Mining Geomechanical Risk 2019 – J Wesseloo (ed.)

doi:10.36487/ACG_rep/1905_31_Woods

Managing decline deformation in an active sublevel caving operation

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Abstract

Telfer Gold Mine is located in the Great Sandy Desert and consists of both open pit and underground operations, including a mature sublevel cave (SLC). Changes to SLC design, with the addition of several sublevels, have resulted in an increased cave influence zone, with particular impact on the 4650 to 4600 Decline. This increased cave influence was identified during the planning stage risk assessment for the additional sublevels and a monitoring plan with associated trigger action response plans (TARPs) were included in the cave major hazard management plan (CMHMP).

Once TARPs were triggered, ground support upgrades and a planned bypass were initiated for a section of the main decline. High underground temperatures and difficult work conditions resulted in the bypass activity being delayed until temperatures subsided. Due to the delays with bypass development and ongoing progression of deformation at a faster-than-expected rate, access through the original section of decline needed to be maintained for a greater length of time and with higher-than-expected deformation rates.

Both a tactical ground support upgrade and a risk management plan based around monitoring data were used to maintain safe access through the main decline until the bypass was complete. Monitoring data showed a clear cause and effect between SLC production and deformation, allowing SLC production holds to be used as a key control.

Keywords*: risk management, deformation, monitoring, mine planning*

1 Introduction

The Telfer Gold Mine (Telfer), owned by Newcrest Mining Limited, is located in the Great Sandy Desert 400 km east-southeast of Port Hedland, and approximately 1,300 km northeast of Perth. The Telfer deposit was discovered in 1971, when anomalous gold and copper values were returned from outcrops in what is now known as Main Dome. In late 2000, the operation was put into care and maintenance after producing approximately 6 Moz of gold. A feasibility study was undertaken in 2002 that established the strategy for mining and processing ore from the surface and underground deposits. This led to the re-establishment of open pit mining operations in 2004 and underground operations in 2006.

Telfer is currently producing from the Main Dome and West Dome open pits and the underground operations, which consist of a sublevel cave (SLC), narrow vein long-hole open-stoping and long-hole retreat stoping. The SLC was initiated in late 2006 at the 4650 Level, 850 m below surface. The cave broke through into the Main Dome open pit in late 2009. The footprint of the cave is approximately 1,000 × 250 m, with the SLC extraction levels down to 1,085 m below surface.

The open pit is currently mining at rates in the order of 50 Mtpa (million tonnes per annum) of ore and waste, while the underground is hoisting in the order of 4 Mtpa. The ore sources combine to feed a mill that treats approximately 24 Mtpa.

2 Mine geology

Telfer's geology is divided into two main geological domes, namely the West Dome and Main Dome, with underground mining operations occurring in the Main Dome.

The current underground operation is constrained within the Malu Formation, which is a massive sandstone and quartzite unit with thinly interbedded pelitic strata. The Malu Formation is divided into three major members; the upper (UMM), middle (MMM), and lower (LMM) members (Figure 1), that have undergone moderate to intense sericite and silica metasomatism.

Monoclinal folding and associated thrust faulting overprint early Telfer Dome folding events. The west over east thrusting events opened bedding resulting in zones of stockwork veining and brecciation. The stockwork associated with the thrust structure cuts across stratigraphy.

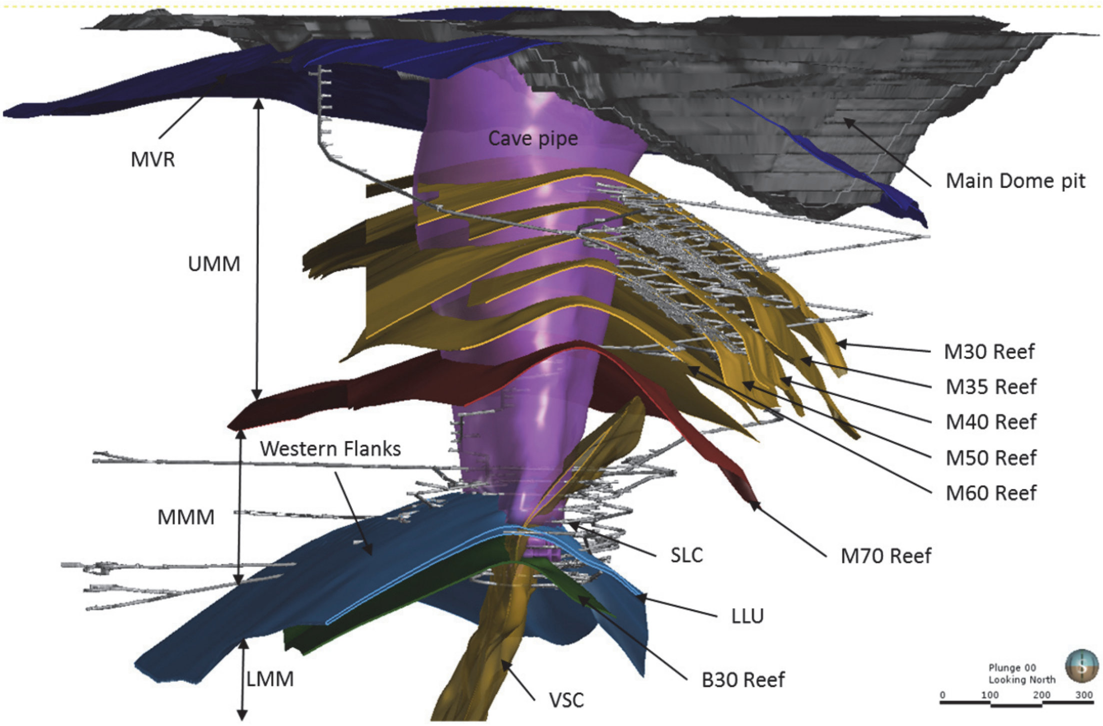


Figure 1 Overview of geological units at Telfer, looking north

A large regional fault zone, the Graben Fault, exists on the eastern flank of the main orebody, which is intersected by mine development. The fault extends the local weathering conditions to depth and is considered the least competent geotechnical domain.

2.1 Rock mass characterisation

The regional faulting, folding and subsequent thrusting has resulted in slip between sedimentary layers. The slip has caused brecciation of the weaker siltstones, facilitating the formation of both reef and shear units throughout the entire mine stratigraphical sequence. This has resulted in frequent and pervasive jointing, decreasing the overall rock mass strength and making it amenable to caving.

The intact rock strength is generally very high (greater than 200 MPa), with the exception being the major ore units (around 80 MPa), with a generally fair quality rock mass, with rock mass rating values between 50 and 60.

The major principal stress has been measured to strike roughly northwest–southeast, dipping around 20° to the southeast.

3 Mine design

The feasibility study for underground mining was completed at the end of 2002, with the mine layout based on that used at Ridgeway, with cave propagation in an east-to-west direction. Following a review of the layout in 2004, the cave advance was changed to west to east, to promote cave initiation and propagation.

