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Rehabilitation of historical mine features: from mitigation towards true risk elimination

Erika Voyer [a,*], Jérémie Arsenault [b]

[a] *Agnico Eagle Mines Limited, Canada*

[b] *WSP, Canada*

Abstract

The Abitibi–Northern Ontario region is one of the most historically significant mining areas in Canada, with more than a century of continuous mineral exploration, underground development, and large-scale mining production. Hundreds of historical mine workings are the legacy of extensive exploration and mining operations, including shafts, raises, portals, drifts, adits and stopes, often connected in complex underground networks.

Over time, these mine features have become part of the regional landscape. Closure and rehabilitation work can be critical, as unmanaged legacy mine hazards may continue to deteriorate and present significant hazards that can affect ground integrity and community safety.

Initial mitigation approaches often focus on containing risks rather than managing the underlying sources of hazards. Advantages to proceeding towards comprehensive, integrated, long-term interventions that aim at eliminating hazards rather than mitigating them include enabling future access to communities, reducing long-term costs and improving the likelihood of relinquishment. Eliminating hazards may require several investigations and design steps, as it is often more complex and costly than short- or medium-term securing measures and therefore requires strong justification before being implemented.

However, historical mining activities were often poorly documented, lack reliable records, and deterioration over time makes it necessary to verify subsurface conditions. Rehabilitation designs of legacy mine hazards start with desktop assessment using sometimes limited historical records to identify potential risks. Field investigations using various survey techniques, along with technical assessments that meet regulatory standards, enable initial assumptions to be refined to design tailored rehabilitation options.

This article presents case studies of completed and ongoing rehabilitation projects in the Abitibi–Northern Ontario region. It outlines both industry and technical perspectives on the challenges posed by limited historical information, considerations guiding the selection of investigation methods and the field constraints encountered during investigation and rehabilitation processes. It demonstrates that effective rehabilitation aimed at eliminating hazards relies on an adaptive, risk-based approach that evolves as new information emerges, ensuring hazards are accurately characterised and properly addressed.

Keywords: *legacy mine hazards, mitigation, investigation, rehabilitation*

1 Introduction

The Abitibi greenstone belt, located in northern Quebec and Ontario, Canada, represents one of the world's most prolific gold-producing regions. Since 1901, more than 124 mines have operated within the belt, collectively producing over 300 million ounces of gold. The region also hosts more than 21 gold deposits, each holding in excess of 3 million ounces (Dubé & Langevin 2020). Several communities within the belt

[*] Corresponding author. Email address: erika.voyer@agnicoeagle.com

contain legacy mine sites within municipal boundaries, which may pose environmental or safety risks, and land use restrictions to local roads, private properties, public and commercial buildings, residential areas and public parks.

Agnico Eagle Mines Ltd (Agnico Eagle) manages several legacy sites and associated mine features in communities that have a rich mining history such as Cobalt and Timmins in Ontario, and Rouyn-Noranda and Val d'Or in Quebec, as presented in Figure 1.

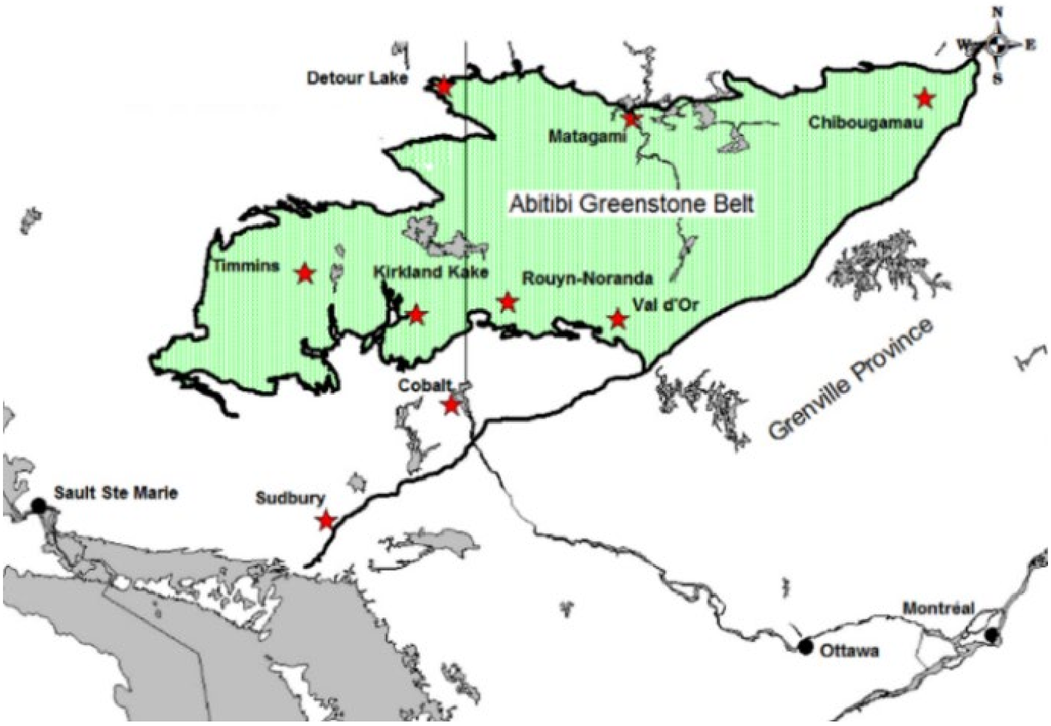


Figure 1 Abitibi greenstone belt across northeastern Ontario and western Quebec (modified from Geotech Ltd 2026)

Legacy mine features in these areas include shafts, raises, adits/portals, drifts, stopes and open cuts that extend to surface, with example photographs shown in Figure 2. Legacy features may be many decades old, and records of these features may be missing or difficult to interpret. A key challenge associated with these legacy mine features is that they can often be located beneath municipal infrastructure, often with no surface evidence indicating their presence. Others are located in wooded areas, often covered with rocks, debris and vegetation. As a result, these mine-related hazards are frequently not identified until they have already impacted surface as presented in Figure 2. Additional challenges include limitations in available historical data, such as uncertainty in the locations and final extents of mine hazards relative to historical drawings, the absence of complete mine plans, and limited information regarding historical mine rehabilitation activities.

