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Caving subsidence backfilling: case studies

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Abstract

Cave mining methods, including block, panel, and sublevel caving, invariably result in surface subsidence as the extraction of material at depth triggers upward propagation of the cave. This process typically begins with undetectable elastic deformation before progressing to visible surface fracturing and the eventual formation of a subsidence crater. As mining continues, these craters expand both laterally and vertically, with unsupported walls subjected to chronic sloughing and erosion. To mitigate the extensive surface footprint, reduce environmental liabilities, and potentially lower closure costs, backfilling the subsidence zone of influence with waste rock or conditioned tailings is increasingly being considered and studied as a proactive engineering solution. This paper examines the technical and economic considerations of backfilling strategies and draw on several global case studies. The findings suggest that while backfilling could effectively limit lateral expansion, reduce water inflow or provide alternative waste rock or tailings storage, success depends on rigorous hydrological management and a detailed understanding of site-specific geotechnical responses.

Keywords: *cave mining, backfill crater, subsidence mitigation, hydrogeological management*

1 Introduction

Subsidence is one of the negative aspects associated with cave mining. Although the final lateral extents of cave subsidence could be approximately 10 times smaller than the typical surface impact of open pit mining, the erratic nature of fully developed subsidence and crater formation significantly reduces mitigation options. Poor stability of the crater walls and subsidence zone make rehabilitation extremely challenging. There are other environmental aspects associated with subsidence, such as oxidation of exposed rock and negative impacts on water quality that can make mine closure difficult and costly. During active cave mining, once the cave breaches the surface, unmitigated subsidence will provide pathways for surface water to reach underground workings and contribute to mudrush hazard. This is because the cave column has the potential to accumulate water and generate fines, and through production activities, provide a discharge point (Jakubec 2018). There have been numerous inrush occurrences during mine operations that have caused injuries, fatalities, and significant disruption, as well as excess dilution.

To mitigate the extensive surface footprint, reduce environmental liabilities, and potentially lower closure costs, backfilling the subsidence zone with waste rock or conditioned tailings is increasingly being considered and studied as a proactive engineering solution. Jakubec et al. (2026) discusses in detail proposed methodology for evaluating caving subsidence backfilling. They suggest 3 basic scenarios for subsidence backfilling: pre-, concurrent-, and post-breakthrough backfilling. This paper examines some technical and economic considerations of backfilling strategies and summarises several cases where subsidence crater backfilling has been undertaken with various degrees of success. With exception of Telfer mine, all backfilling so far was post-breakthrough filling of subsidence craters.

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2 Subsidence terminology

Typically, 4 stages of subsidence evolution can be recognised:

The first stage is elastic deformation. As the cave propagates upwards, the surface will begin to deform elastically before visible tension cracks appear. This movement can be detected with instrumentation or aerial surveys. The second stage is when visible cracks appear and, in most of cases, the crater gradually forms as the surface subsides. The third stage is when the subsidence crater propagates laterally as mining below continues and a mobilised zone is formed. As the crater deepens, unsupported crater walls are subjected to sloughing and erosion. Failure modes of the walls and crater wall angles in this unconfined zone will depend mainly on rock mass conditions and the structural framework. The fourth stage is when mining below ceases and compaction and consolidation of the caved zone take place. Downward movement of the crater floor will decelerate, but unsupported crater walls will continue to unravel under gravity and erosion. Colluvium will gradually accumulate at the base of the crater walls and lateral expansion of the subsidence will eventually reach equilibrium. This process can take years and decades, depending on conditions. Typical subsidence morphology, after Laubscher et al. (2017), at the final stage of mining is illustrated in Figure 1.