The SLC is based on a transverse layout, with crosscut centres spaced at 14 m (9 m pillars and 5 m wide crosscuts) and sublevels spaced at 25 m. The slot drive is on the western flank of the orebody, with production retreating in a centralised v-shape towards the eastern flank, where perimeter drives and ore passes are located (Figure 2). The crusher and shaft is located on the western side of the SLC, with haulage drives passing under the SLC.

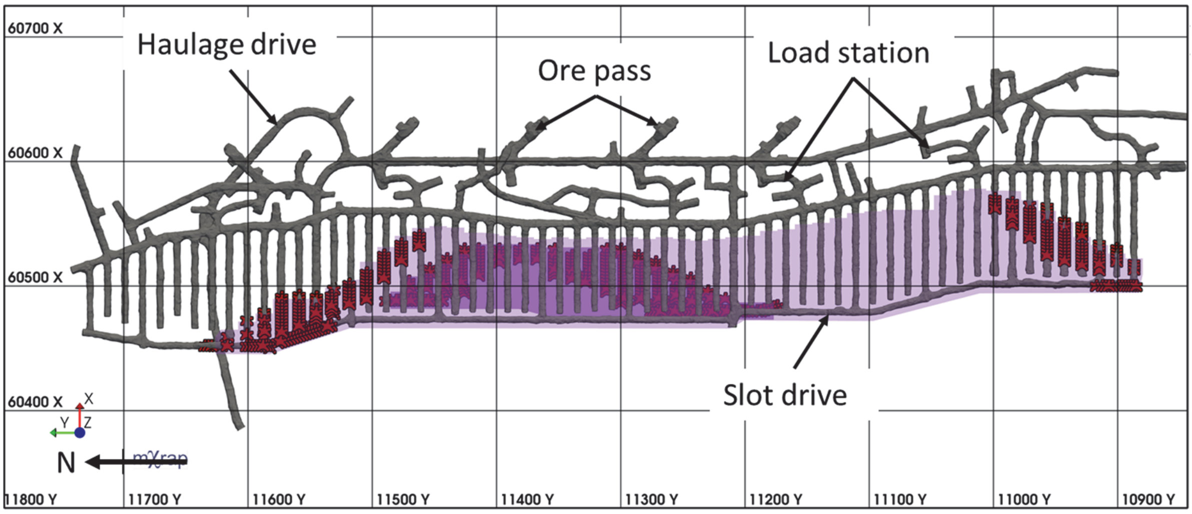


Figure 2 Plan view of SLC 4475 and 4440 Level layout and v-shape production front

Caving was initiated at the 4650 Level and planned to progress seven sublevels to the 4500 Level (Figure 3), with the truck haulage drive and orepass infrastructure located on the eastern side at the 4470 Level.

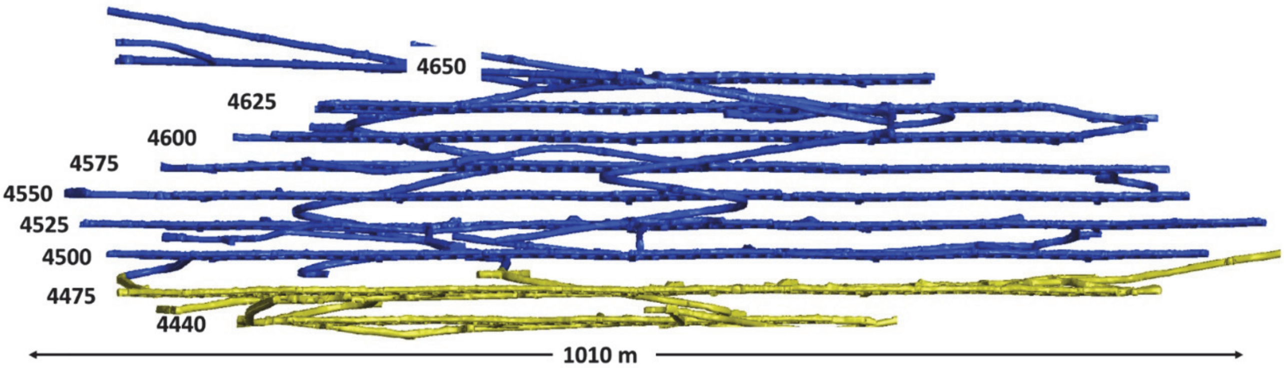


Figure 3 Feasibility study mine plan in blue, with additional sublevels added after 2013 in yellow, looking east

3.1 Mine history

The 4650 Level had a footprint of 315 × 185 m, with levels progressively increasing in size and stepping out to the north and south, as far as the 4525 Level (1,010 × 165 m). Below the 4525 Level the footprint began to reduce in north–south extent.

Di Giovinazzo and Singh (2010) indicated that caving initiated at a hydraulic radius (HR) greater than 25 m based on monitoring data. Monitoring holes were no longer accessible after this point to confirm the HR at which caving initiated, however, localised instability in the backs was recorded. Cave breakthrough to surface occurred in 2009. Following breakthrough, the concentration of seismic activity related to cave growth has been located predominantly in the northeast and southwest of the SLC, in the areas of maximum stress concentration.

3.2 Change to mine design

Between 2013 and 2016, two additional sublevels were added below the original feasibility design. In 2013, a planning study and risk assessment was undertaken to include the 4475 Level in the long-term mine plan. The risk assessment identified that deepening of the original SLC footprint would result in a subsequent increase in the cave influence zone, with the potential to impact existing mine infrastructure.

In 2016, the 4440 Level was included in the mine plan, located in the north and central part of the SLC footprint, extending the SLC 60 m below the feasibility design.

A third level, the 4410 Level was initially included in the mine plan extension however was later removed from the plan due to technical and economic factors.

4 Cave interaction management

The risk assessment for mining the 4475 Level identified that the cave zone of influence would increase with the additional level, with development on the eastern abutment particularly impacted. At the risk assessment stage a rule-of-thumb cave influence zone of 70° from horizontal was used to identify areas of development at risk (Figure 4).

Areas of critical infrastructure plotting within or close to the projection were given a residual risk rating based on existing controls. Recommended actions to better identify the cave influence zone through non-linear modelling, interpretation of seismic data and monitoring were recommended, with the eventual requirement to bypass areas.

