergence in the back was measured at 52 mm and the walls at 50 mm.

An electrical cutout in the northern wall was closed in January of 2022 due to convergence beginning to affect the electrical equipment contained within. The cutout was closed with concrete and long support was installed through the cured pour to add stability to the area. In February of 2022 the southern shoulder of ESD-6J entrance was showing damage caused by the convergence and scaled and re-supported with short support and an additional row of long support was installed. 9 m length 17.8 mm diameter cablebolts were selected to embed the cables into deeper, more competent ground prior to further movement.

In March 2022, the decision was made to install 9 m long infill cables to mitigate some of the movement. The additional cables were installed in the back and north shoulder. 9 m cables were again used with the aim of anchoring into more competent ground and providing additional support pressure. The cables were also selected given their relatively minimal impact to production compared to alternative support options.

From March 2022 to May 2022, drift convergence continued with reduced movement in the back. Convergence rates increased in May of 2022, and due to the faulted nature of the ground, it is believed that preferential sliding planes developed, forming a pronounced wedge-like structure in the back as shown in Figure 7.

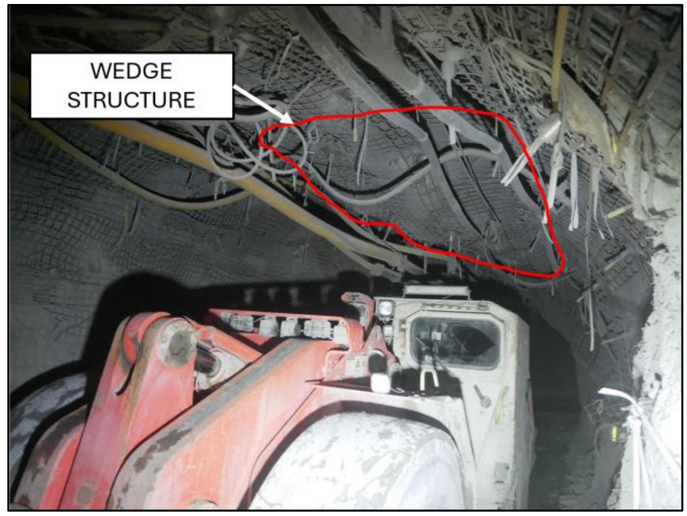

Figure 7. Entrance of ESD-6J Drive looking west towards EAC-6, showing limited vertical access for production equipment – November 2022. "Wedge" structure is highlighted for clarity. The concrete floor at the entrance of ESD-6J drive had been removed already at this point to allow for increased vertical clearance for production equipment.

Over time, distinct trends were apparent in the MPBX data as shown in Figure 8 and Figure 9 and summarized below:

- The nearest instruments in the north and south walls both showed a typical pattern of progressive, stress-driven bulking near the skin of the drift profile with relatively low depth of yield (<2.7 m) and low, steady rates of deformation (<1 mm per day).
- The nearest instrument in the back showed deeper seated yield up to 6.7 m depth and irregular movement rates of up to 1 to 2 mm per day.
- The nearest instrument in the back was damaged due to ground movement in May 2022.