This paper first provides an overview of the assessment and investigation stages for remediation of legacy mine features, with examples from projects completed by WSP, followed by 3 case studies from rehabilitation projects at legacy sites owned by Agnico Eagle in the Abitibi–Northern Ontario region.

(a) (b)

Figure 2 (a) Examples of mine hazards (courtesy of WSP Canada Inc.); (b) Examples of mine hazard subsidence failures (courtesy of WSP Canada Inc.)

2 Assessment and investigation stages

Projects of this nature start with an initial data review completed using all available historical information, drawings and existing mining and geotechnical reports. Based on this review, a simple mine geometry model can be developed using appropriate software. A data gap analysis is then conducted to identify missing information required for collection at subsequent project stages. Where required and if sufficient data are available, a desktop stability assessment of crown pillars and stopes is then undertaken using estimated bedrock rock mass parameters and stope and crown pillar geometries derived from historical drawings. If warranted, an initial site visit can be performed to validate historical information against current site conditions. Limited surveying may also be completed at this stage to enable georeferencing of historical data from the local mine grid into a modern universal system.

Following the initial review and stability assessments, detailed work plans are developed for field investigation activities. These activities may include excavation of shafts, raises, and mined-to-surface openings, geotechnical drilling investigations of stope crown pillars and hanging walls, and the identification of existing openings to surface. The equipment and tools typically used during these investigations include:

- unmanned aerial vehicles: drones used for surface and underground surveys
- surface surveying equipment: theodolite and GPS-based survey instruments
- borehole cameras: ranging from simple Seesnake®-style cameras to advanced articulating systems (e.g. GeoVision)
- void survey scanners: borehole and surface void surveys conducted using laser cavity monitor survey equipment in dry conditions and sonar scanning technologies in flooded conditions.

Investigations at legacy sites may require multiple phases of field investigation and reassessment before a definitive remediation design can be developed where required. For example, during a project in southern Ontario, Canada, 3 rounds of investigation were required to fully define the underground mine workings, assess their stability, and develop a suitable remediation strategy.

Figure 3 illustrates the various stages of the legacy stope investigation process and is summarised as follows:

- First investigation: The mine's longitudinal section was investigated using 6 diamond drillholes, 5 of which successfully intersected the underground workings. Cavity monitoring surveys, deployed through selected boreholes, were used to generate the initial 3D void geometry. Due to line-of-sight limitations, some blind spots could not be fully surveyed. The dark grey areas shown in Figure 3 represent the voids derived from cavity monitoring surveys.
- Second investigation: Based on the results of the first investigation, additional stope delineation was undertaken. This phase included 3 diamond drillholes and, in one particularly difficult to locate area, 7 percussive drillholes, 3 of which intersected the stope. By the completion of this stage, the stope, along with connected raises and drifts, was sufficiently defined. Subsequent stability assessments determined that the crown pillar was not stable over the long term.
- Third investigation: Six large-diameter percussive holes were drilled into the stope to facilitate placement of cemented backfill (paste). During the backfilling process, additional void spaces and a previously unidentified raise were discovered, characterised and included in the ongoing remediation.

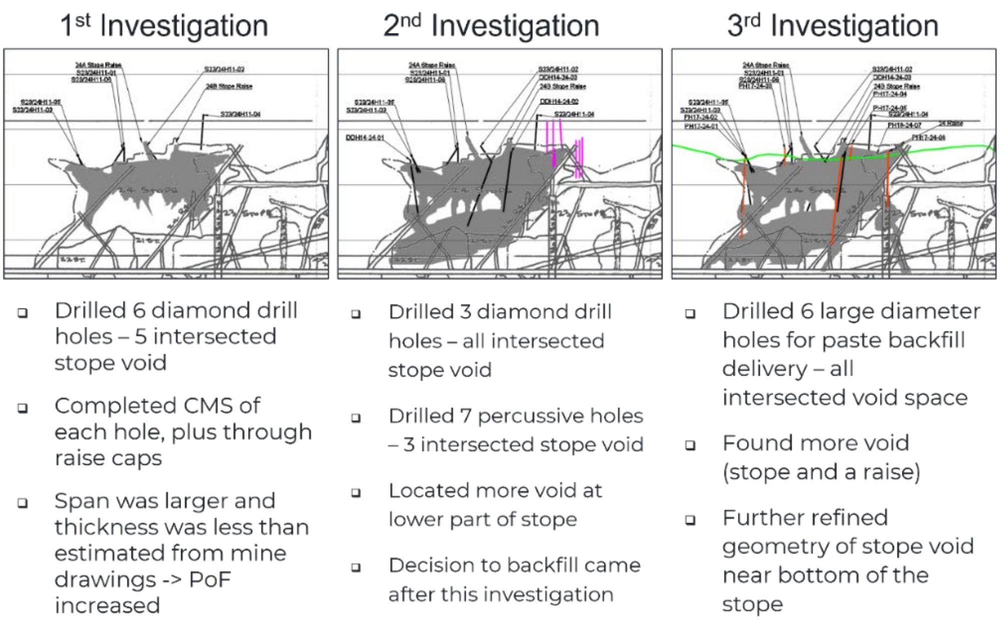


Figure 3 Iterative stages of investigation and assessment for a legacy stope

3 Case studies

The following cases illustrate ongoing and completed projects at various stages of investigation, assessment and remediation.

3.1 Case 1: Abitibi–West

3.1.1 Background

The site is a former gold mine located west of Rouyn-Noranda in the Abitibi region. The site is divided into 2 former mining zones, extending from west to east. The West Zone was accessed through inclined shafts #1 and #2, while the East Zone was mined through shaft #3, also inclined. It was first operated between 1935 and 1942 when approximately 530,000 tonnes of ore were processed, yielding just over 2 million dollars' worth of gold at the time. The mine was closed due to the Second World War, the low grade of the remaining ore reserves and the lack of capital available for further exploration. The mine workings were then left to flood (Stewart, 1947). Subsequent underground work and drilling occurred from 1945 to 1946, followed by renewed exploration in the late 1970s (WSP 2025a).

Through a series of acquisitions, Agnico Eagle became the property owner in 2023. During site visits and early investigations, physical mine hazards and existing fencing were identified and documented.