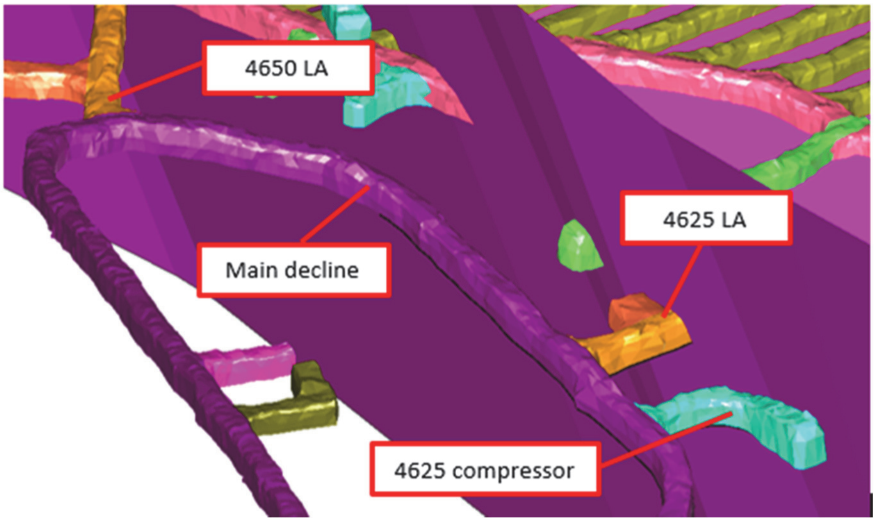


Figure 4 70° cave influence zone projection from the 4475 risk assessment highlighting potential interaction with the main decline around the 4650 to 4625 Levels

4.1 Cave monitoring and management

Based on the findings from the 4475 Level risk assessment and results of non-linear numerical modelling, a monitoring plan was developed for cave interaction with critical infrastructure which was included in the cave major hazard management plan (CMHMP) with an associated trigger action response plan (TARP). The monitoring plan included a series of 35 m long multi point borehole extensometers (MPBXs), light detection and range (LiDAR) scanning and damage mapping of the targeted areas.

4.2 Main decline 4650 to 4600 interaction

The focus of this study is on the area of eastern decline known as the 4650 to 4600 Levels, a 300 m long section running parallel to the cave, approximately 35 m to the east. It is situated in a structurally complex setting near the confluence of the monocline, A Reefs and vertical stockwork (VSC) structures (Figure 5).

The 4650 to 4600 Decline has experienced significant stress change over the excavation history. The 4650 was the initial SLC undercut level with the area experiencing elevated sub-horizontal stress as caving initiated. As the 4625 Level progressed north, the 4650 to 4600 Decline was located in the high stress northeast abutment, before additional sublevels extended deeper and further north shielding the decline.

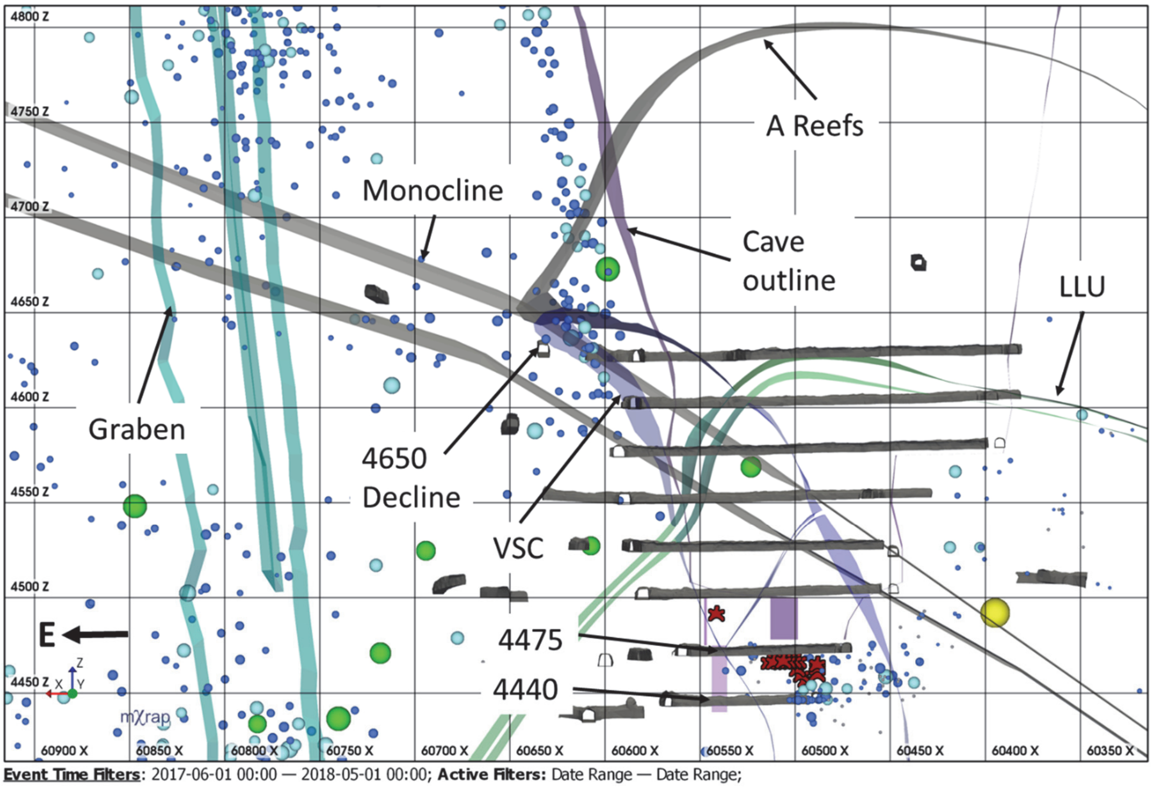


Figure 5 Section through the 4650 Decline area showing the confluence of structures

4.3 Trigger for decline bypass

The requirement for a bypass of the 4650-4600 Decline section was initially flagged in 2016 during the study phase for the SLC extension below the 4500 Level. At the time it was expected that a bypass would be required prior to mining the lowest planned extension level; the 4410 Level.

Monitoring remained ongoing during cave production and in mid-2017 one of the MPBX within the 4650 to 4600 Decline breached the TARP major trigger (Figure 6). The associated TARP response was to rehabilitate the area and commence designing a decline bypass, which was to commence development at breach of the critical trigger. The bulk of SLC production at that stage was coming from the 4500, 4475 and 4440 Levels, with development of the 4410 Level suspended, as mentioned in Section 3.2.

With damage manifesting faster-than-expected, a 540 m long decline bypass was designed before the critical trigger was reached and commenced in November 2017 (Figure 7). Development throughout November to March was significantly hampered due to excessive heat and humidity issues, a challenge frequently encountered for lateral development at Telfer during the summer months. To ensure timely completion of the bypass post-summer, a rapid development plan was implemented which realised lateral development rates of up to 188 m per month, with over 100 m from a single heading alone. Decline bypass breakthrough was achieved in mid-June 2018, with the entire bypass project being completed free of injury and incident.