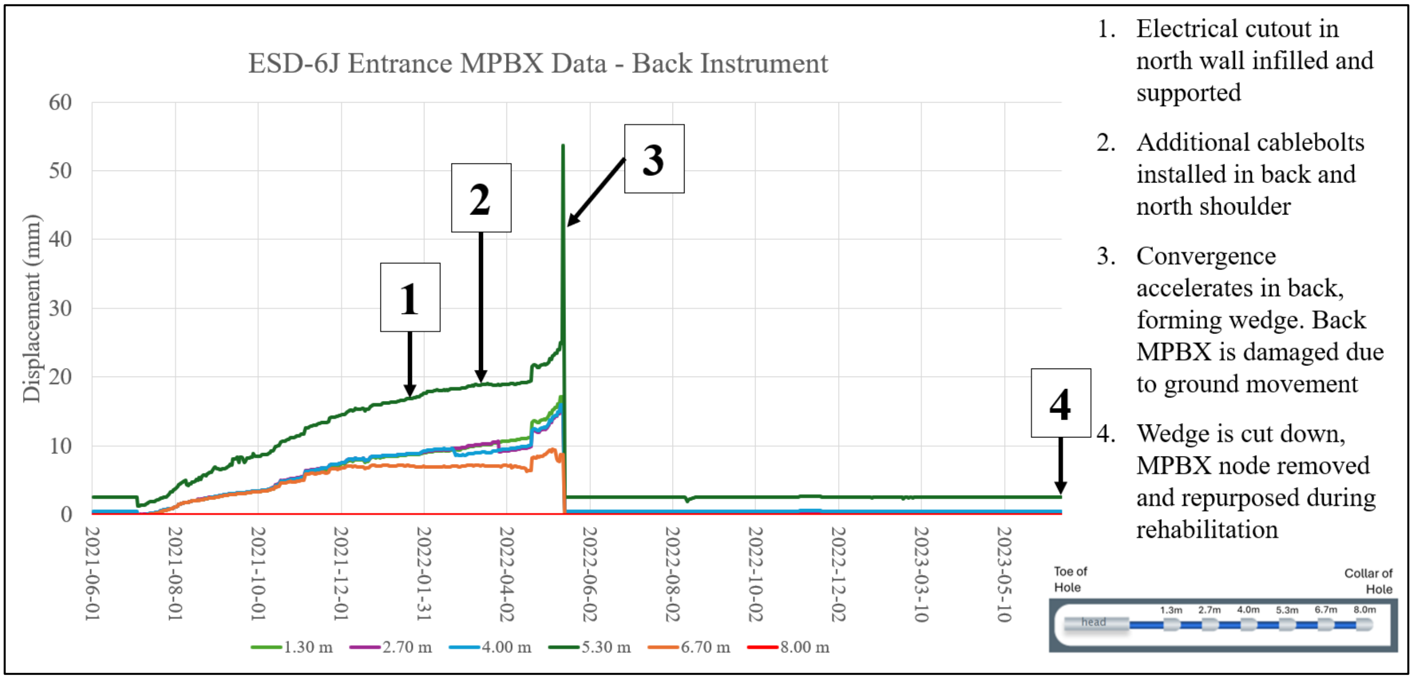

Figure 8. MPBX data from back instrument located closest to convergence area in ESD-6J. Reference image of MPBX positioning from Mine Design Technologies, 2018.