Near each shaft, several stopes were mined close to surface, leaving them open to surface with very thin crown pillars that may be unstable and at risk of failure (WSP 2025b). Figure 4 illustrates the locations of surface openings and the hazards specifically related to crown pillar conditions. This case study focuses on the recent investigation of shaft #3 and the East Open Stope, each presenting unique features, highlighting key findings and technical challenges.

Figure 4 Surface openings mine hazards location (blue zones are the stopes)

3.1.2 Recent investigations and stability assessments

3.1.2.1 Shaft #3

During 2024 a site visit, it was observed that shaft #3 was covered by 2 concrete slabs and surrounded by a temporary snow fence. An excavation program was then planned in 2025 to expose the structure down to bedrock where feasible. The excavation work exposed a concrete structure covering shaft #3 and revealing an unexpected large concrete structure with a sloped north face that acted as a collar structure for the inclined shaft, as presented on Figure 5.

The top part of the shaft was surveyed using a C-ALS (cavity auto-scanning laser system). The survey showed the shaft is inclined at an angle of approximately 45°, with span and width of approximately 2.5 m and 3.0 m, respectively. Pictures taken of the inside of the concrete structure revealed wooden debris around the shaft collar and visible old tracks along which hoisted carts circulated. Timber for roof support at the shaft brow was also observed during the investigation.

The concrete collar floor was found to be built in deeper than the observed bedrock elevation. Figure 5 also presents the C-ALS surveys of the shaft looking west and the inside of the concrete structure. Given the dip of the shaft, it was identified that the stability of the brow area needs to be assessed as part of the remediation design. The survey also suggested that the roof of the concrete structure was in poor condition, with the aggregate being exposed on nearly the whole surface. The concrete walls appeared in better shape, except around the openings where significant erosion and weathering occurred.

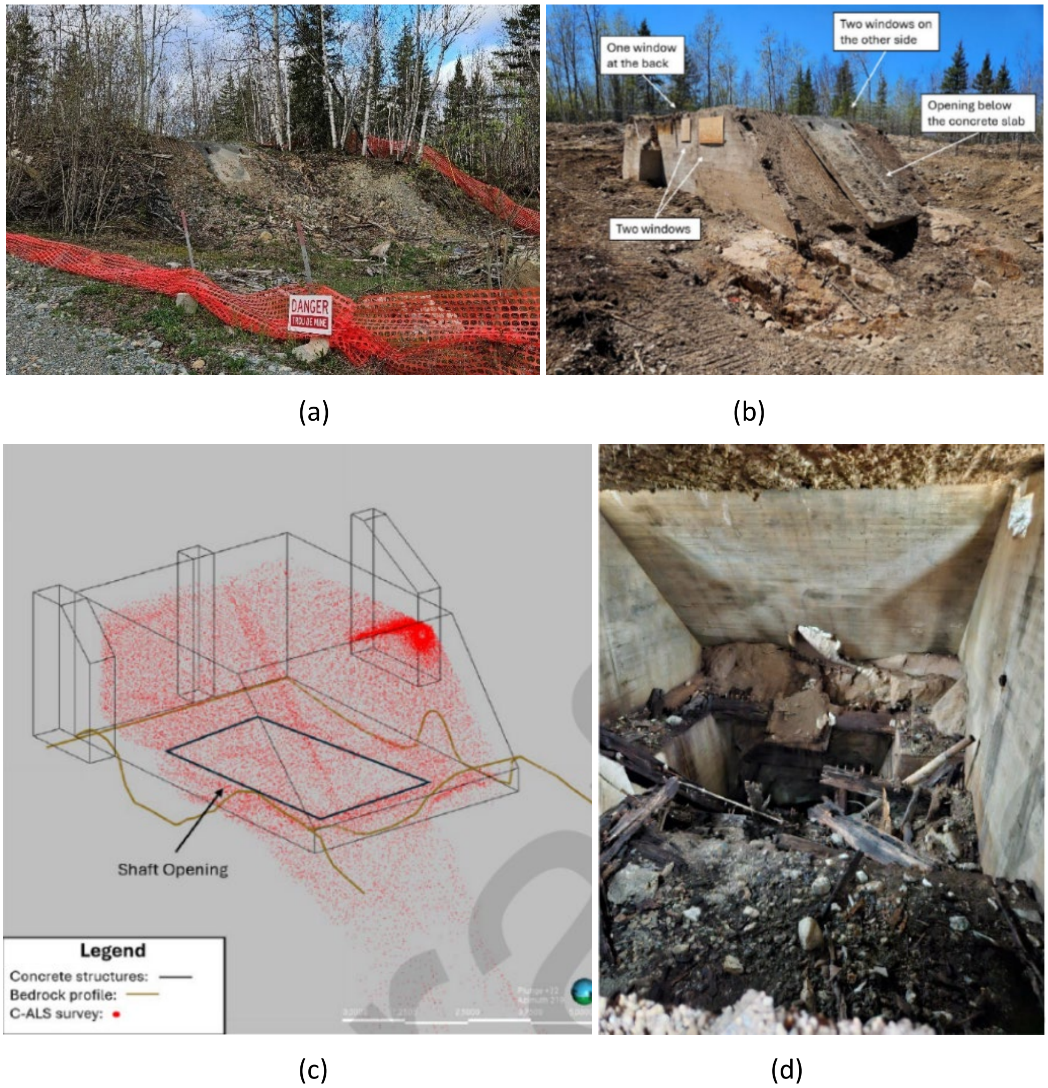


Figure 5 (a) Shaft #3 before excavation; (b) Shaft #3 after excavation exposing the concrete structure; (c) C-ALS surveys of Shaft #3 looking west and bedrock profile; (d) Inside of the concrete structure of Shaft #3

The excavation works exposed bedrock on all sides to allow geotechnical mapping of the bedrock profile around the concrete structure, to support developing the plan for corrective measures. Figure 5 shows the bedrock profile with a schematic representation of the exposed concrete structures.