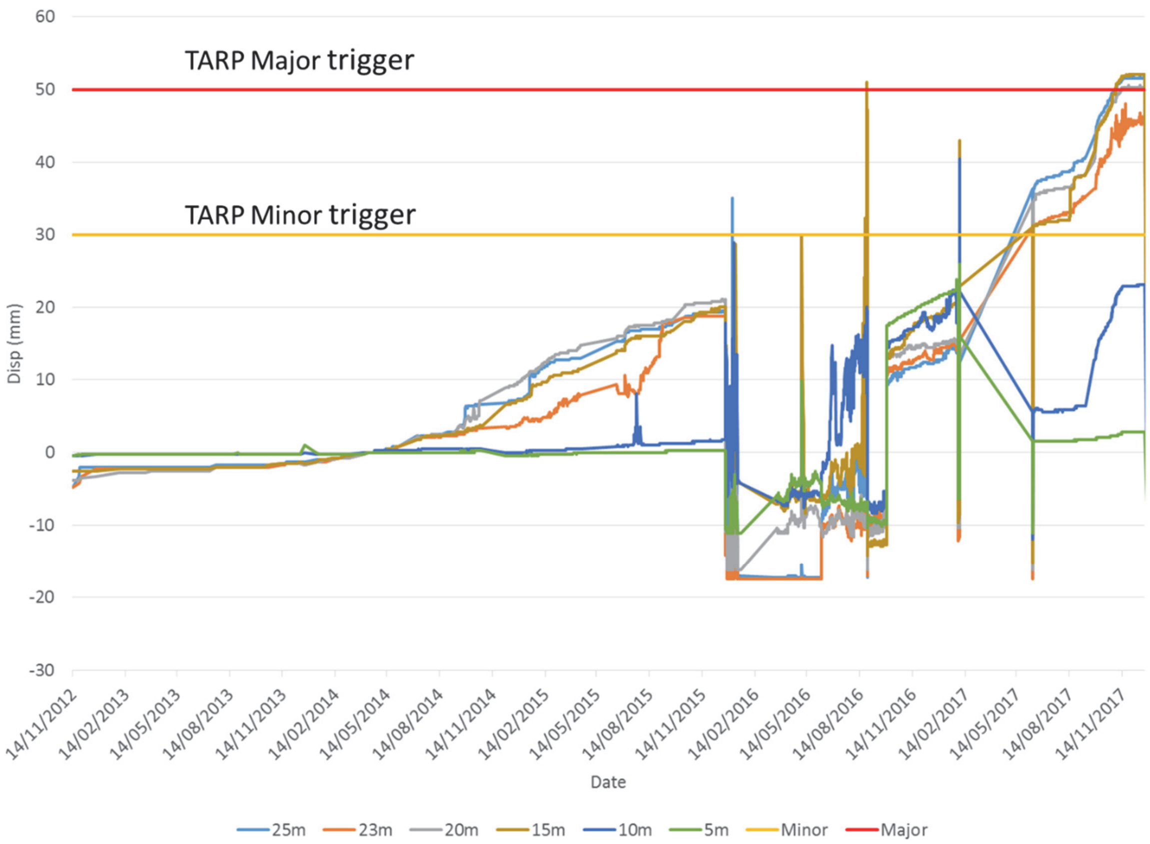


Figure 6 MPBX data from the 4650 Decline area with cave major hazard management plan (CMHMP) and TARP triggers used to implement support upgraded and bypass

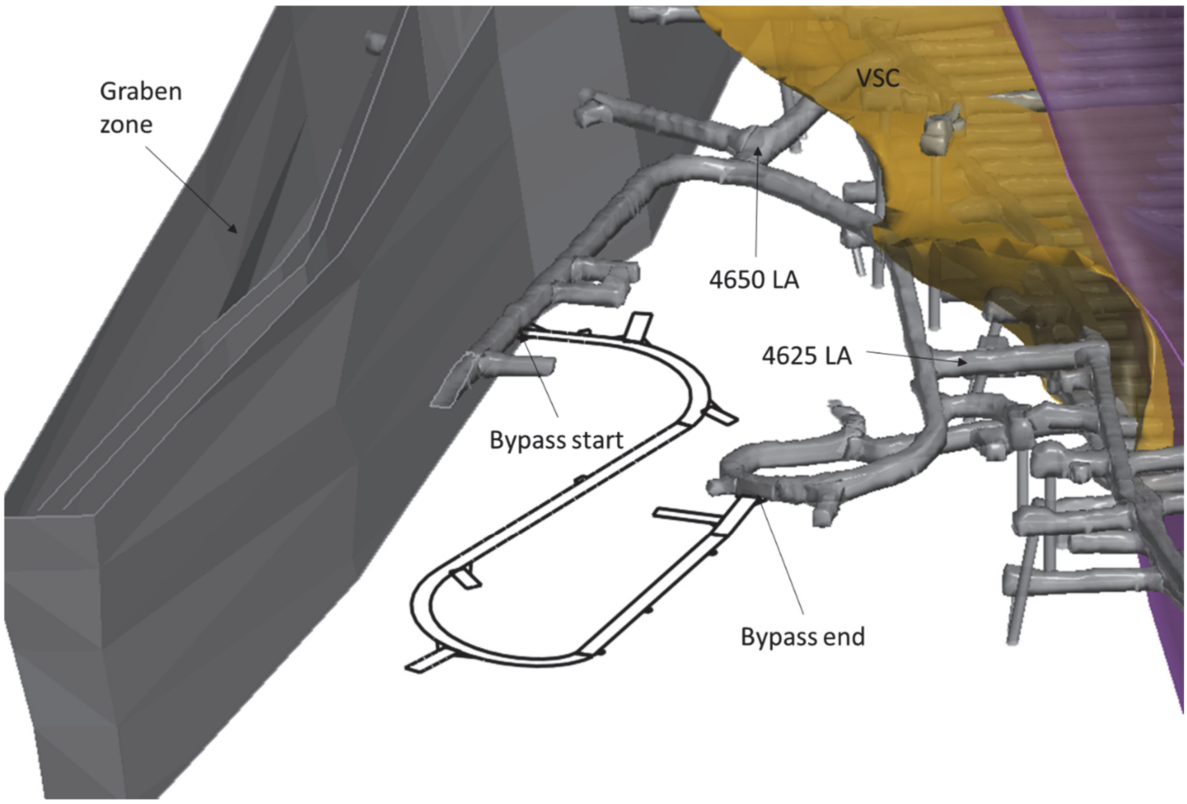


Figure 7 Decline bypass excluding the section of decline nearest the cave and VSC, A Reef and monocline contacts

5 Damage and ground support

5.1 Damage mechanisms

As the additional sublevels were mined, the increased cave influence zone and rock mass strain resulted in buckling of the bedded strata around the decline due to floor to back convergence, dilation and shearing of structures resulting in the clamping and rupturing of support elements. This is typical of the damage mechanisms described by Beck and Sandy (2003).

Floor to back convergence was evident with mesh doubling up on itself as shearing occurred (Figure 8), however, the backs of the drive generally showed minimal signs of deformation or ground support loading. This suggested that backs movement recorded by LiDAR scanning (Figure 9) occurred as walls sheared past each other and the lower side walls kicking out, rather than bulking of the backs. There was also potential for global deformation of the drive towards the cave, which could not be monitored with the SMART cables and LiDAR scans.