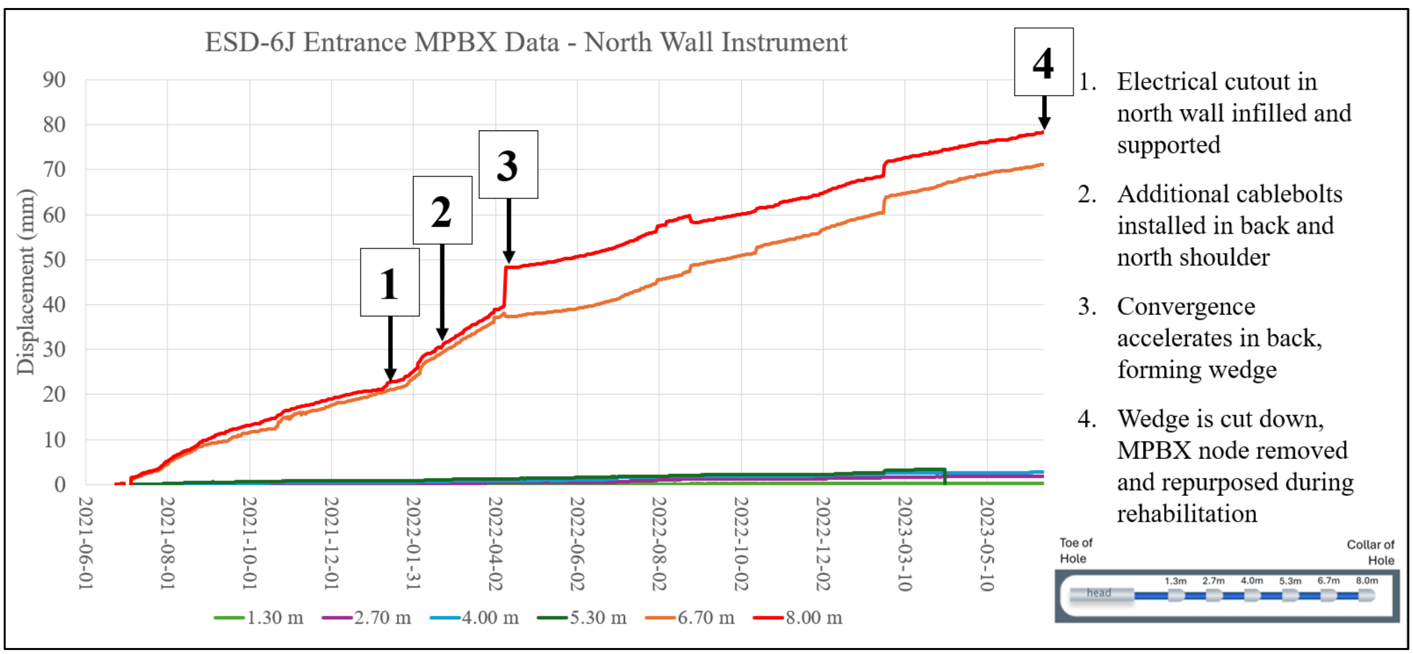

Figure 9. MPBX data from northern wall instrument located closest to convergence area in ESD-6J. Reference image of MPBX positioning from Mine Design Technologies, 2018.

The floor began to heave during March 2022, with movement concentrated in the center of the drift, heaving to a vertical displacement of approximately 25-30 cm by October 2022. In October 2022 the concrete floor in ESD-6J was removed from the entrance of the extraction drive up to the first drawpoint J07-N. Even with the floor removed, vertical clearance remained tight for production equipment, but allowed the production team continued access to the drive while a plan was developed to scale, reprofile, and re-support the back of the drift. Repouring the concrete flooring would not be convenient until more vertical equipment clearance was available. Cutting the floor down and repouring was not attractive as this would have created a depression in the floor that would collect drainage due to the grading of the drive.

Scaling and re-supporting of the back wedge was completed July 2023. The rehabilitation targeted only the wedge that had formed and leaving any areas that were intact and supported alone. This wedge was approximately 10-12 meters in length with the drive and spanned most of the width across the approximately 4 m wide drive. Approximately one meter of vertical height was gained through the scaling process, with the rehabilitation crew aiming to keep a smooth and arched profile in the back through the scaling and re-supporting process. Smaller wall sections that had been damaged through convergence and subsequent equipment damage from the tighter confines were scaled and re-supported as well. The floor was repoured, and production access was restored to the drive.

As of this writing, the entrance of ESD-6J still remains open and the production equipment has ample room for access. Routine monitoring is conducted in the entrance of the drive, with low convergence rates observed in small sections at less than 1 mm/day. The abutment stress from the cave is thought to have progressed outwards beyond this section of ESD-6J over time, reducing the amount of convergence observed. The current ground support in the area appears to have stabilized the excavation under this reduced stress load.

Key learnings from the events described are as follows:

- Face mapping and visual monitoring provided useful information in terms of understanding the fault characteristics and spatially defining where convergence was concentrated. Convergence scanning helped to confirm the relative rates of deformation and to spatially define areas for rehabilitation.
- The MPBX data provided valuable information regarding the depth of yield in the excavation back. This helped to inform the appropriate length of ground support to install during rehabilitation activities.
- The integration of all available monitoring data helped to make well informed decisions with respect to rehabilitation activities.
- Understanding caving induced stresses and the changes in stress at specific caving stages aids in understanding ground movement and ground support reaction to movement

5. EXAMPLE #2: ESD-6L AND DRAWPOINT L18-N

The drawpoint L18-N and the surrounding area are heavily affected by two intersecting faults. Both faults are highly sheared, highly altered, and created extremely poor ground conditions in the extraction level. These faults are distinct from the fault that is located in ESD-6J but create similarly poor ground conditions. Some difficulties were observed during installation of ground support (e.g., collapsing holes) and there were additional difficulties maintaining an even development profile.

MPBX data was not available for the immediate area affected by the convergence in L18-N and ESD-6L from L18-L19 drawbells. There was an adjacent MPBX array installed near L17 (one drawpoint over to the west) that correlated with the relative movement rates observed in the area, but not to the same magnitude. The MPBX data was therefore of limited usefulness for monitoring the convergence. Field inspections and convergence scanning were heavily relied upon for monitoring and rehabilitation planning for this area of ESD-6L.

A map of the rehabilitation completed in the discussed area of ESD-6L extraction drive is presented in Figure 10.