3.1.2.2 East Open Stope

The East Open Stope is the easternmost mine feature on the property and is a crown pillar enclosed by a fence installed in 1995 restricting access to the open cut. The fence was reported to be in a poor condition after an inspection by the regulators prior to Agnico Eagle’s acquisition. The data review also indicated that part of the crown pillar was not included in the existing fence perimeter. A preliminary desktop analysis was completed to define a new fence perimeter based on the limited information available at the time. The stability of the remnant crown pillar of the East Open Stope was also assessed; it was found to be not long-term stable and needing to be included in the fence perimeter (WSP 2025a). Due to the lack of information on the current geometry of the stope and the geotechnical conditions, conservative assumptions were applied for most of the input parameters.

To support decision on final remediation measures, a targeted field investigation was carried out in summer 2025 (WSP 2026a). Prior to drilling, trees were cleared for access and drilling pads. The investigation was planned using a 3D Leapfrog Works model supplemented by a drone survey to obtain updated topography and aerial imagery.

Three boreholes were initially planned to confirm the geometry of the upper and middle sections of the stope and to assess the thickness and condition of the remnant crown pillar. Because early results differed from expectations, based on a legacy 3D mine model, 2 additional boreholes were added. The final program consisted of 142.8 m of drilling.

The drilling results confirmed the current geometry of the stope and crown pillar through void sonar surveys and provided new information on the geotechnical characteristics of the upper rock mass. The updated interpretation aligns with available historical plans.

Empirical methods were used to assess the stability of both the crown pillar (scaled span method [Carter 2014]) and the hanging wall (stope stability graph method [Matthews et al. 1981; Nickson 1992; Potvin 1988; Potvin & Milne 1992]). Due to the shallow dipping nature of the orebody and mined out stopes, results from these methods were judged overly conservative, based on the experience of the project team. To improve clarity in the results and reliability, further 2D numerical modelling was conducted to evaluate stress distributions in the overlying rock mass. The modelling results indicated that the hanging wall in the portion of the stope exposed at surface is stable and does not require remediation. However, tension cracking and differential horizontal movement may occur under current conditions. These potential deformations do not pose a hazard to the public given current site use but could limit future development involving permanent infrastructure.

For the section of the stope underlain by the remnant crown pillar, numerical modelling indicates that the pillar is not stable in the long term. A crown pillar failure could also induce localised hanging wall instability, expressed as tension cracks and differential horizontal movement, but significant subsidence farther from the crown area is considered unlikely.

3.1.3 Future investigations and remediation plan

3.1.3.1 Shaft #3

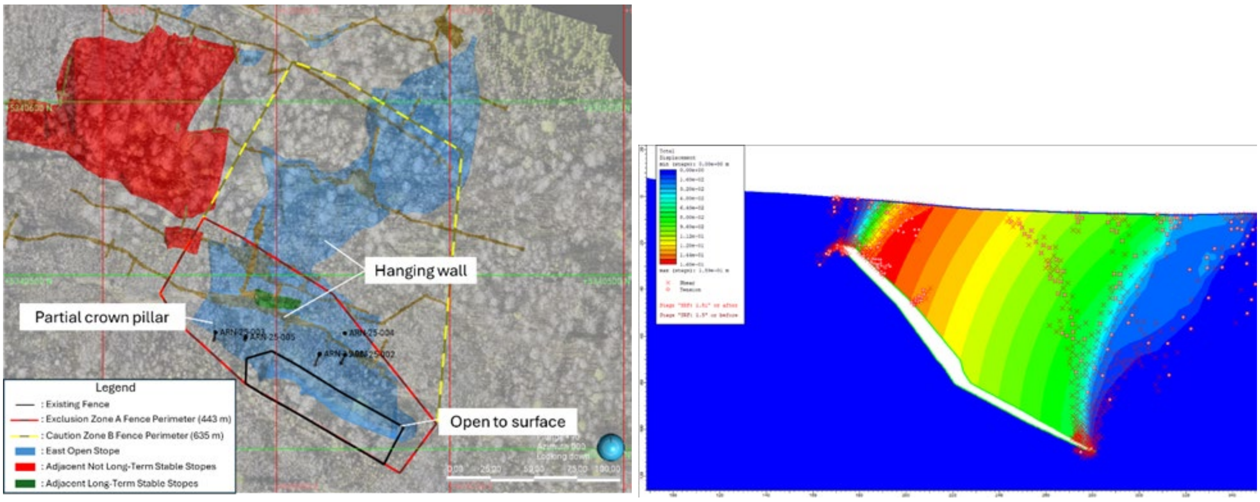
The investigation confirmed that shaft #3 remains open to surface and is currently covered by a concrete structure. Although temporary measures have been implemented to restrict access, a permanent remediation strategy is required. Based on the information available, a conceptual remediation design will be developed, supported by a gap analysis to identify remaining risks and uncertainties.

The objective of the planned next phase is to evaluate remediation options that meet long-term stability requirements at the shaft brow and comply with regulatory standards for shaft closure. Given current observations, the existing concrete structure will likely need to be demolished, as retaining an elevated structure would require monitoring and could pose a long-term risk. Based on current design work for remediation, a concrete slab anchored to bedrock spanning both the opening and the potentially unstable brow area is considered an appropriate long-term solution.

3.1.3.2 East Open Stope

Two main zones were delineated (zones A and B), as presented on Figure 6. Zone A in includes the surface-daylighting portion of the stope, the remnant crown pillar, and the upper section of the hanging wall. To protect public safety, a new fence – properly sized and complying with regulatory standards – will be installed around this zone in the short term.

A lower-risk Zone B is associated with the elevated potential for tension cracking and differential horizontal movement at surface above the stope footprint. Access restriction is not recommended at this time; however, future land use planning should restrict permanent infrastructure development due to the potential for ground deformation even before crown pillar failure.



(a) (b)

Figure 6 (a) East Open Stope and safety perimeters; (b) Modelling results supporting the perimeters

To eliminate the risk rather than limiting access, backfilling remains a viable long-term, maintenance-free remediation solution capable of securing both zones without restricting land use. Given the mine configuration, with openings spanning multiple levels with a shallow dip, additional investigation and design work will be required to evaluate the feasibility of backfilling and other options.