Figure 8 Damage within the decline showing shearing of the side walls, bulking between reinforcement elements and mesh folding over on itself

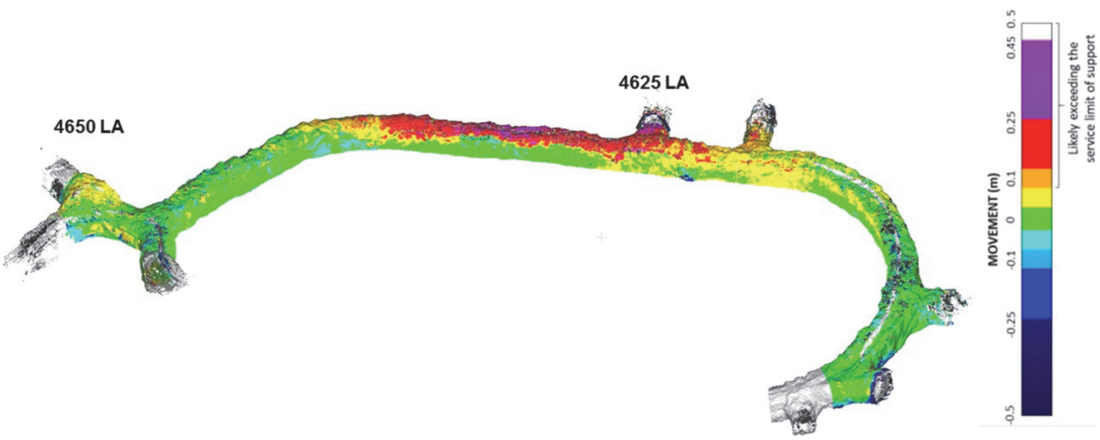
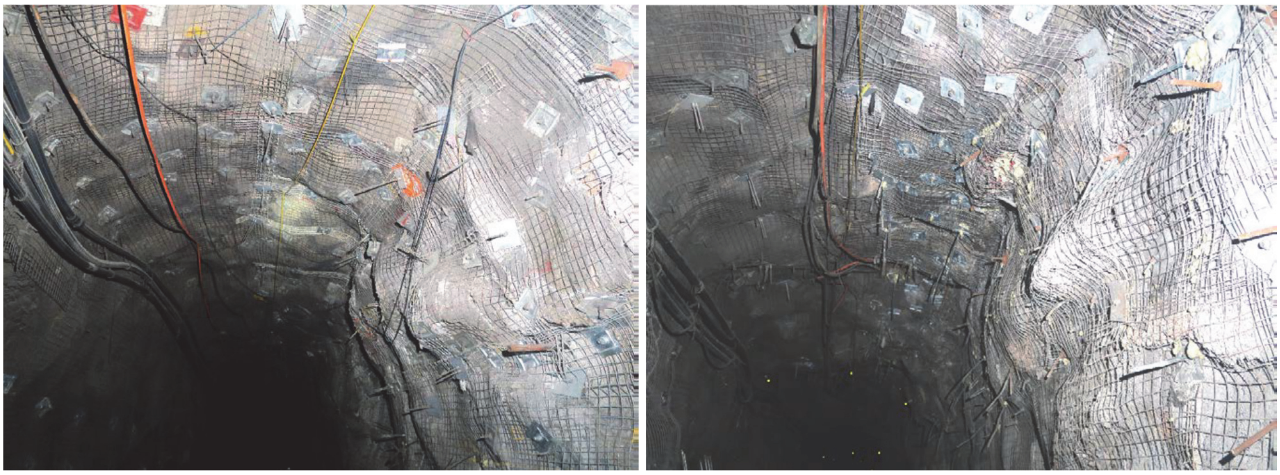


Figure 9 4650-4600 LiDAR scan comparing January 2018 to April 2018 looking east

As noted earlier, deformation occurred at a faster rate than anticipated, with bulking particularly evident between reinforcement elements. Figure 10 shows the change in conditions over a three-month period.



(a) (b)

Figure 10 Increase in deformation and buckling of side walls due to floor-to-backs convergence in (a) March 2018; (b) June 2018

5.2 Ground support upgrade strategy

Ground support upgrades were required to maintain a serviceable decline until the bypass development could be completed. The upgrade strategies focussed on creating a deformable shell that would retain the bulking ground by increasing the surface support capacity, length of support elements and extending support to the floor. The support upgrade utilised the existing fibre reinforced shotcrete (FRS), so new FRS was not required.

The support upgrade program commenced using a combination of either strengthened overlap mesh or Osro straps with 6 m cable bolts and 2.4 m Mechanical Dynamic® (MD) bolts. Due to difficulty keeping cable bolt holes open for installation, the decision was made to use 6 m self-drilling anchors with cement grout in the side walls and 6 m cable bolts in the backs where the depth of damage was less, allowing for installation (Figure 11). During upgrade depth of damage up to 2 m was recorded in the drive side walls.

Figure 11 Decline upgrade with strengthened overlap mesh to floor, 2.4 m MD bolts and self-drilling anchors waiting to be plated

6 Monitoring

6.1 Monitoring

An additional monitoring plan was developed and implemented as part of the risk management process to maintain decline access until the bypass could be completed. The monitoring and management plan included SMART cables, increased frequency LiDAR scanning, visual inspections, and analysis of seismic activity rate and magnitude to complement the existing MPBXs.

6.1.1 SMART cables

A series of 6 m SMART cables were installed in intersections and the backs of the decline through the 4650 to 4600 Decline.

A number of the SMART cables within intersections showed a displacement trend related to SLC production (Figure 12). The increased rate of deformation is exhibited following restart of the 4440 N production area and reduction in deformation during an underground production hold for material handling maintenance. This is a trend also displayed in seismic monitoring.

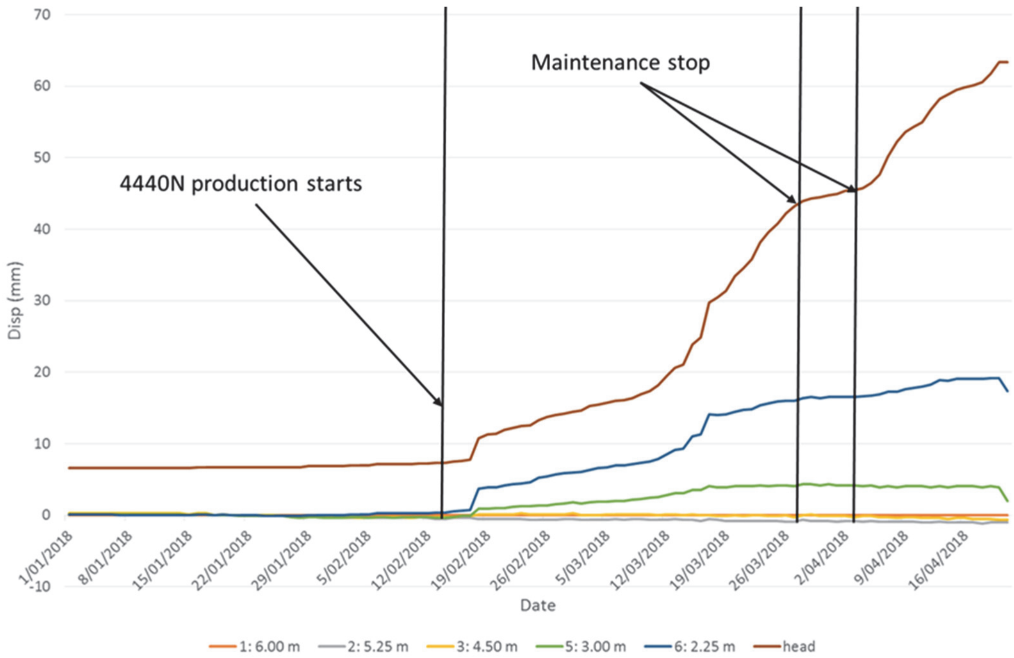


Figure 12 4620 intersection SMART cable plotting displacement, also showing a strong correlation with production

6.1.2 LiDAR

Weekly LiDAR scans were undertaken to supplement single point monitoring data and quantify deformation. The LiDAR data was processed offsite and therefore, had a minimum one-week processing and reporting timeframe. As the LiDAR data is not georeferenced, results were analysed with respect to SMART cable data and visual observations.

