doi:10.36487/ACG_repo/2435_O-01

Influence of pre-existing mobilized zones on B3 cave propagation and initial subsidence at the New Afton mine

K. Davenport[a] and C. Kamp[b]
[a]*Knight Piésold Ltd., Canada*
[b]*New Gold Inc., Canada*

ABSTRACT

New Gold's New Afton Mine is an operating gold-copper block cave mine located 10 km west of Kamloops, British Columbia, Canada. Block 3 (B3) mining was initiated in June 2021 and comprised New Afton's second lift, located approximately 750 metres below ground and partially beneath the previously mined Lift 1 West Cave (600 m below ground). B3 cave propagation resulted in mobilization of the overlying Lift 1 extraction level and existing muckpile, with increasing subsidence observed on surface. The timing and extent of B3 cave progression and initial subsidence expression are interpreted to have been significantly influenced by pre-existence of broken, mobilized material within the overlying West Cave muckpile and its associated subsidence zone. Initial minor subsidence deformations from B3 mining were observed throughout the existing West Cave subsidence zone as the B3 cave initially yielded an intact orebody region adjacent to West Cave, resulting in limited remobilization of the West Cave muckpile along its westernmost boundary. More significant, accelerating surface deformations were observed as the B3 caved zone fully-mobilized the Lift 1 extraction level and the overlying West Cave muckpile.

State-of-the-art block cave and subsidence monitoring programs have been implemented at New Afton to track cave propagation and subsidence progression in response to mining, including towards critical surface infrastructure. This paper summarizes observed B3 cave propagation and initial subsidence manifestation, using examples from the available instrumentation and monitoring techniques. Application of each monitoring technique to observation-based interpretation of the conceptual B3 block cave (i.e., seismogenic, yielded, and caved zones) and subsidence zone (i.e., crater, fractured, and continuous zones) subcomponents is also presented

1. INTRODUCTION

New Gold's New Afton Mine is an operating gold-copper block cave mine located 10 km west of Kamloops, British Columbia, Canada. The New Afton orebody comprises a copper-gold porphyry-style deposit, which was historically surface-mined within the Afton Open Pit (between 1977 and 1997 by another operating company) before transitioning to underground block cave mining.

Mining of the initial Lift 1 block caves (West Cave and East Cave) was initiated in late-2011. Production continued through early-2022 and resulted in the development of substantial caved and subsidence zones on site. Subsequent Block 3 (B3) mining was initiated from partially beneath the previously mined West Cave. B3 mining resulted in cave propagation and mobilization of the overlying Lift 1 extraction level and West Cave muckpile, along with increasing subsidence magnitudes and rates on surface. The pre-existence of broken, mobilized material from Lift 1 mining, within the overlying West Cave muckpile and its associated subsidence zone, is interpreted to have significantly influenced the timing and extent of B3 cave progression and initial subsidence expression.

The observed B3 cave propagation and initial subsidence manifestation are summarized herein, using examples from available instrumentation and monitoring method. The application of each instrumentation and monitoring technique to the observation-based interpretations of the B3 block cave (i.e., seismogenic, yielded, and caved zones) and subsidence zone (i.e., crater, fractured, and continuous zones) subcomponents is also presented.

2. MINING OVERVIEW

2.1. Overview

Block cave mining at New Afton began in late-2011 and reached commercial production in July 2012. The initial Lift 1 mining phase comprised production from adjacent West and East Caves between 2011 and early-2022. Subsequent B3 mining was initiated in mid-2021 and remains active at the time of writing (February 2024). All three caves have been initiated using the advance undercut method and the orebody has caved readily without need for preconditioning. Ore from both Lift 1 and B3 has been transported via load-haul-dump equipment to an underground crusher and then conveyed to surface for milling. Tailings produced were deposited within the New Afton and Pothook Tailings Storage Facilities (TSFs), transitioning into the presently active Afton Pit thickened and cement-amended in-pit TSF, beginning in late-2022.

The New Afton site was previously operated as a surface mine within the historical Afton Open Pit (between 1977 and 1997), under another operating company. Open pit mining was advanced to a depth of approximately 230 metres below ground surface (mbgs) and resulted in development of extensive waste rock dumps to the south and southwest of the Afton Pit. Tailings from open pit mining were deposited within the Historical Afton TSF, located west of Afton Pit and current underground mining area.

The locations of the Lift 1 (West and East Caves) and B3 block caves and the Afton Pit are shown on Figure 1, alongside illustrations of the existing Lift 1 mobilized zone (model representation) and subsidence zone (cumulative displacement magnitudes from amplitude-based satellite inSAR).

2.2. Lift 1 block caves (completed)

New Afton's initial Lift 1 block caving phase comprised production from the adjacent West and East Caves, located on the same extraction level and separated by an approximately 50-metre-thick pillar of waste material (RPA, 2020). The Lift 1 extraction level is located approximately 600 mbgs and partially beneath the historical Afton Pit, which has a depth of approximately 230 m and overlies East Cave. Lift 1 production and mine layout are summarized below:

- **Lifespan**: Sept. 2011 to Feb. 2022
- **Mined tonnes**: ~ 48 million tonnes
- **Avg. Production rate**: ~ 13,000 tpd
- **Height-of-draw**: ~ 320 to 500 m
- **Extraction level specifications**:
  - **Layout**: El Teniente; two caves
  - **Production** Drives: 4-5
  - **Drawbells**: 161
  - **Depth**: 320 to 600 mbgs
  - **Dimensions**: ~150 m x 800 m

Lift 1 mining began within West Cave in early-2012 and breakthrough (initiation of surface deformation) from this panel was observed in February 2013. East Cave production was initiated in mid-2013 and broke into the Afton Pit in mid-2016. East Cave footprint extends partially below the historical Afton Pit and subsidence has substantially deformed the pit walls. Pit geology (varying lithologies and structures) has resulted in complex and diverse deformation behaviour within the various pit sectors (Davenport et al., 2022). Mining within West and East Caves was completed in April 2021 and February 2022, respectively, as shown on Figure 2. Observed subsidence rates slowed following Lift 1 closure and prior to the onset of influence from B3.