3.2 Case 2: Abitibi–Central

3.2.1 Background

Sites #1 and #2 are located west of Val d'Or, near Malartic. Between 1939 and 1965, the sites produced roughly 1.7 million ounces of gold, after which mining activities ceased and the mill continued to operate until 1971 (Golder Associated 2007). Through a series of acquisitions, Agnico Eagle became the sole property owner of both sites in 2024.

The mineralised zones consist of steeply dipping, subparallel and tangled narrow veins which commonly reach surface and are overlain by 10–20 m of clays. Historical mining primarily used cut-and-fill methods (approximately 75% of the orebody), with the remaining 25% extracted by shrinkage stoping. Available information indicates that stopes were backfilled either with sand-and-gravel mixtures or, in later years, with hydraulic fill from the process plant. Neither fill type incorporated any type of binding agent (WSP 2026b).

Between 1965 and 2006, several crown pillar failures were observed, many of which are documented on historical mine plans and sections. The sites are enclosed with fencing to prevent public access. Site #2 is significantly less documented, increasing the level of planning required to carry out effective field investigation. Crown pillars were previously reviewed in a desktop study (Golder Associates 2007), and limited drilling confirmed some geometric parameters. However, no geotechnical drilling or void surveying has been completed to date. Site #1 stopes extend over 350 m, while those of site #2 expand over 450 m, in a narrow and overlying system.

Observations from the 2025 program suggest that sandfill might have mobilised in certain stopes, augmenting risks of crown failure where backfill prevented it in the past. Available historical long sections do not reliably represent this condition, and this uncertainty needed to be incorporated into the investigation planning.

3.2.2 Recent investigations and stability assessments

In 2025, a review of existing data followed by a preliminary drilling campaign was completed, along with updated crown pillar stability assessments based on the results. The objective of this initial program was to confirm the location of mine openings and increase confidence in planning the detailed investigation scheduled for 2026.

At the outset of the project, a 3D model of site #1 mine was available for review. Historical mine plans and drawings produced were compiled and a 3D model for site #2 was constructed using Leapfrog Works. Figure 7 shows an example of the modelling of a stope based on the georeferenced mine plans. A site visit was also conducted to survey visible remaining surface infrastructure for comparison with the model and to provide confidence that the georeferencing was accurate.

(a) (b)

Figure 7 Modelling of stopes 1-5-21 based on historical mine plan; (a) Plan view; (b) Longitudinal view

The first investigation program was carried out in winter conditions late 2025 and consisted of 4 boreholes designed to support rock mass characterisation and stope geometry validation of both sites. A total of 142 m of drilling was completed over 24 days and 3 boreholes successfully intercepted their targeted stopes.

For site #1, 2 boreholes targeted stopes 1-F-50 and 1-D-47. Both intercepted the stopes at the expected elevations. Survey results indicate that stope 1-F-50 is partially backfilled, whereas stope 1-D-47 is empty.

Two boreholes were then drilled at site #2, targeting stopes 1-5-21. The first hole did not intercept its target. The second hole intercepted the stope, although a few metres below the planned elevation. Based on the results, the elevation of the site #2 model was adjusted, providing adequate confidence in the model to proceed with the second phase of detailed drilling investigation.

Overall, the preliminary drilling campaign achieved its primary objective of validating the 3D model prior to planning the detailed crown pillar investigation. The intercepted stopes were located where expected, and their geometries were consistent with historical mine plans. One notable exception is stope 1-5-21 at site #2, which was intercepted approximately 3 m below its expected elevation. It remains to be determined whether this vertical offset applies across the entire site #2. This potential shift will be considered during planning of the detailed drilling program.

Crown pillar stability assessments for the 3 surveyed stopes were completed using the scaled span method (Carter 2014). From the surveyed geometries and rock mass classifications obtained during the preliminary drilling, based on acceptable guidelines for crown pillar stability (Carter et al. 2008 after Carter & Miller 1995), stope 1-F-50 is considered long-term stable, while stopes 1-D-47 and 1-5-21 are not, as summarised in Table 1. The acceptable guidelines for crown pillar stability in the context of mining use and public access are derived from a relationship between the scaled span (Cs) and the Probability of Failure (PoF) based on logistic regression of the crown pillar failure database.

Based on the recently acquired preliminary investigation geotechnical data, crown pillar stability assessments were also completed for all other stopes located above the second level at both sites. Of these, 21 stopes are considered to not be long-term stable, while 20 are considered long-term stable, as presented in Table 2.

These 21 stopes will be the focus of the detailed investigation in 2026. All stopes, including those surveyed, are shown on Figure 8.

Table 1 Summary of the crown pillar stability assessment

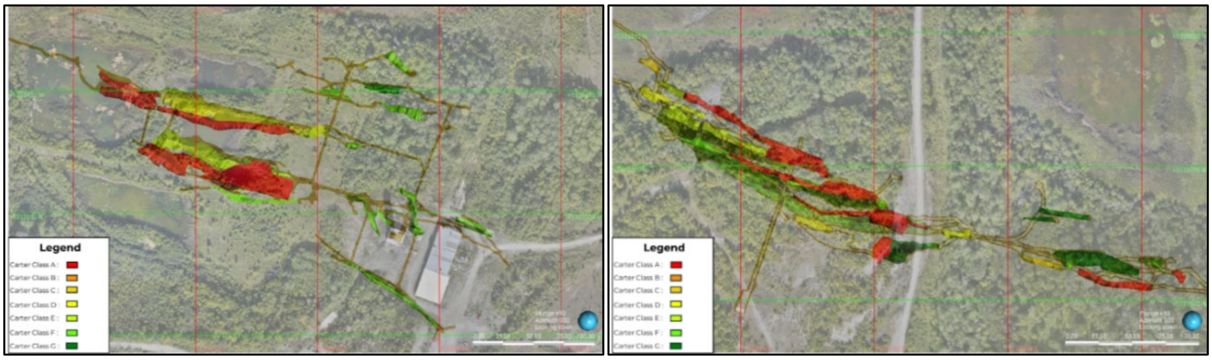
Stope	Q	PoF (%)	Class	Serviceable life	Public access
1-D-47	3.2	4.8	E	Medium term	Discouraged
1-F-50	4.7	0.9	F	Long term	Allowed
1-5-21	4.7	4.7	D	Short term	Prevented