6.1.3 Visual observations

Visual observations and damage mapping were regularly undertaken based on the Kaiser support damage scale (Kaiser et al. 1992).

6.2 Production and seismic activity rate

As discussed in Woods et al. (2018), there is a clear link between SLC production and cave growth activity and seismic activity rate. Therefore, seismic activity rate around the 4650 to 4620 Decline area was used as a proxy for rock mass damage and deformation in the decline.

This link, that was further reinforced during the March 2018 underground maintenance shutdown, (Figure 13), enabled management to use draw control as an effective risk management strategy.

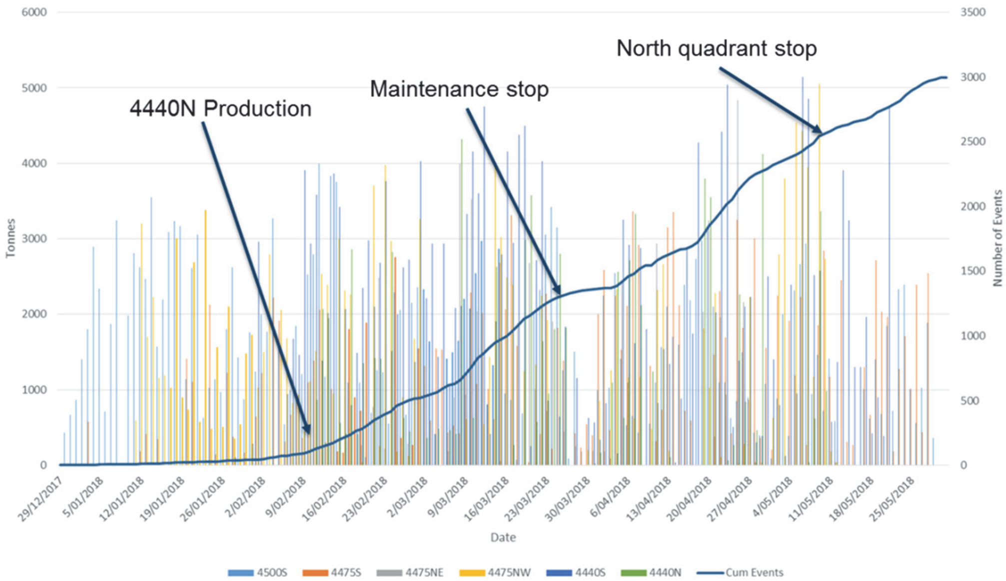


Figure 13 Plotting the 4440 S production suggested that draw from the central section of the SLC also affected the 4650 Decline

It was orginally theorised that the northern production areas, 4475 N and 4440 N, were the major drivers for seismic activity rate and deformation around the 4650 to 4600 Decline and that the 4500 S, 4475 S and 4440 S production areas had minimal effect (Figure 14). In May 2018 the northern production areas were halted to reduce deformation, however, deformation and seismicity did not decrease as expected (Figures 12 and 13).

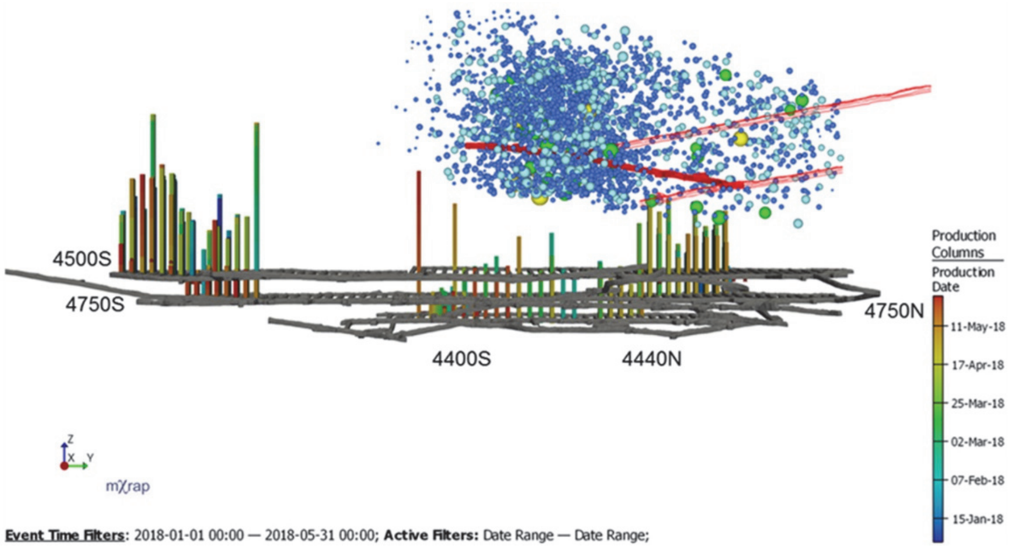


Figure 14 Location of SLC production between January 2018 and May 2018, 4650 Decline area (red) and volume filter of events around the decline are, looking west

Plotting cumulative seismic events against production for each mining area enabled the influence of cave draw in each production area to be correlated to seismic activity rate (Figure 13). Based on this information, production in the 4440 S was also suspended. This was potentailly caused by the interaction of the VSC contact with the SLC 4440 N and S production front and confluence of structures around the 4650 to 4600 Decline (Figure 15).

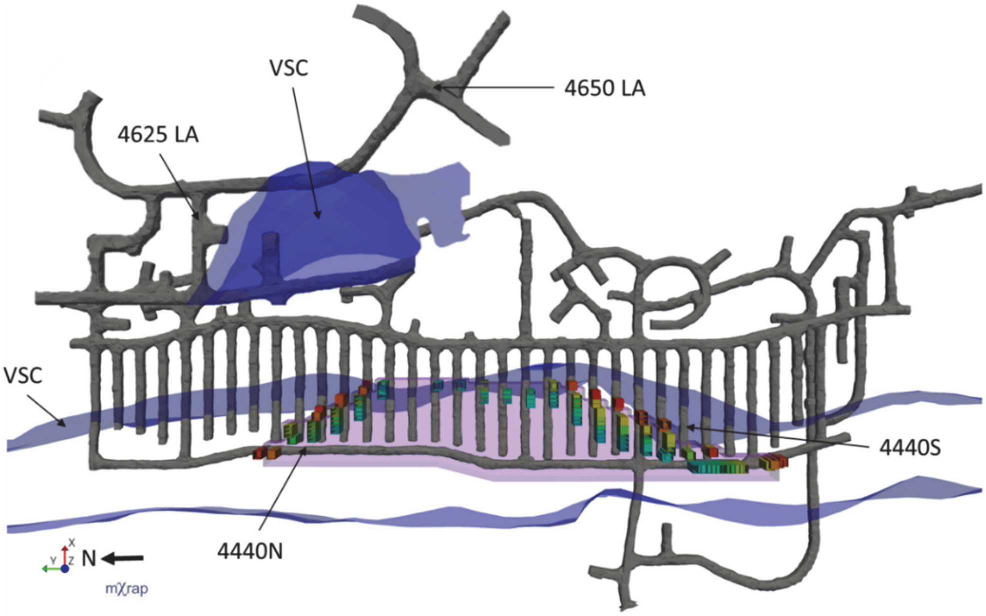


Figure 15 Location of production between January 2018 and June 2018 on the 4440 I-Level and 4650 to 4600 Decline area and VSC contact

6.3 Monitoring and production

Combining both the seismic activity rate and SMART cable data, Figure 16 confirms that SLC production was the major driver of deformation in the 4650 to 4600 decline area. This clear cause and effect allowed management to use SLC production suspension as an effective risk management tool until the bypass was completed.