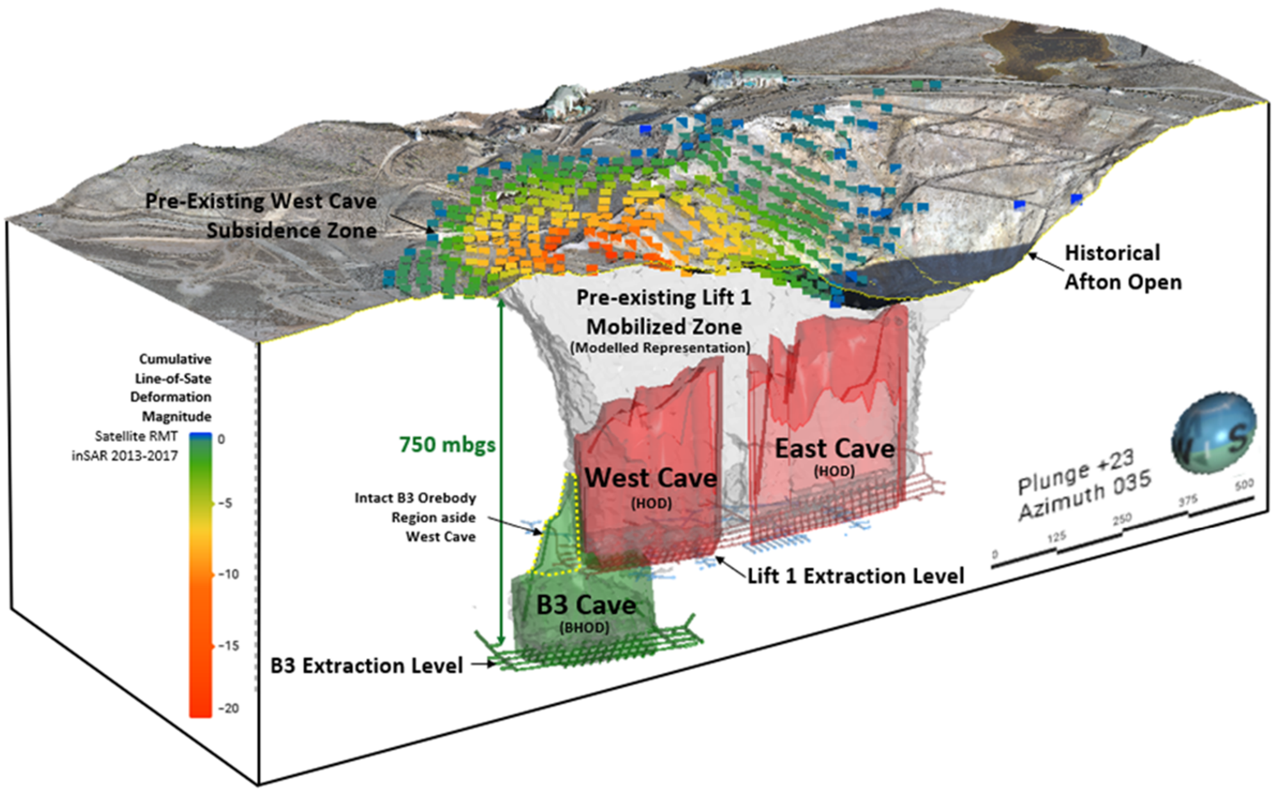

Figure 1 Block 3 and Lift 1 caves alongside existing subsidence zone, and site infrastructure.

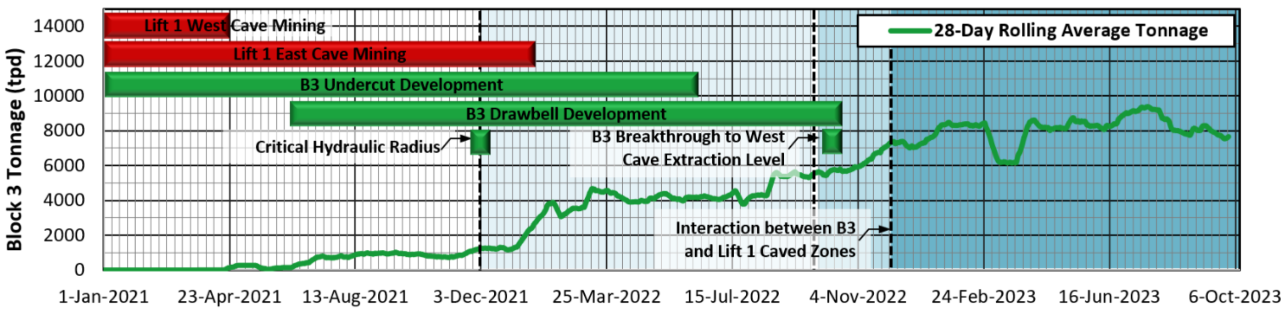

Figure 2 Block 3 development, tonnage, and mining milestones relative to Lift 1 closure.

2.3. B3 block cave (active)

B3 mining was initiated in June 2021 (date of 1st drawbell completion) and comprised New Afton's second lift, located approximately 750 mbgs and partially beneath the previously mined Lift 1 West Cave. B3 production and mine layout are summarized below:

- **Lifespan**: Mid-2021 through 2025
- **Mined tonnes**: ~5 of 10 million tonnes
- **Recent production rate**: ~8,500 tpd
- **Height-of-draw**: ~ 160 m
- **Extraction level**:
  - **Layout**: El Teniente: one cave
  - **Production Drives**: 4
  - **Drawbells**: 65
  - **Depth**: 750 mbgs
  - **Dimensions**: ~120 m x 250 m

B3 undercut and drawbell development began in December 2020 and June 2021, respectively. Cave propagation is interpreted to have been initiated in late-December 2021, following the achievement of critical hydraulic radius (HRcr). Production tonnages were ramped up to about 4,000 tpd following initiation of caving, followed by a steady increase to about 8,500 tpd by early-2023. Continued mining resulted in the cave propagating up towards and into contact with Lift 1 West Cave, as described in Section 4.

The B3 cave location is shown on Figure 1. B3 development, tonnage, and caving milestones are summarized on Figure 2.

3. GEOLOGICAL SETTING

The New Afton deposit comprises a copper-gold porphyry-style orebody. The deposit is generally continuous and dips sub-vertically westward from the base of the historical Afton Pit, where it was initially mined (RPA, 2020). Mineralization resulted from late-stage hydrothermal activity driven by remnant heat from porphyry intrusion. The principal host rock for the New Afton deposit comprises crystalline and polymictic fragmental volcanics (BXF) belonging to the Triassic Nicola Formation, along with lesser monolithic intrusive breccias. These rocks were altered and mineralized by a monzonite intrusive consisting of a fault controlled elongated stock and related dike swarm. The monzonite intrusions are generally weakly mineralized to unmineralized (RPA, 2020).

The New Afton orebody caves readily without a requirement for preconditioning. Rock mass classification, based on core logging and B3 face mapping (Bieniawski, 1989; RMR89), indicates a median rock mass rating of 52 with a median RQD of 78 and median uniaxial compression (UCS) of 65 MPa, excluding faults. Differing lithological properties and the presence geological structures significantly influence the geomechanical behaviour of caving and subsidence. The following five generalised geotechnical domains have been defined by New Afton local to the mining footprints and/or within the subsidence zone (Figures 3 and 4):

1. **Crystalline and polymictic fragmental volcanics** (BXF) are the predominant lithology within and north of the orebody and comprise primarily fragmental volcanic breccia with intervals of crystalline volcanic rocks. (RPA, 2020).
2. **Diorite** is present within the eastern extent of the deposit, where it has intruded the BXF as a coeval diorite sill (RPA, 2020). This lithology was pervasive within East Cave and is present in the southern extent of the B3 footprint.
3. **Monzonite** intrusive rock is present in steeply dipping fault-controlled stocks within the central Lift 1 footprint and to the south of the B3 cave.
4. **Picrite** bounds the orebody to the south and southwest, extending throughout the subsidence zone in these directions. The rock mass is distinctly less competent than other rock types, which impacts geomechanical behavior both within the mine and subsidence zones (RPA, 2020, Davenport et al., 2022).
5. **Kamloops and Ashcroft** group sedimentary rocks are present along east and southwest margins of the deposit, respectively. The Ashcroft formation abuts the picrite within the subsidence zone to the southwest of the mine area and comprises fine grained sandstone and clast-supported pebble conglomerate (RPA, 2020). Volcanic and sedimentary rocks of the Kamloops Group are present north of the deposit in contact with the BXF.
6. **Major Structures** have a strong influence on geomechanical behaviour. The orebody is bounded to the north and south by east-west striking, steeply dipping footwall and hanging wall faults. The hangingwall is defined by carbonate healed faults present along the picrite-BXF contact. The footwall fault is present within the BXF and has a similar strike, dip, and plunge to the hangingwall (RPA, 2020). The orebody and subsidence zone are transected by numerous faults in a range of orientations (RPA, 2020), as shown at the B3 extraction level on Figure 4. A notable example is the approximately 12 m wide north-south trending B3_6 fault that crosscuts the central B3 cave and comprises a healed carbonate fault with rubbly reactivated shears, as shown on Figure 5.

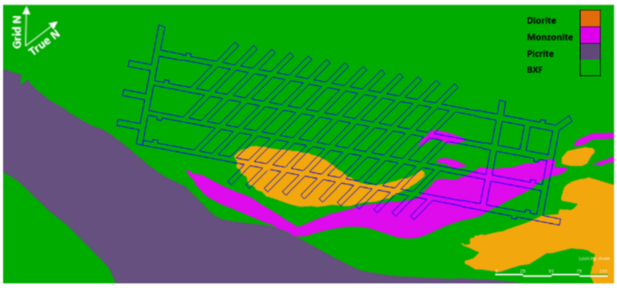

Figure 3 Lithology at the B3 extraction level.