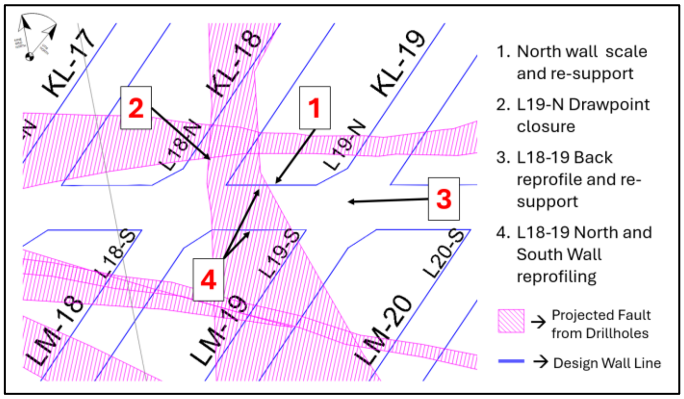

Figure 10. Map of completed rehabilitation in ESD-6L due to convergence. Projected faults from drillhole interpretation are overlaid.

During December 2022 the L18-N drawpoint was hung up for almost the entire month due to oversize material becoming stuck in the drawbell. During hang-ups, material cannot be drawn from a drawpoint until freed, and the muck that normally flows through the drawbell can consolidate and increase loading on the extraction level.

Mine operations made multiple efforts with drill and blast techniques and mechanical rock breaking equipment to dislodge the oversized material, but the drawbell had issues keeping material flowing due to the coarse fragmentation. Cave loading from the consolidated muck pile began to concentrate in the adjacent drawpoint brow and pillars. Damage became visible in late December 2022 and into January 2023. From this initial weakening and mobilization of already poor ground, the movement continued over a period of several months at a rate of 1-2 mm per day until rehabilitation efforts were required in September 2023. A portion of this time of movement can be seen in Figure 11.

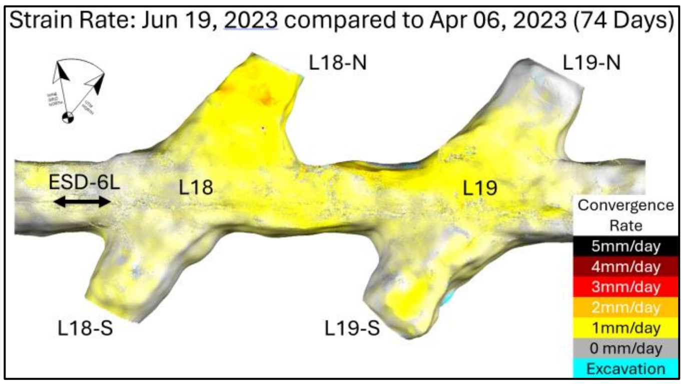

Figure 11: Example ESD-6L convergence scan showing April to June 2023 strain rates.

In September of 2023 a reprofiling of the north wall of the strike drive between L18 and L19 drawpoints was completed. The wall had deteriorated to the point where shotcrete was slabbing off the wall and visible shoulder shearing was occurring. The wall was reprofiled, with new short and long support installed. Ground movement continued after this rehabilitation, extending into the surrounding back and opposite south wall of the extraction drive.

L18-N drawpoint continued to see damage, reaching strain rates of 4-5 mm per day. Severe damage in the walls and brow of the drawpoint was observed as shown in Figure 12. During October 2023, the L18-N drawpoint was stuffed with oversize material and sprayed closed with fibre-reinforced shotcrete. 47mm Splitsets loaded with #7 forged head resin rebar (known as hybrid bolts) and OSRO straps were installed to add support pressure. Drain holes were drilled through the shotcrete to eliminate any potential fluid pressure buildup.

Figure 12. L18-N drawpoint in October 2023 prior to being closed. Ground movement and resultant damage can be seen in both walls and the back, with the right wall encroaching on the drawpoint opening.

In November 2023, the L19 intersection and the surrounding area required reprofiling and re-supporting of the back. The continued stress on the area heavily affected the already hummocky back profile, damaging and breaking up both the shotcrete and rock behind. A decision was made to scale, reprofile, and re-support the area. This involved scaling out the damaged shotcrete and rock from almost the entire back of the intersection and into a portion of the adjacent drawpoint entrances. Short support included new fibrecrete and hybrid bolts, and 9 m length cablebolts were used for long support. Continued production from adjacent drawpoints was maintained during the rehabilitation but two-way traffic in ESD-6L drive was not possible. A before and after rehabilitation comparison is shown in Figure 13, with the bulked and hummocky back removed and reshaped to a smoother arched back profile.