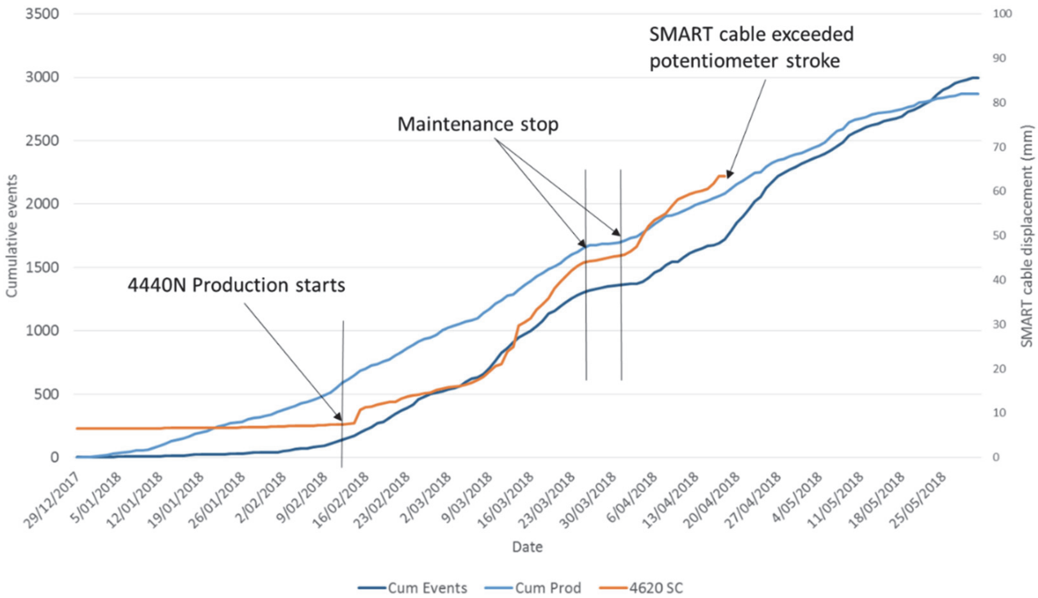


Figure 16 Clear correlation between SLC production, seismic activity rate and deformation monitoring around the 4650 Decline area

7 Risk management

Due to delays with bypass development and greater-than-anticipated deformation rates, a risk management approach was developed to maintain safe and serviceable access through the main decline until the bypass was complete. The risk management approach combined tactical ground support upgrades with a TARP; complimenting the monitoring plan already in place. Once the bypass was complete, the existing decline section was decommissioned and walled off.

Tactical ground support upgrades and rehabilitation were undertaken early on, increasing the surface support capacity, reinforcement length and reinforcement density as part of preventative support maintenance. Installing new reinforcement also created additional deformation capacity in the ground support system, which was used to determine TARP strain and deformation limits.

A targeted monitoring strategy was implemented, as discussed earlier, allowing for TARP triggers to be created and implemented based on observed data, with deformation rates and limits set as in Table 1 and Table 2. Breach of any measurement, monitoring or observational trigger would result in the associated response (Table 2).

Table 1 Triggers based on monitoring data and observations

Measurement	Normal	Moderate trigger	Major trigger	Critical trigger
SMART cable strain	<0.40%	0.40–0.59%	0.60–0.89%	≥0.90%
Disp. rate	<1 mm/day	1–2 mm/day	2–5 mm/day	>5 mm/day
LiDAR deformation (from baseline)	<50 mm	50–100 mm	100–150 mm	>150 mm
Deformation phase	Regressive	Regressive	Progressive – onset of failure	Progressive – advancing or accelerating failure
Monitoring				
Seismic system	Normal cave related seismicity	Minor clustering of activity in decline area. Recorded events are small, i.e. <0.4 M_L	Seismic event characterised as moderate – potential hazard, i.e. 0.4 M_L < event < 1.5 M_L within 75 m of decline area	Seismic event characterised as large – potential hazard or significant – high hazard, i.e. 1.5 M_L < event < 2.0 M_L within 160 m of decline area or >2.0 M_L anywhere near mine
Observation				
Inspection	S0 to S1 on the support damage scale	Majority S1 damage, isolated areas of S2	Majority S2 damage, isolated areas of S3 requiring rehab	Spreading of S3 damage, isolated areas of S4 or fall of ground identified

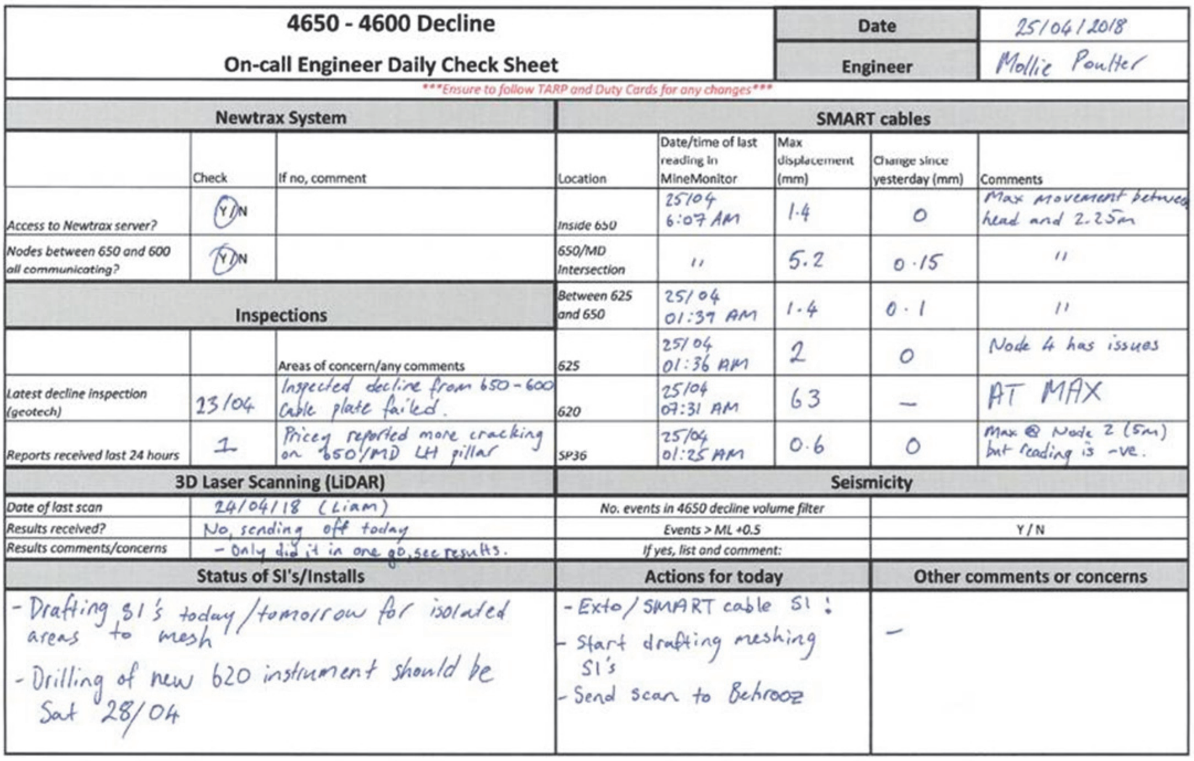
Table 2 Response based on monitoring data and observations