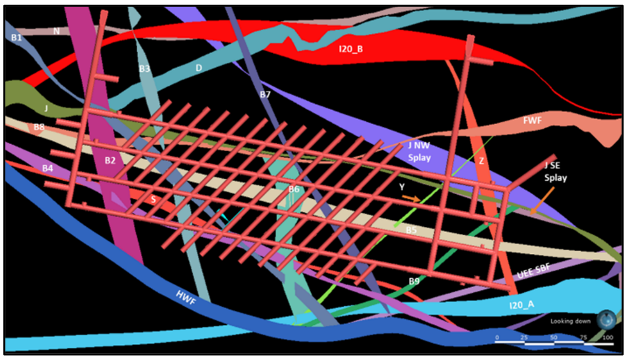

Figure 4 Faults at the B3 extraction level.

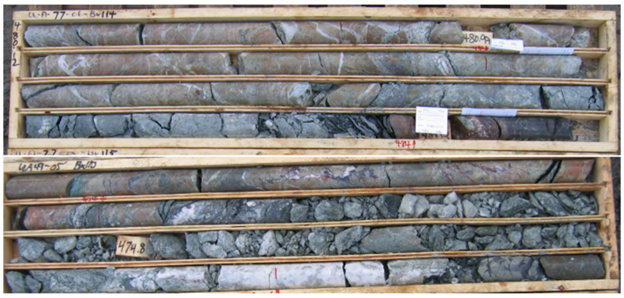

Figure 5 Example core box photographs from the B3_6 fault zone.

4. CAVE AND SUBSIDENCE MONITORING PROGRAMS

4.1. Overview

State-of-the-art block cave and subsidence monitoring programs have been implemented at New Afton to track cave propagation and progression of subsidence deformations in response to B3 mining, including towards critical surface infrastructure. Available monitoring techniques and their application to B3 cave and/or subsidence monitoring are discussed in the following subsections.

4.1.1. Cave Monitoring

Cave shape monitoring is highly important both in guiding mine operations and to inform assessment of significant potential safety hazards (e.g., air blast) that may occur due to adverse or unknown cave performance. Comprehensive instrumentation and remote sensing networks were installed throughout the B3 caving orebody to achieve the following monitoring objectives:

- **Monitor cave establishment** – Monitoring during the cave construction period, including undercutting and drawbell blasting.
- **Confirm cave initiation** – Identify progression towards and confirm the achievement of HRcr and initial upward cave growth (propagation).
- **Monitor cave propagation** – Monitor the rate of cave growth resulting from steady state drawpoint production. Confirm the cave shape is progressing per expectations, without deviating, chimneying, or stalling due to geological or production influences.
- **Evaluate air blast risk** – Monitor the air gap between the cave back and the muckpile to inform assessment of potential air blast risk.
- **Assess ore flow within muckpile** – Monitor muckpile movement to assess draw, ore recovery, and potential for dilution.
- **Monitor cave breakthrough to West Cave** Monitor caved zone breakthrough into the overlying West Cave extraction level, to timeously retreat from the level, implement access restrictions, and implement air blast bulkheads.
- **Monitor cave breakthrough to surface** – Utilize the underground cave and surface subsidence monitoring systems to validate the interaction between the B3 and Lift 1 caves and the onset of initial subsidence manifestation (timing, location, and extent).

The B3 cave profile monitoring program comprised routine monitoring (typically weekly during the cave propagation phase) and interpretation-based modelling of the caved zone to achieve the aforementioned monitoring objectives. Multiple monitoring methods (listed in Table 1 and shown on Figure 6) were utilized within the B3 cave to achieve the following objectives:

- **Provide data suitable to characterize and track progression of the conceptual B3 block cave zones** summarized below (after Laubscher, 2017):
  - *Caved Zone* – the region consisting of rock blocks that have fallen from the cave back (i.e., the muckpile)
  - *Air gap* – the air-filled void between the cave back and the top of the muckpile
  - *Yielded Zone* (zone of loosening) – the region between the seismogenic zone and cave back, where disintegration of the rock mass occurs. No seismicity is observed within this zone.
  - *Seismogenic Zone* – the region between the yielded zone and the intact rock mass, where stress changes from undercut or cave progression cause seismicity due to slip on joints and brittle rock failure
  - *Pseudo-continuous Domain* – the region of largely intact rock mass overlying and laterally surrounding the aforementioned zones.
- **Develop sufficient redundancy** between instrumentation systems to minimize loss-of-data coverage in the event of a single system outage and to allow for cross-verification of findings between independent monitoring systems.

Application of the available instrumentation and remote sensing techniques observation-based interpretation of the conceptual cave zones is described in Table 1 and illustrated conceptually on Figure 7. An example incorporation of B3 microseismic, MTDR/OTDR, Geo4sight, and Cave Tracker data to cave profile interpretation is exemplified on Figure 8.

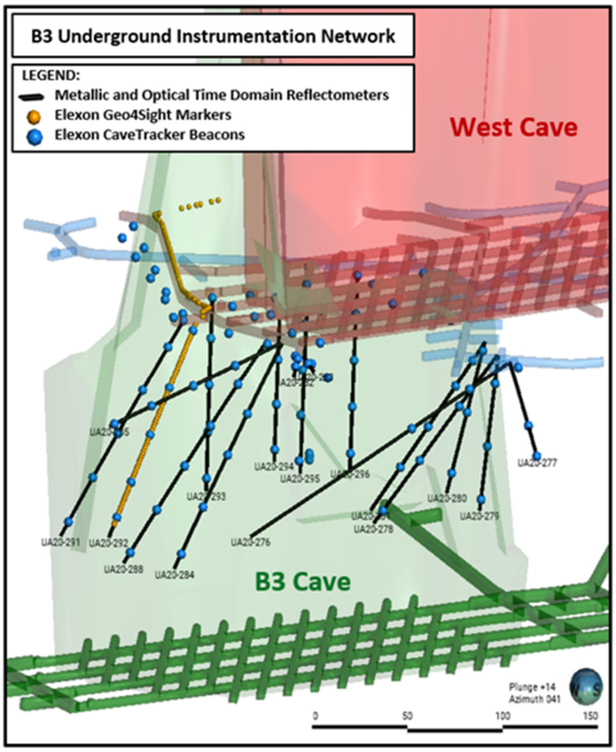

Figure 6 B3 underground instrumentation and monitoring network.

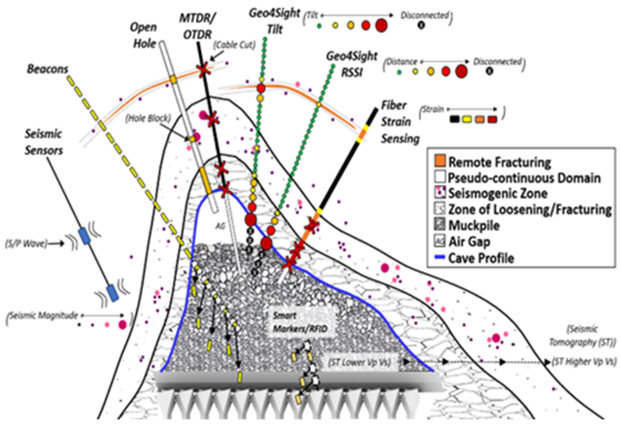

Figure 7 Instrument application to conceptual block cave zones (Kamp, 2024).