Note: Classification based on Guidelines for use of the scaled span method for surface crown pillar stability assessment (Carter 2014)

Table 2 Summary of crown pillar stability assessment – updates desktop study for remaining targets

	Not long-term stable					Long-term stable	
Class	A	B	C	D	E	F	G
Site #1	4	0	0	1	1	10	1
Site #2	7	0	2	3	3	5	4
Total	11	0	2	4	4	15	5
Grouped Total	**21**					**20**	

Note: Classification based on *Guidelines for use of the scaled span method for surface crown pillar stability assessment* (Carter 2014)



(a) (b)

Figure 8 Map of scaled span method results; (a) Site #1; (b) Site #2

3.2.3 Future investigation and remediation plan

The 2026 investigation program will focus on assessing the level of risk associated with the crown pillars identified as not long-term stable and on evaluating potential remediation solutions. The primary objective will be to collect detailed geotechnical data (rock mass quality, presence and characteristics of fill material) and geometrical information (crown pillar and void dimensions). By validating the current risk level for each crown pillar or sector, appropriate risk mitigation and remediation scenarios will be developed based on the identified conditions and constraints.

Data collected during the detailed investigation will support stability analyses using the scaled span method, the stope stability graph method for stope walls, and plug failure analyses where required. The results will guide the development of remediation strategies for both sites, tailored to the conditions encountered. These strategies may range from medium-term securing measures to localised backfilling or excavation by zones.

3.3 Case 3: Northern Ontario – Cobalt mining camp area

3.3.1 Background

The Cobalt site is a former underground mining operation located near the town of Cobalt, Ontario (Figure 1). Mining on this property is estimated to have occurred between the 1920s to 1940s and possibly up to the 1970s in some areas with limited documentation left behind (WSP 2025c).

The mine features associated with this site became visible to the public when near-surface underground mine workings from similar sites in the town failed and caused subsidence events. Investigations were first initiated on behalf of Cobalt municipality by Golder Associates Ltd (Golder is now part of WSP Canada Inc.) in the late 1980s. In the early 1990s, Golder conducted the first geophysical and drilling investigations on the site to define any potential impacts to infrastructure (roads and residential properties).

The first data reviews, geophysical surveys and drilling investigations completed on the Vein 9 stope (Figure 9), indicated an undulating vein mined to surface in the west end and underground portion towards the east end (Figure 10). Based on the historical drawings and investigations by Golder, the width of the Vein 9 stope is approximately 5 m and it is 60 m long (striking NE–SW). Data also indicated the Vein 9 stope was partially backfilled with waste rock and included a wooden timbered floor. The open cut in the west end was backfilled to surface and secured with a mine hazard fence. Towards the west end of the Vein 9 stope is a residential property which has been reported to have had a surface subsidence event beneath the residential driveway (Golder Associates 1992).

While fencing provided a degree of surface access control, early investigations suggested that the underground workings extended beyond the fenced area, highlighting the importance of confirming stope geometry and crown pillar conditions to understand the true extent of the hazard and determining adequacy of current risk mitigation measures related to the residential property.

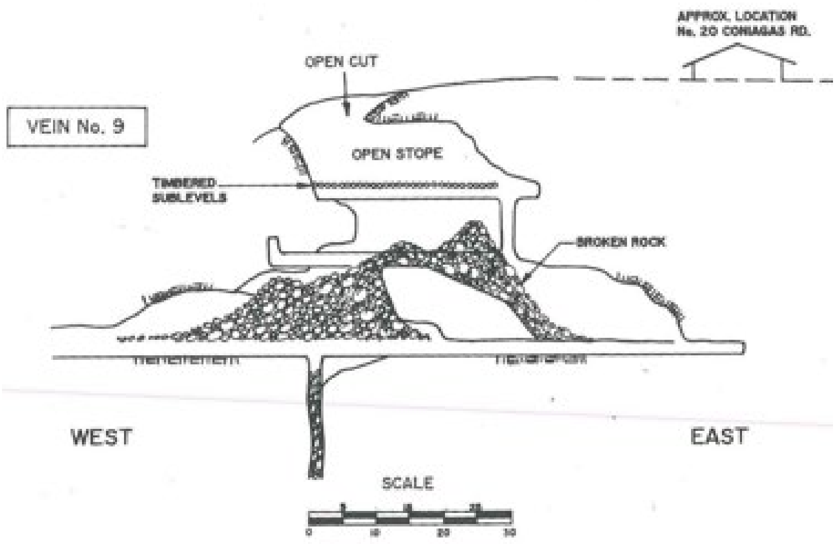


Figure 9 Vein 9 stope simple longitudinal section (Golder Associates 1992)

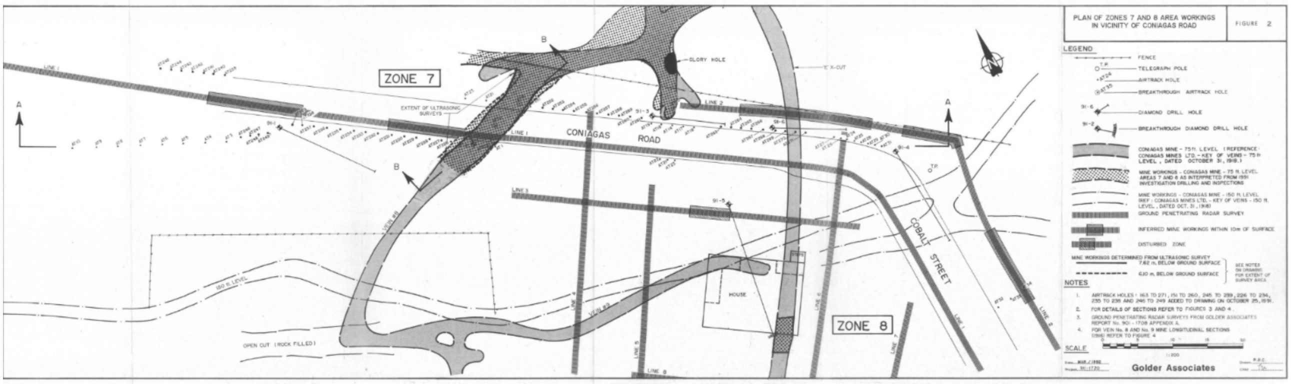


Figure 10 Vein 9 stope plan drawing (Golder Associates 1992)

3.3.2 Recent investigations and stability assessments

Investigations resumed in 2019 and included void surveys of the accessible open cut portion of the Vein 9 stope on the west end. These investigations indicated that underground workings extended beyond the fenced perimeter towards adjacent properties. A crown pillar stability assessment conducted at that time concluded that the crown pillar was not long-term stable, prompting recommendations for additional drilling to better define stope geometry and support rehabilitation planning.