Measurement	Normal	Moderate trigger	Major trigger	Critical trigger
Action and response	Continue inspections as per schedule Continue daily monitoring data checks Continue weekly LiDAR scanning and review	Review monitoring data, verify with underground inspection Review bogging location and tonnes since last scan/inspection	Carry out immediate inspection and map new damage Increase inspection frequency as required Review production in SLC Northern quadrants affecting deformation, modify draw strategy to slow down deformation Draft and issue plan to rehabilitate area	Carry out immediate inspection and map new damage Stop production in SLC Northern quadrants Barricade decline between 4650 LA and SP36 to prevent personnel access to hazardous area Review risk assessment and update prior to recommencing SLC production in northern quadrants
Notification (in addition to weekly reporting)	Nil	Escalate to geotechnical superintendent during the shift	Escalate to geotechnical, production superintendents and underground mining manager ASAP	Escalate to geotechnical, production superintendents and underground mining manager ASAP

An inspection schedule with associated duty cards and reporting requirements was also produced for various roles from underground supervisors to the underground manager. This ensured there was regular visual inspection and reporting in conjunction with monitoring.

Reporting of TARP status occurred weekly, or when the TARP progressed to the next trigger level. Weekly presentations to the underground workforce were also undertaken, providing them with information on monitoring data, progression of deformation and production holds.

In conjunction with the TARPs, and to record any change in status, a daily operational geotechnical monitoring check sheet was complete (Figure 17).



4650 - 4600 Decline

On-call Engineer Daily Check Sheet

Date	25/04/2018
Engineer	Mollie Poulter

Ensure to follow TARP and Duty Cards for any changes

Newtrax System

	Check	If no, comment
Access to Newtrax server?	Y / N	
Nodes between 650 and 600 all communicating?	Y / N	

Inspections

		Areas of concern/any comments
Latest decline inspection (geotech)	23/04	Inspected decline from 650 - 600 Cable plate failed.
Reports received last 24 hours	1	Pricey reported more cracking on 650/MD LH pillar

SMART cables

Location	Date/time of last reading in MineMonitor	Max displacement (mm)	Change since yesterday (mm)	Comments
Inside 650	25/04 6:07 AM	1.4	0	Max movement between head and 2.25m
650/MD Intersection	"	5.2	0.15	"
Between 625 and 650	25/04 01:37 AM	1.4	0.1	"
625	25/04 01:36 AM	2	0	Node 4 has issues
620	25/04 07:31 AM	63	–	AT MAX
SP36	25/04 01:25 AM	0.6	0	Max @ Node 2 (5m) but reading is -ve.

3D Laser Scanning (LiDAR)

Date of last scan	24/04/18 (Liam)
Results received?	No, sending off today
Results comments/concerns	- Only did it in one go, see results.

Seismicity

No. events in 4650 decline volume filter	
Events > ML +0.5	Y / N
If yes, list and comment:	

Status of SI's/Installs	Actions for today	Other comments or concerns
- Drafting SI's today/tomorrow for isolated areas to mesh - Drilling of new 620 instrument should be Sat 28/04	- Exto/SMART cable SI: - Start drafting meshing SI's - Send scan to Behrooz	–

Figure 17 Daily geotechnical operational check sheet

Due to the significant deformation consuming ground support capacity, the excavation vulnerability and potential for damage from seismic activity increased around the 4650 to 4600 Decline. The remaining support capacity could not be accurately estimated, therefore either further preventative ground support maintenance needed to be undertaken or the trigger for deformation slowed via suspending SLC production.

With the strong cause and effect observed between monitoring data, seismic activity rate and SLC production, SLC production holds were used to slow deformation in the 4650 to 4600 Decline from one month prior to bypass completion and ultimately a full SLC production stop used to reduce the likelihood of a potential seismic trigger 10 days before bypass completion.

8 Conclusion

The increased cave influence zone and potential effect on critical mine infrastructure was identified at the planning stage and a management plan including monitoring triggers implemented. Despite the early identification of deformation and implementation of support upgrade and bypass planning, deformation occurred at a faster than anticipated rate and to a greater extent.

The risk management plan established to manage deformation, maintain decline access and continue with SLC production focussed on a monitoring plan consisting of multiple monitoring types. The different monitoring methods displayed a clear cause and effect with SLC production, giving mine management confidence in the ability to use production holds as an effective control.

The tactical ground support upgrades and strategy performed well, with surface support retaining large scale deformation despite individual reinforcement elements shearing or breaking. There were no falls of ground recorded.

The potential for large seismic events occurring in close proximity to the decline in combination with the significantly consumed support capacity led to a production hold until the bypass was complete, rather than further ground support maintenance.

Acknowledgement

The authors thank Newcrest Mining Limited and Telfer Mine management for permission to publish this paper. They also acknowledge previous members of the Telfer geotechnical department.

References

Beck, DA & Sandy, MP 2003, 'Mine sequencing for high recovery in Western Australian mines', *AusIMM Bulletin*, May/June, no. 3.

Di Giovinazzo, M & Singh, U 2010, 'Instrumentation and monitoring of cave initiation at Telfer Mine', in Y Potvin (ed.), *Proceedings of the Second International Symposium on Block and Sublevel Caving*, Australian Centre for Geomechanics, Perth, pp. 145–155.

Kaiser, PK, Tannant, DD, McCreath, DR & Jesenak, P 1992, 'Rockburst damage assessment procedure', in PK Kaiser & D McCreath (eds), *Rock Support in Underground Mining and Construction*, A.A. Balkema, Rotterdam, pp. 639–647.

Woods, MJ, Poulter, ME & King, RG 2018, 'Progression and management of seismic hazard through the life of Telfer SLC', in Y Potvin & J Jakubec (eds), *Proceedings of the Fourth International Symposium on Block and Sublevel Caving*, Australian Centre for Geomechanics, Perth, pp. 623–636.