Table 1 B3 Cave Monitoring Techniques

Underground Instrumentation or Monitoring Technique		**Zones of Primary Use (Figure 7)**				**Description of Instrumentation/Monitoring Technique and Application**
		Seismogenic Zone	Yielded Zone	Cave Back	Muckpile	
In-Situ Instrumentation	Geo4Sight Markers (Elexon)	(✓) The transition from the seismogenic to yielded zone is detectable using tilt	✓	✓	-	**Wireless, multi-node deformation instruments capable of monitoring cave back position (based on Marker disconnection/ consumption) and assessing yield zone extent (based on angular deformations and signal-strength changes)**. These instruments are particularly suitable for cave profile monitoring due to their high-deformation tolerance as compared to conventional cabled and are typically borehole-installed at 2-metre spacing. Battery lifespan may be a limiting factor for some applications and should be considered in planning of installation timing and/or selecting appropriate data collection frequencies.
In-Situ Instrumentation	Cave Tracker Detector & Beacon System (Elexon)	-	-	(✓) Inferred from moving/ non-moving beacons	✓	**The Cave Tracker System comprises wireless beacons and detectors capable of monitoring ore flow within the muckpile**. Beacons emit a scheduled electromagnetic signal which the detectors use to determine straight-line range. Multiple detector range measurements can be processed to determine the beacon position and movements from prior installation and previously monitored positions (Aguirre & Lloyd, 2020). Beacon positions were assessed three times-per-week during B3 cave propagation and reported weekly. Position accuracy varied spatially (due to detector positions and the number of detectors in range) but commonly exceeded 10-20 metres. This makes the system suitable for week-to-week assessment of muckpile movement and draw but limited the utility for precise monitoring of cave back position. Battery lifespan may be a limiting factor for some applications and should be considered in planning of installation timing and/or selecting appropriate data collection frequencies.
In-Situ Instrumentation	Metallic time domain reflectometers (MTDRs)	-	✓ Partial Clipping	✓ Full Clipping	-	MTDRs monitor progression of ground displacement along borehole embedded coaxial cables (LDF4-50A). Clipping is interpreted to occur at small displacement magnitudes and clipping in advance of the cave back (within the yielded zone or concentration of strain above) is possible. Two MTDRs were installed within each B3 borehole and **partial- and full-clipping (clipping of one or both cables, respectively) were generally interpreted to occur within the yielded zone and at the cave back respectively**.
In-Situ Instrumentation	Optical time domain reflectometers (OTDRs)	-	✓ Partial Clipping	✓ Full Clipping	-	OTDRs monitor progression of ground displacement along borehole embedded fibre-optic cables (FT4). Clipping is interpreted to occur at small displacement magnitudes and clipping in advance of the cave back (within the yielded zone or concentration of strain above) is possible. Two OTDRs were installed within each B3 borehole and partial**- and full-clipping (clipping of one or both cables, respectively) were generally interpreted to occur within the yielded zone and at the cave back respectively.**
Remote Sensing	Microseismic Event Location	✓	(✓) Inferred between cave back/ seismogenic zone	-	-	An ESG microseismic system comprising primarily of uniaxial and triaxial geophones situated outside of the B3 caving orebody was **used to monitor event frequency (relative to time and tonnage), location, and moment magnitudes of microseismic events within the seismogenic zone**. These data are useful to confirm cave initiation (increasing microseismicity once hydraulic radius is achieved) and to provide advanced indication of upcoming yield and caved zone progression.
Remote Sensing	Passive Seismic Tomography	-	✓ Inferred	✓ Inferred	-	Passive seismic tomography was used to generate three-dimensional visualizations of the relatively aseismic region comprising the inferred caved and yielded zones. This technique was **used to periodically determine cave and yielded zone extent,** as described in Kamp (2022).

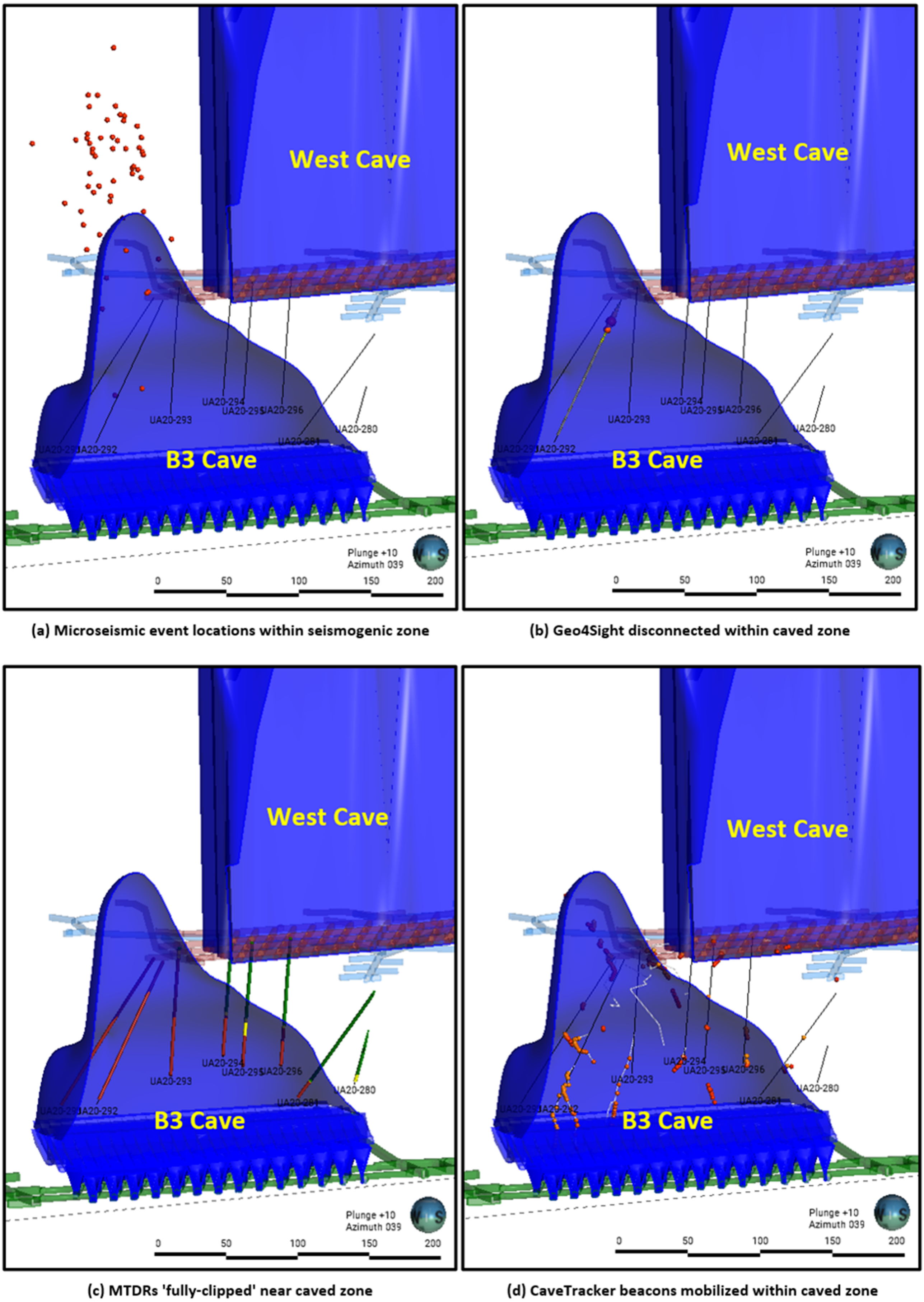

Figure 8 Application of monitoring data to B3 caved zone interpretation.

4.1.2. Subsidence monitoring

Surface subsidence deformations resulting from Lift 1 and B3 mining have been rigorously monitored and evaluated primarily due to the presence of surface infrastructure, including multiple TSFs, in proximity to the mining area. Observed Lift 1 subsidence and monitoring thereof using the numerous available instrumentation and remote sensing techniques has been comprehensively studied and presented previously in Davenport et al. (2022), Kamp et al. (2020), and Davies et. al. (2018). These routine monitoring practices have continued into the B3 mining phase to inform the following primary monitoring objectives (after Davenport et al., 2022):

- Identify initial subsidence expression (location and displacement rates) from B3 mining (i.e., surface breakthrough)
- Track and quantify the spatial progression of ground deformations towards critical site infrastructure
- Monitor influence of surface deformations on site infrastructure that is already present within the subsidence zone
- Understand how geological structure, lithology, topography, and historical waste dumps influence the subsidence shape and displacement rates.
- Provide input data for calibration of predictive numerical subsidence models that are used to forecast subsidence impacts to surface infrastructure and inform mitigation design, where required.

The primary monitoring methods used to identify and monitor initial B3 subsidence progression are summarized in Table 2 along with a description of their application to observation-based interpretation of the following conceptual B3 subsidence zone subcomponents (after Laubscher, 2017, see Figure 9):

- Crater Zone – the region overlying the mining area where cave breakthrough to surface or into the existing West Cave mobilized zone occurs. Soil and bedrock materials in this region move vertically downward within the muckpile.
- Fractured Zone – the region extending from the crater zone to the limit of visually discernable surface deformations/tensile cracking. Surface expressions begin as hairline tensile cracks near to the outer limit of the fractured zone, increasing to large offset scarps and toppling failures nearer to the crater zone.
- Continuous Subsidence Zone – the region of elastic deformation outside the fractured zone, where small-scale displacements occur and are measurable but not visually discernable.