Subsequent drilling (4 diamond drillholes illustrated on Figure 11 coloured yellow) and void surveying in 2020 refined the understanding of the stope geometry and confirmed that a portion of the crown pillar extending beyond the fenced area required rehabilitation. A preliminary concept was developed based on the improved geometry, but residual uncertainty remained regarding the full extent and volume of the stope, as well as the condition of historically placed backfill.

A follow-up field investigation was completed in 2023 to confirm the surface extents, reduce the void geometry uncertainty and support a constructable rehabilitation design. The program integrated:

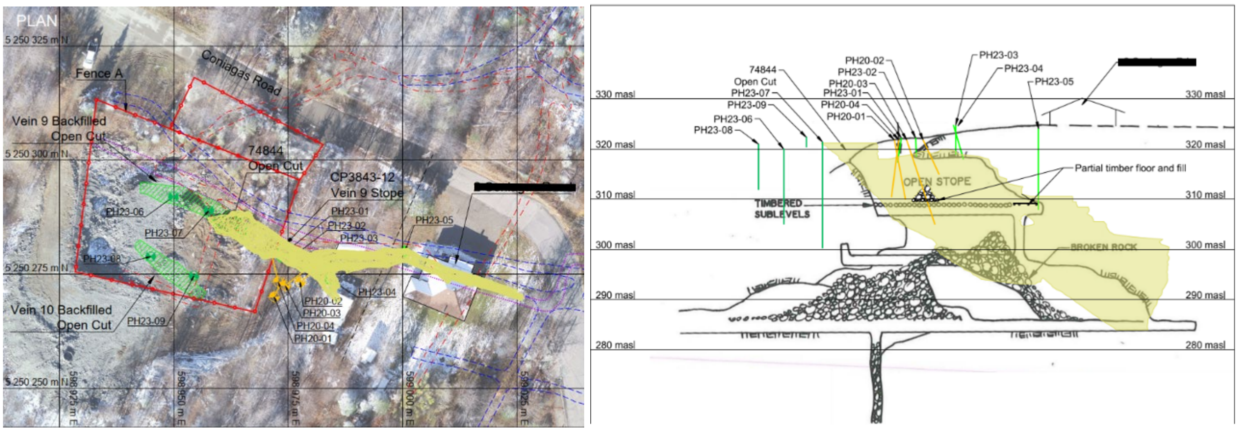
- detailed land survey to confirm property boundaries and constrain field activities
- excavation of historically backfilled areas to define lateral stope extents at the bedrock interface
- probe drilling combined with laser void surveys to develop a robust 3D stope model.

Excavation confirmed that the surface extents of the Vein 9 were contained within the existing fenced area at the bedrock interface, reducing uncertainty regarding offsite impacts (WSP 2025c). Additionally, 2 probe boreholes, in the west end of Vein 9, confirmed that no voids existed in this area (green hatched zone in Figure 11).

Five diamond drillholes and subsequent void surveys were used to generate a detailed 3D wireframe void of the Vein 9 stope (yellow geometry in Figure 11). This model demonstrated that the void volume was significantly larger than earlier estimates, and allowed the stope to be subdivided into 2 functional zones:

- upper stope with a relatively thin crown pillar, assessed as not long-term stable
- lower stope with a substantially thicker crown pillar, assessed as long-term stable and not requiring rehabilitation.

The refined geometry showed total void volumes on the order of several thousand cubic metres and provided a defensible basis for targeting rehabilitation to the portion of the stope presenting long-term risk, including being located directly under the residential property.



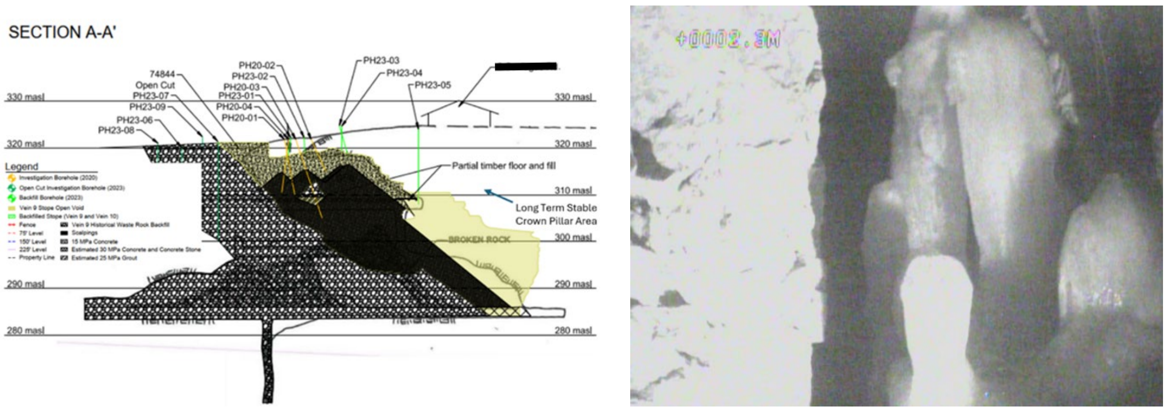
(a) (b)

Figure 11 (a) 2020 and 2023 drilling investigations of Vein 9 stope (WSP 2026); (b) 2020 and 2023 longitudinal section of Vein 9 stope superposed to historical drawing (WSP 2026)

The primary rehabilitation objective for the Vein 9 stope was to eliminate the hazard posed by void space beneath the unstable portion of the crown pillar, rather than relying on long-term access restriction.