Figure 13. Pre and post rehabilitation comparison of L19 intersection rehabilitation. Both photos looking east towards EAC-7.

Reprofiling of the southern and northern walls of ESD-6L between L18 and L19 drawpoints was completed in February 2024. The cumulative convergence of the drive was creating tights for production equipment through this section of the drive. A larger cut of rock was removed from the southern wall of ESD-6L in order to minimize exposure of the poorer ground in the north wall that had already been rehabilitated prior.

As part of the rehabilitation of the southern wall a novel technique for New Afton is being trialled using plastic spacers to embed an additional layer of welded wire mesh nearer to the inside skin of the sprayed fibrecrete cover. The objective is to reduce cracking and slabbing of the spray to cover by increasing its flexural toughness with increased embedded reinforcement per findings from Raffaldi et al (2018). An image of the spacers holding the additional reinforcement screen in place prior to spraying is shown in Figure 14.

Figure 14. Plastic spacers used to hold a sheet of mesh in place to be sprayed over.

Key learnings from the events described are as follows:

- Face mapping of the area during development aided in understanding of the ground characteristics, particularly the quality and location of the faults and fault affected areas.
- Frequent convergence scans were used to monitor convergence rates and define the spatial extents to target for rehabilitation.
- Even with rehabilitation and fresh ground support, areas can still continue to move if poor ground conditions and uneven cave loading conditions exist, and if historical movement has further weakened the rock mass.
- Removing hung up material to manage cave loading through draw control should be treated as a priority. Ensuring even, continuous production across the caving footprint mitigates uneven cave loading.
- Completing rehabilitation in manageable sections can be an effective strategy if planned and timed correctly, in this case separating back reprofiling, wall reprofiling, and drawpoint closure into separate actions.

6. CONCLUSION

A summary of the strengths and weaknesses of the individual convergence monitoring systems used in New Afton's B3 extraction level can be found in Table 1. Together, these convergence monitoring practices have helped to facilitate safe and efficient production from the B3 extraction level at New Afton. Rehabilitation planning is best informed when a combination of visual monitoring, convergence scanning and MPBX data are available. Visual monitoring provides the geotechnical team insight into the manner of ground deformation occurring in the extraction level. The use of multipoint borehole extensometers and handheld LiDAR scanning for convergence mapping aid in understanding the depth and extent of ground failure to be able to properly assess the correct timing and method of rehabilitation work. Convergence monitoring will continue for the life of the B3 cave and other mine workings in order to maximize both safety and productivity. In addition, insights gained from convergence monitoring can be useful for planning potential improvements to ground support standards currently used.

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Table 1. Strengths and weaknesses of extraction level monitoring methods used at New Afton Mine

MONITORING TECHNIQUE	STRENGTHS	WEAKNESSES
VISUAL INSPECTIONS	Can be completed as frequently as necessary (and routinely). Provides better understanding of smaller details of damage. High quality photos allow for effective communication of rehabilitation plans to operations personnel.	Relies on the experience of the inspector to determine what is/is not important. Typically, can only identify convergence larger than 20 mm, once ground support has already been damaged (e.g. shotcrete bulging or cracking, bolt plates flaring out under load). Time consuming to perform an inspection of an entire extraction level.
CONVERGENCE SCANNING	Relatively easy to obtain point clouds (less than 15 minutes in an extraction drive). Shows physical extents of movement to determine boundaries for rehabilitation. Can view magnitude of movement and movement rates from scans.	Time consuming to process and analyze scans (more than an hour for large scans). High initial cost for scanning unit and software Movement detection is limited to accuracy of scanner, typically need a few centimeters of movement before detection. With the limited accuracy, scans are more infrequent, and therefore snapshots in time are analyzed rather than a continuous picture.
MULTI-POINT BOREHOLE EXTENSOMETERS (MPBX)	Continuous, real-time data that can be measured in millimeters of deformation. Shows depth of failure to better understand ground movement and ground support assessment installed within the rockmass.	Effective area of monitoring is small, requires a high number of instruments for a large area. Requires initial setup of instrument and infrastructure, not easy to install on an ad hoc basis. Each additional instrument is an additional cost. Can be fragile, in high movement areas instruments have a limited useful life and also are prone to equipment damage.