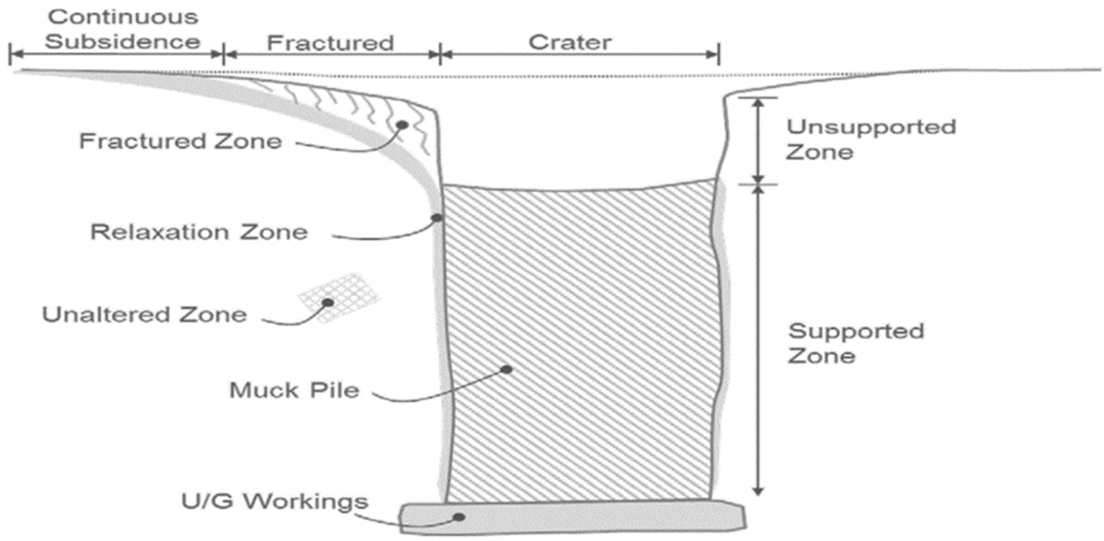

Figure 9 Conceptual subsidence zone subcomponents

Table 2 Subsidence Monitoring Techniques

Subsidence Instrumentation or Monitoring Technique		**Description of Instrumentation/Monitoring Technique and Application**			
		Crater	**Fractured**	**Continuous**	**Description of Instrumentation/Monitoring Technique and Application**
Remote sensing	Amplitude-based Satellite InSAR (APinSAR)	✓	✓	-	**Two-dimensional (vertical and east-west) and line-of-sight deformation monitoring used throughout the interpreted subsidence crater and fractured zones**, where observed deformations exceed the monitoring capability of conventional-phase based inSAR (i.e., exceed 0.5 m/yr.). Updated results are available approximately every 2 weeks.
	Phase-based Satellite InSAR (PSinSAR)	-	(✓) Near the outer fractured zone limit	✓	**Two-dimensional (vertical and east-west) and line-of-sight deformation monitoring throughout the continuous subsidence zone and outer fracture zone limits**, where deformations remain within the capability of conventional PSinSAR (i.e., less than 0.5 m/yr.). Updated results are available approximately every 2 weeks.
	Aerial Photogrammetry	✓	✓	-	**Vertical displacement monitoring throughout the subsidence crater and fractured zones**. Suitable for monitoring of deformation magnitudes exceeding approximately 0.5 metre, depending on configuration. Updated results are available approximately monthly.
In-Situ Instrumentation	Robotic total station (RTS) prism survey-monuments	✓	✓	✓	**Automated three-dimensional surface displacement monitoring of survey-monuments located throughout the subsidence zone and surface facilities**. Suitable for use within the crater, fractured, and continuous subsidence zones. Frequent readings (sub-daily) using Leica MS30 and MS60 total stations allow temporal trends to be tracked between inSAR or photogrammetric surveys.
	Differential global positioning system (DGPS) survey-monuments	✓	✓	✓	**Manual three-dimensional surface displacement monitoring of survey-monuments located throughout the subsidence zone and surface facilities**. Suitable for use within the crater and fractured zone (where safe access is possible). Relatively high noise levels make suitable only for long-term trend assessment (e.g., monthly, quarterly) within the continuous subsidence zone where displacement rates are small. Supplementary to prism survey-monument coverage, where line-of-site to the RTS is absent.
	Slope inclinometers	-	✓	✓	**Manually surveyed (traversing probe) inclinometers are used to monitor the magnitude, orientation, and profile distribution of subsurface displacements within the continuous subsidence zone and outer limits of the fractured zone**. Inclinometers have become damaged with increasing displacement (typically lateral displacements beyond 0.3-0.5 m, depending on localization) and are not suitable for monitoring within the crater zone or inner fractured zone. Results available approximately monthly.
	Metallic time domain reflectometers (MTDRs)	-	(✓) Clip at or near the outer fractured zone limit	✓	**Automated monitoring of ground displacement progression along coaxial cables (LDF4-50A) embedded in drillholes and used to monitor the relatively small deformations within the continuous subsidence zone and outer fractured zone.** Cables typically clip as strain increases with the approaching fractured zone. Deformation magnitudes are not quantified using MTDRs at New Afton.
	Geo4Sight Markers (Elexon)	(✓) Marker consumption within the crater zone is likely	✓	✓	**Automated monitoring of ground displacement by wireless, multi-node deformation instruments (markers), particularly suitable monitoring within the fractured zone due to their high-deformation tolerance as compared to conventional cabled instruments and can locate the crater zone extent by way of substantially elevated angular deformation, decreasing signal strength (RSSI), and/or Marker disconnection.** Instruments installed within fully grouted boreholes at 2 m spacing.

5. OBSERVED CAVE PROPAGATION AND INITIAL SUBSIDENCE EXPRESSION

5.1. Overview

The timing and extent of both B3 cave progression and initial subsidence expression are interpreted to have been significantly influenced by the pre-existence of broken, mobilized material within the overlying West Cave and its associated subsidence zone. Initial B3 mining advanced inferred seismogenic, yielded, and caved zones upwards towards Lift 1 and into an intact orebody region situated adjacent to the previously mined West Cave (see Figure 1), as the B3 cave began to expand (laterally and longitudinally in the direction of undercut progression). Slightly increasing surface deformation rates were observed throughout the existing West Cave subsidence zone as the B3 cave initially began to yield this intact orebody region, resulting in limited remobilization of the West Cave muckpile. More significant subsidence (accelerating deformation rates and increasing magnitudes) was observed as the B3 cave front substantially mobilized the Lift 1 extraction level and existing West Cave muckpile from below. Continued mining following substantial mobilization of the West Cave resulted in expansion (widening) of the B3 cave zone and deepening and expansion of the pre-existing subsidence zone.

The observed B3 cave propagation, interaction between the B3 and Lift 1 caves, and initial B3 subsidence manifestation are summarized in the following subsections, using examples from the available instrumentation and monitoring techniques.

5.2. Initial B3 cave propagation

Undercutting of the B3 orebody began in the western footprint extent in December 2020, with drawbell development beginning in June 2021 (see Figure 2). Low magnitude microseismic events were observed immediately above the undercut level and progressed spatially along with development.

B3 cave propagation is interpreted to have been initiated in late-December 2021 following the achievement of HRcr. Monitoring immediately following this milestone exhibited increasing microseismic event and MTDR clipping frequency as the seismogenic and yielded zones, respectively, advanced upwards over the initial caving area. These initial responses are shown alongside B3 tonnage on Figure 10.