A phased backfilling approach was selected, consisting of bulk filling with uncemented aggregate comprised of concrete stone and scalpings (scalpings hatch in Figure 12), followed by placement of an upper level of cemented backfill to achieve tight filling beneath the Upper Stope crown pillar region. Cemented backfill was used specifically where aggregate alone could not reliably achieve contact with the crown but was not intended to function as a self-supporting structural plug. All backfilled placement was via the 5 drillholes completed in 2023.

This approach allowed rehabilitation efforts to focus on remediating the mine feature while avoiding unnecessary disturbance of areas assessed as stable.



(a) (b)

Figure 12 (a) Longitudinal section of Vein 9 stope showing remediation filling (WSP 2026); (b) Initial ice conditions inside the stope

3.3.3 Remediation execution and challenges

Although inspected during summer months, significant ice accumulation within the Vein 9 stope was identified during pre-remediation inspections (Figure 12b) and represented a major constructability challenge. Ice increases the risk of void bridging, obscured stope geometry, and reduced confidence in achieving tight contact between backfill and the crown pillar. Early mitigation attempts using hot water and heated concrete were unsuccessful, leading to a pause in remediation activities. A staged mitigation program was subsequently implemented, combining tarping, forced heated air, downhole steaming, and temperature monitoring. These measures reduced ice accumulation to acceptable levels, enabling backfill placement to proceed and supporting effective elimination of the hazard beneath the unstable crown pillar.

Uncemented aggregate backfilling was carried out using a combination concrete stone and scalpings delivered through the 2023 drillholes and the open cut (towards the west). Concrete stone was used to block connectivity to deeper mine levels, while scalpings were used for bulk filling of the upper stope, leaving a controlled void to accommodate cemented backfill placement beneath the crown.

Cemented backfill was placed in multiple stages using different mix strengths to meet specific functional requirements, including blocking deeper connections, achieving flowable fill beneath irregular or obstructed zones, and achieving tight contact with the crown pillar. Placement was monitored using downhole cameras and weighted tape measurements to confirm backfill elevation and continuity.

In total, approximately 3,000 m³ of aggregate and cemented materials were placed. Concrete quality was verified through casting concrete cylinder testing, and as-built conditions confirmed tight filling beneath the unstable portion of the crown pillar.

Following completion of backfilling, boreholes were sealed to surface, the site was regraded, fencing was removed, and access controls were implemented using surface berms and boulders.

The rehabilitation was completed in accordance with provincial rehabilitation requirements and achieved the objective of eliminating void space beneath the portion of the crown pillar assessed as not long-term stable. No ongoing monitoring or maintenance has been identified as necessary.

The site is considered suitable for repurposing with unrestricted surface access; however, a land use restriction against construction of buildings over the rehabilitated stope was recommended to manage residual uncertainty typical of legacy mining environments.

4 Lessons learned and conclusion

The rehabilitation of legacy mine hazards in the Abitibi–Northern Ontario region requires a structured, risk-based approach, adaptable as new information becomes available through several stages of investigation. As demonstrated in the case studies presented, historical mining records are often limited and incomplete, and subsurface conditions must be verified through targeted investigation before long-term remediation strategies can be defined.

Based on the authors’ experience, the following lessons can be applied to similar legacy sites:

- **Progressive, iterative investigation materially changes outcomes.** In all cases, the refined 3D openings void geometry developed during the follow-up investigations demonstrated that early-stage interpretations underestimated the extent of the conditions. Targeted rehabilitation decisions would not have been defensible without this level of confirmation.
- **Hazard elimination requires flexibility in execution.** The ability to pause, reassess and adapt the execution strategy is critical to achieving effective remediation objectives.
- **Not all legacy features require uniform treatment.** Based on a risk driven approach, differentiating between unstable and stable portions of the hazards and site areas allows rehabilitation efforts to be focused where required, avoiding over-intervention while still achieving risk reduction objectives.
- **Integrated, risk-based approaches support long-term closure objectives.** By addressing the hazard source rather than relying on perpetual containment, the rehabilitation supports future land use and long-term liability reduction – key considerations from an industry perspective.

The investigation of shaft #3 and the East Open Stope in the sector of Abitibi–West highlighted the complexity of updating partial and past hazards related assessments, rehabilitating aging infrastructure and the need to integrate multiple investigation methods – from excavation and C-ALS scanning to geotechnical drilling and numerical modelling. These efforts confirmed the presence of significant previously ignored hazards, including an inclined open shaft and a remnant crown pillar assessed as not long-term stable. The results enabled the delineation of hazard zones and the development of conceptual remediation pathways, ranging from short-term fencing to long-term solutions such as structural covers and possibly engineered backfilling.

At the Abitibi–Central, the preliminary drilling program successfully validated the 3D models and confirmed the geometry and condition of several key stopes. The preliminary drilling campaign achieved its objective of providing the confidence needed to support the planning the detailed crown pillar investigation. The updated stability assessments identified 21 crown pillars as not long-term stable, forming the basis for the detailed investigation program planned for 2026. This next phase will refine geotechnical and geomechanical data, enabling the evaluation of tailored remediation options ranging from medium-term securing measures to more comprehensive interventions such as backfilling or excavation by zones.

The Cobalt site Vein 9 case study demonstrates that effective rehabilitation of historical mine hazards depends on an adaptive, risk-based process that integrates progressive investigation with flexible execution. Initial discovery of potential impacts from the Vein 9 stope stared in the late 1980s and early 1990s, with additional work being reestablished in 2020, 2023 and final remediation in 2024. The unexpected presence of ice in the stope illustrates how field conditions can directly affect implementing rehabilitation measures. At the Vein 9 stope, the combination of geometry confirmation, targeted backfilling, and responsive field management enabled elimination of a long-term hazard beneath a developed area.

The approach and lessons presented are transferable to other legacy sites where documentation is limited and subsurface conditions evolve as investigation proceeds. Staged investigation programs, integrating historical records, field data, along with empirical and numerical assessments, demonstrate that effective rehabilitation must be grounded in a thorough understanding of site conditions, to move beyond simple access restriction towards eliminating hazards at their source. Progressing from desktop review to field investigation, stability assessment, and ultimately long-term remediation design ensures that legacy mine features are accurately characterised and responsibly addressed. This structured, evidence-based approach reduces long-term risk, supports community safety, and enables future land use flexibility.

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