Continued mining and development advanced seismogenic, yielded, and caved zones upward towards the Lift 1 extraction level elevation between December 2021 and March 2022. Propagation resulted in the following monitored responses:

- Upward and eastward progression of microseismic events as the seismogenic zone progressed in advance of the cave back and front.
- Upward and eastward progression of MTDR and OTDR clipping events as the yielded zone and cave back (monitored as partially- and fully clipped occurrences, respectively; Table 1) propagated upwards and expanded eastward.
- Increasing angular deformation (change-in-dip) and signal-changes (RSSI) monitored by Geo4Sight Markers installed in the orebody below Lift 1 extraction level. These responses are predominantly interpreted to have occurred as the yielded zone progressed ahead of the cave back. Very minor tilt changes appear to correspond with the transition from the seismogenic zone into the yielded zone, with more substantial tilt prior to caving. Some evidence of strain concentration was observed, comprising zones of localized elevated tilt or signal-loss, well above the interpreted yielded zone extent. The progression of monitored deformation and signal-loss is shown alongside interpreted cave propagation on Figure 11. Angular deformations typical of the yielded zone are shown on the December 2021 and March 2022 visualizations.
- Progressive up-hole disconnection (or consumption) of Geo4Sight markers was

observed as the caved zone propagated upwards. This is interpreted to have occurred as markers (individual or groups thereof) yielded from the cave back and fell with the surrounding rock mass onto the muckpile. Initially, all Geo4Sight markers were connected to within approximately 30 metres above the undercut level. Markers were then sequentially consumed with cave progression. Disconnection was preceded by increasing tilt, generally followed by a rapid signal strength decrease (as the rock yielded and failed) leading up to marker consumption (disconnection). This sequence is illustrated versus the interpreted caved back location on Figure 11.

- Cave Tracker beacons were progressively mobilized as muckpile progressed upwards, (see Figure 8d for example) and was drawn down. Beacon movements were assessed weekly and provided useful insight into muckpile flow directions (e.g., vertical flow assessment, rilling) and muckpile drawdown rates. As noted in Table 1, these instruments provided only a rough approximation of the cave back location, due to the system's relatively low position accuracy, as compared to Geo4Sight.

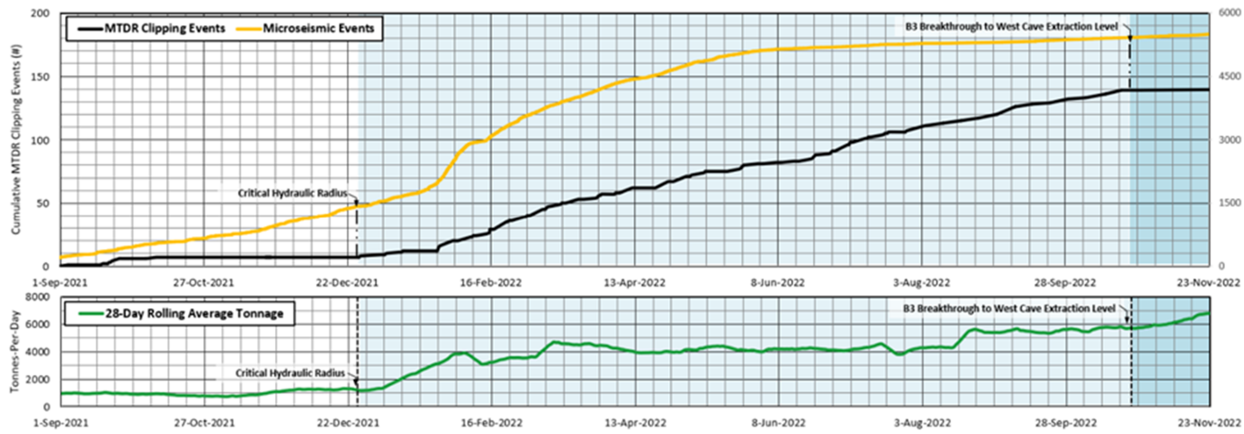

Figure 10 Microseismic and MTDR clipping frequency versus B3 tonnage.

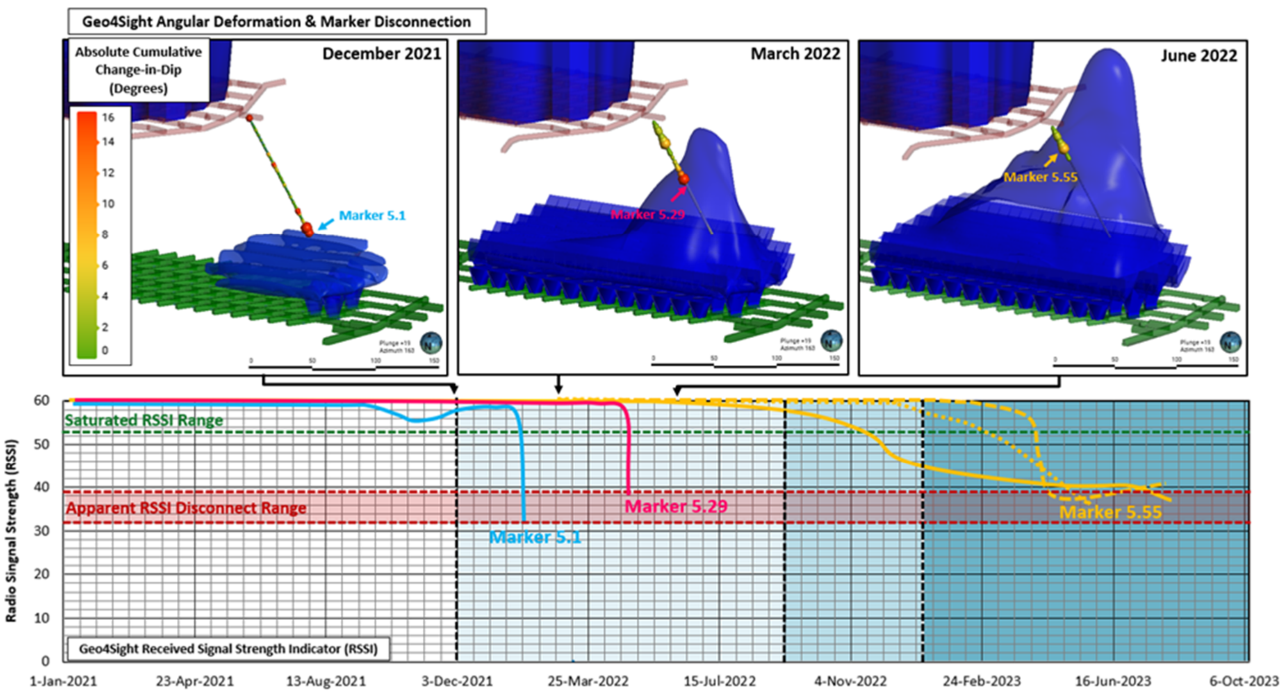

Figure 11 Geo4Sight angular deformation, signal-loss, & marker consumption from B3 caving.

5.3. Interaction between B3 and Lift 1

Initial interaction between the B3 fractured zone and the existing Lift 1 mobilized zone is interpreted to have occurred in approximately March 2022. At this time, the cave back remained below the Lift 1 extraction level (interpreted based on connected Geo4Sight markers, fully-clipped MTDRs and OTDRs, and the absence of significant damage within the westernmost Lift 1 EAC-1 extraction level drift. Initial interaction, associated with the B3 yielded zone, is interpreted to have occurred within the southwestern corner of the Lift 1 extraction level, where minor shotcrete cracking and floor heave were observed in this timeframe.

Continued mining advanced the peak of the B3 caved zone into the intact orebody region adjacent to West Cave (as designed and between approximately March and June 2022). Confirmation of caving in this region was initially extrapolated from microseismicity (as shown on Figure 8a) and inferred from height-of-draw (since no instruments targeting cave back detection were installed above and west of Lift 1). This finding was subsequently confirmed by Cave Tracker mobilization from the area.

The initial mobilization of the Lift 1 extraction level by the B3 caved zone is interpreted to have occurred in October 2022, with connection between the B3 and Lift 1 caved zones developing starting in approximately December 2022. Like the initial fractured zone interaction, the caved zones are interpreted first to have connected within the southwestern extent of Lift 1. The extent of caved zone breakthrough to Lift 1 West Cave subsequently expanded southward, northward, and eastward as the B3 caved zone matured. Mobilization of the West Cave extraction level was monitored with instrumentation installed along the EAC-1 access drift (OTDRs, MTDRs, and Geo4Sight) and was later confirmed following mobilization of Cave Tracker beacons installed throughout the West Cave production drives. Re-mobilization of the West Cave muckpile was inferred following this breakthrough milestone, consistent with observed subsidence findings. A sequence of B3 caved zone shapes leading up to, during, and after the initial caved zone interaction with West Cave are shown on Figure 12, alongside observed surface displacement trends.

5.4. Initial B3 subsidence expression

Observed displacement rates within the existing Lift 1 subsidence zone slowed following the conclusion of West and East Cave mining (after about February 2022), as shown on Figure 13. Relatively minimal deformations were observed between Lift 1 closure and initial B3 surface influence, as described in Davenport et al. (2022). This aligns with expectations and subsidence model predictions prior to B3 interaction with the existing West Cave mobilized and subsidence zones.

Slightly increasing surface deformation rates were observed using amplitude-based satellite inSAR and prism survey-monuments throughout the existing West Cave subsidence zone beginning in March 2022, as shown on Figure 14. This timing corresponds to initial B3 yielding and caving of the intact orebody region adjacent to West Cave. Limited remobilization along the western edge of West Cave is inferred to have driven the observed increase.

More significant subsidence (accelerating deformation rates and increasing magnitudes) was observed as the B3 cave front substantially mobilized the Lift 1 extraction level and existing West Cave muckpile from below/west (interpreted using Geo4Sight, OTDRs, MTDRs, and Cave Trackers). These accelerating subsidence trends are shown on Figures 13 and 14 from prism survey-monument and satellite inSAR data, respectively.

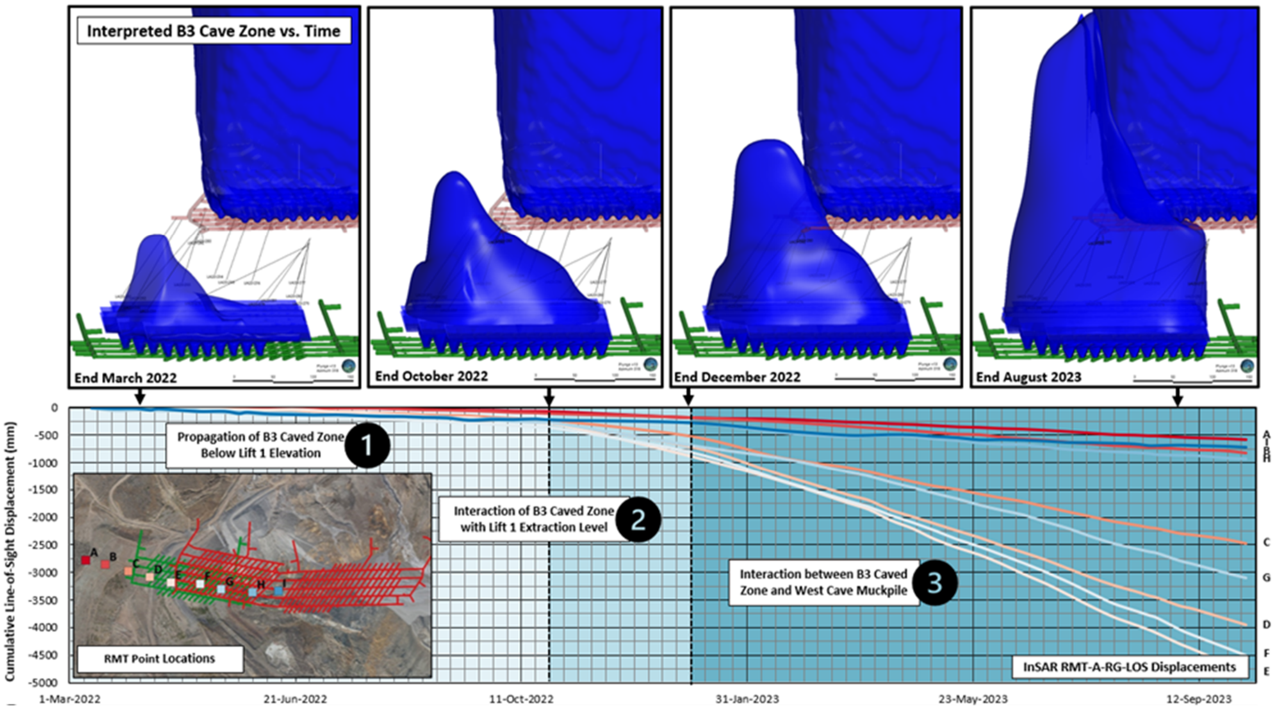

Figure 12 Caved zone propagation versus observed subsidence magnitudes.

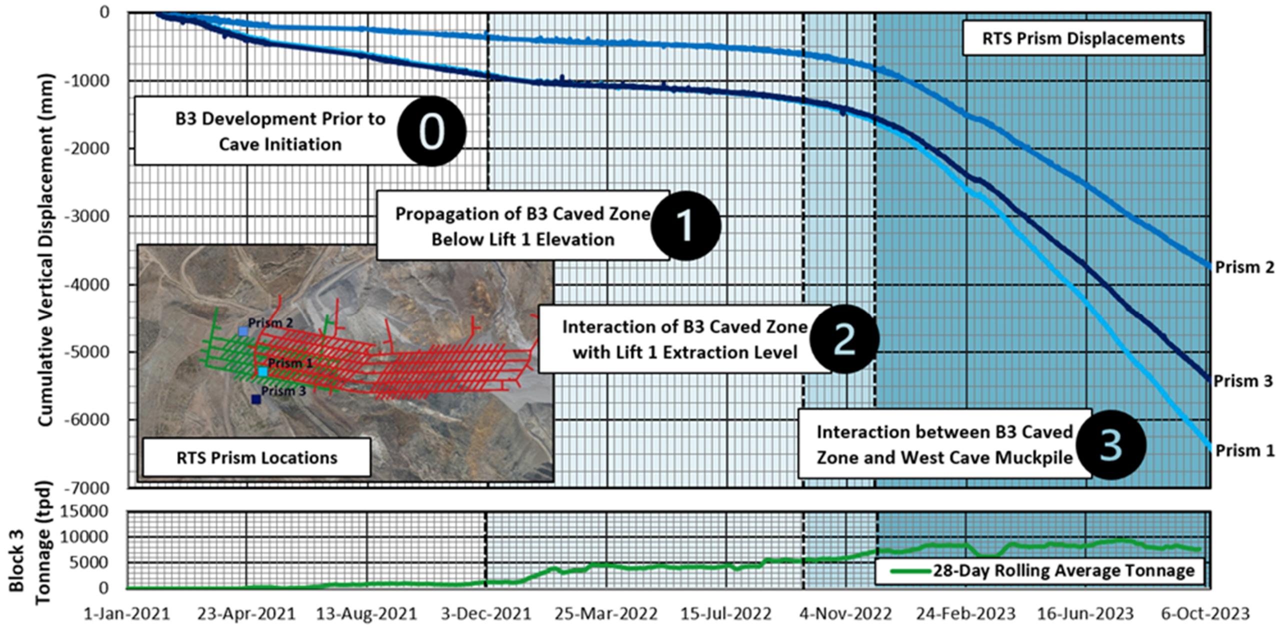

Figure 13 Long-term Lift 1 and B3 subsidence prism displacement magnitudes vs. tonnage.

Continued mining following the substantial mobilization of the West Cave extraction level and muckpile has resulted in the observed deepening and expansion of the pre-existing Lift 1 subsidence zone. Observed vertical subsidence magnitudes overlying the B3 cave footprint range from approximately 3.5 to 5 m (Figure 15; in October 2023), decreasing with distance from the mining area. Surface displacement rates have been closely related to mine production tonnages, as shown on Figure 14.

The B3 subsidence extent, spatial distribution, and magnitudes observed using aerial photogrammetry between June 2022 and October 2023 are shown on Figure 15. The subsidence extents continue to be influenced by presence of major geological structures and comparably deformable geological units, which previously constrained and promoted expansion of the subsidence zone during Lift 1 mining, respectively (Davenport et al., 2022). Large-scale subsidence within the northwestern extent of the subsidence fractured zone makes a 'V' shape, bounded by the picrite-BXF contact and a confining series of geological structures (faults) located to the north. Relatively higher displacement magnitudes from B3 are present overlying the comparably weaker picrite rock mass and significant localization of deformation from B3 has occurred along the boundary. This is exhibited by the development of an approximately 1 m vertically offset crack at this boundary during B3 mining, as shown on inset image on Figure 15.

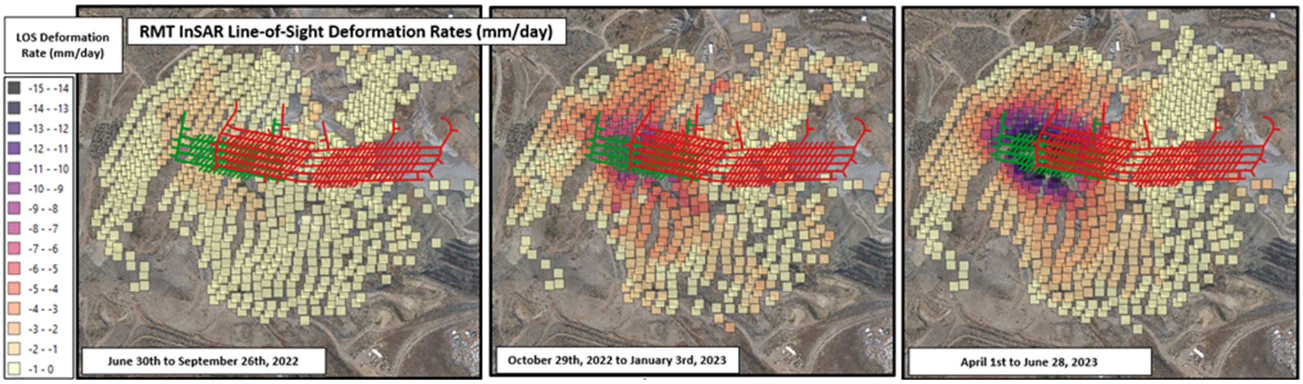

Figure 14 Initial subsidence extents and displacement rates from B3 mining.

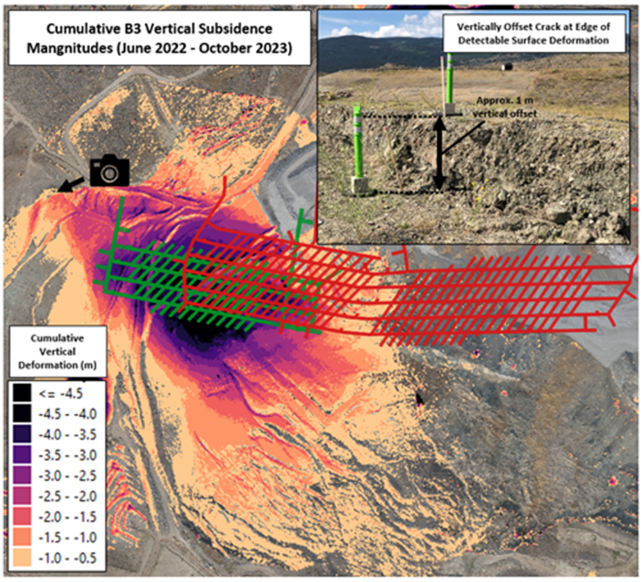

Figure 15 Observed subsidence magnitudes (June 2022 to October 2023).

6. KEY CONCLUSIONS AND CLOSING

Initial B3 mining was observed to have advanced caving upwards towards Lift 1 and into an intact orebody region adjacent to the previously mined West Cave. The onset of initial subsidence was observed prior to substantial remobilization of the Lift 1 extraction level or muckpile from below and is inferred to have resulted from limited remobilization along the western side of West Cave. More significant subsidence (accelerating deformation rates and increasing magnitudes) was observed as the B3 cave front substantially mobilized the Lift 1 extraction level and re-mobilized the West Cave muckpile. The initial subsidence manifestation from B3 mining was consistent with expectations and rapidly remobilized the full extent of the West Cave subsidence zone. Surface displacement rates remain closely related to mine production tonnages and subsidence extents continue to be influenced by presence of major geological structures and comparably deformable geological units.

B3 cave and subsidence monitoring programs effectively tracked cave initiation, initial propagation, interaction with the overlying West Cave, and the onset of surface subsidence. The following are key conclusions and learnings from the B3 performance monitoring programs for consideration in subsequent New Afton and other block cave applications:

- A risk was identified prior to B3 mining that caving might remobilize the West Cave muckpile instead of propagating into the intact orebody region located west of Lift 1. This was mitigated by using a western cave initiation and developing a favorable height-of-draw profile to support vertical cave draw. Instrumentation and remote sensing data (microseismicity and subsequent Cave Tracker movements) confirmed that caving of this region was successful. Additional Geo4Sight would have enhanced tracking of the cave back in this region. Open observation drillhole(s) may also have been a benefit.

- Elexon Geo4Sight instrumentation proved highly valuable to monitoring progression of both the yielded and caved zones, based on angular deformation (change-in-dip) and marker disconnection, respectively. No marker disconnections occurred above the interpreted cave back, indicating that Geo4Sight appears substantially less susceptible to disconnection within the yielded zone or along strain concentrations (e.g., structures, fractures) above the cave. Both MTDRs and OTDRs are susceptible to this issue, with the potential to result in inaccurate interpretation of caved zone extents.
- Monitoring of initial breakthrough of the B3 caved zone to Lift 1 (extraction level and West Cave) with OTDRs, MTDRs, and Cave Trackers proved challenging. OTDRs and MTDRs commonly clipped above the cave back and the Cave Tracker system had relatively low beacon position accuracy due to the detector layout (quantity, location distribution). Additional Elexon Geo4Sight installations from the overlying extraction level would have benefited breakthrough assessment. Installation of Geo4Sight markers within the Lift 1 extraction level drives was also found to be helpful to monitor/confirm underground breakthrough. Open observation drillholes and remote optical cameras may also have been an opportunity for improvement, provided they could be kept functional for routine monitoring.

Experience and learnings from the B3 cave and subsidence monitoring programs will be incorporated into the upcoming New Afton C Zone monitoring programs and have been made available herein for the consideration of other industry practitioners.

ACKNOWLEDGEMENT

The authors would like to acknowledge numerous individuals at New Afton who contributed to the development of this paper through their dedicated work installing and maintaining both surface and underground instrumentation as well as assisting with subsidence and/or cave interpretation. Knight Piésold Ltd. would particularly like to thank New Afton for the opportunity to become involved in underground B3 cave monitoring and for supporting the publishing of findings in the spirit of shared learning with other industry practitioners.

REFERENCES

Bieniawski, Z. T. (1989). Engineering rock mass classifications. New York: Wiley.

Davenport, K., Dick, G. & Kamp, C. (2022). Observed Subsidence Progression at New Afton Mine in Response to Lift 1 Mining. In Y Potvin (Ed.), Caving 2022: Fifth International Conference on Block and Sublevel Caving, (pp. 749-766) Australian Centre for Geomechanics, Perth, Australia.

Davies, A. G. L., Hamilton, D. B. & Clayton, M. A. (2018). Understanding and managing surface subsidence at New Gold's New Afton block cave operation. In Y Potvin & J Jakubec (Eds.), Proceedings of the Fourth International Symposium on Block and Sublevel Caving, (pp. 703-716) Australian Centre for Geomechanics, Perth, Australia.

Kamp C., Tomas, A., Hamilton, D. & Davies, A. (2022). Smart technology for monitoring caving subsidence. In R Castro, F Báez & K Suzuki (eds), MassMin 2020: Proceedings of the Eighth International Conference & Exhibition on Mass Mining, (pp. 289-298) University of Chile, Santiago.

Laubcher, D., Guest, A. & Jakubec, J. (2017). Guidelines on Caving Mining Methods (The Underlying Concepts). SMI BRC, WH Bryan Mining & Geology Research Centre, The University of Queensland, Australia.

RPA (2020). Technical report on the New Afton Project, British Columbia, Canada, NI 43-101 Report.