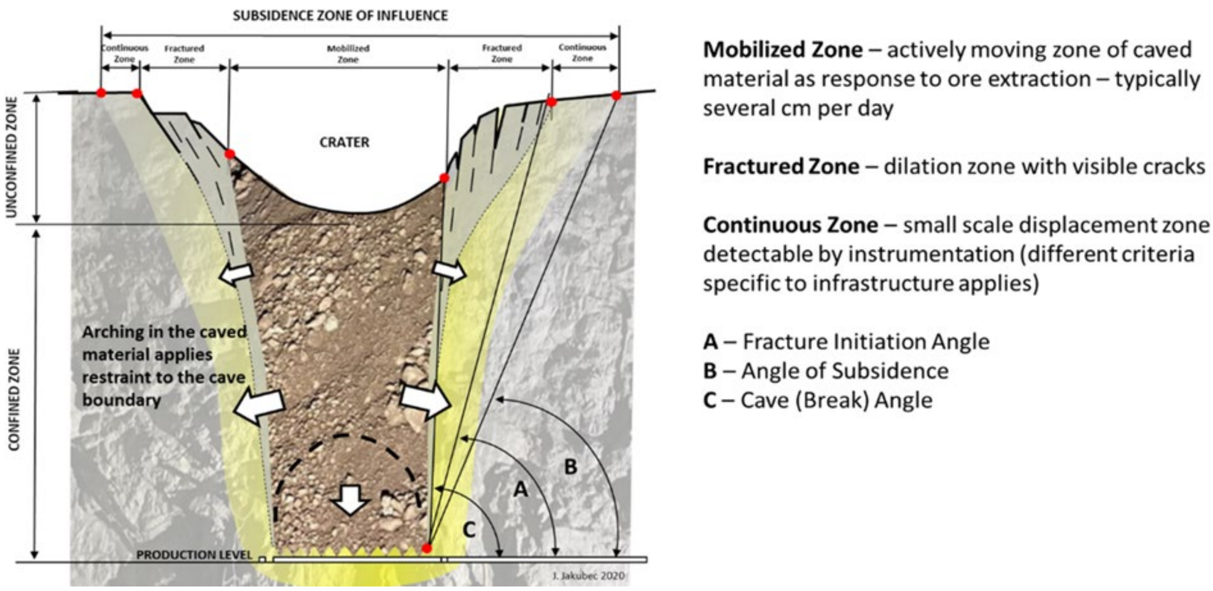


Figure 1 Typical cave mining subsidence morphology of the final stage of mining (modified from Laubscher et al. 2017)

There could be an exception to the gradual formation of subsidence with a collapse of the surface if a significant void is formed during the caving process or if the crown pillar above the cave collapses, e.g. Northparkes (Fowler et al. 2003). Caving of semi-circular kimberlite pipe-like orebodies in competent host rock can, and in most cases does, form steep empty stopes with relatively stable walls that could be several hundred metres high (Jakubec et al. 2018). Crater shape and behaviour of unconfined crater walls near the surface depends on local conditions and could be very complex. A typical example is the New Afton mine cave where subsidence geometry and dynamics are influenced by several factors like former open pit wall geometry, intersected waste rock fills, large-scale structures, topography and presence of weak lithological units with poor rock mass quality (Davies et al. 2018).

Several factors will influence the geometry and rate of vertical and horizontal subsidence progression. Laubscher (1994) defined the following factors that play a role on subsidence geometry: rock mass conditions, large-scale structures, depth of mining, bulking factor, rate of mining, and size and geometry of the caving footprint.

Typical production rates for a cave with, for example, a 100,000 m^2 footprint could be 30–40 ktpd. That would translate to 14,000–18,000 m^3 per day, using a broken rock density of approximately 2.2 t/m^3. If surface expression of the crater is, for example, twice the mining footprint, i.e. 200,000 m^2, the average vertical movement of the subsidence surface as the rock moves down in the crater would be approximately 10 cm per day. Of course, subsidence does not move evenly, but it gives an idea of the rate of movement.

3 Pros and cons of backfilling subsidence

Where technically feasible and economically viable, backfilling the subsidence zone of influence could have a number of advantages. There are a few disadvantages in specific cases that are also indicated.

3.1 Pros

Limiting lateral expansion of surface disturbance: backfilling provides lateral support to the cave boundary, inhibiting the expansion of the fractured zone. If the crater is backfilled, the surface footprint is reduced and could be potentially even smaller than the caving footprint of the block or panel below. This could be very significant from an aesthetic point of view but also serves to minimise surface water diversion, reduce the entry of near-surface fines that contribute to mudrush risk and could be a significant advantage for mine closure.

The depth of the crater could be limited or even eliminated: this could provide a basis for rehabilitation and recultivation of the surface of otherwise inaccessible unmanaged subsidence that is typically fenced and off limits.

Limited surface water inflow into the cave: reduction of water inflow into the cave will have significant economic and safety benefits in terms of pumping requirements, mudrush risk and dilution.

Waste rock and possibly tailings storage: backfilling with waste rock or a mix of waste rock with conditioned tailings could have economic and social benefits.

Limiting acid rock drainage: disposal of acid generating rock into the subsidence could simplify mine closure and waste rock management.

3.2 Cons

Hydrogeological risks: in arid climates, backfilling can transform a ‘terminal sink’ (which contains contaminants) into a ‘through-flow’ system, facilitating the migration of acid mine drainage into regional groundwater.

Operational safety hazards: backfilling above an active cave can increase mudrush risk if water is allowed to pond on the surface or if the fill material liquefies. Furthermore, operating heavy machinery on a subsiding surface requires stringent safety protocols and may be limited by the trafficability of the material.

Resource sterilisation: placing waste rock or tailings into the subsidence zone can sterilise underlying ore resources, making future extraction difficult or economically unfeasible if cut-off grades are lowered in the future.

Dilution: migration of backfill fines can lead to dilution and operational issues; however, migration is not a given, and mitigation measures of uniform draw and pre-screening of backfill materials are available.

4 Possible backfilling scenarios

Backfilling is increasingly viewed not just as waste disposal, but as an engineered solution to manage subsidence, stabilise ground, and reduce environmental liability. The strategies vary based on material type, timing, and placement method to cater to the specific risks associated with caving-induced subsidence.

4.1 Material selection for fill

Two base materials are available for filling: waste rock and tailings. These can be used individually or in combination, in various processed forms:

1. Waste rock: waste rock from open pit mining or underground development has been used for bulk filling of subsidence craters and open pits, mainly to stabilise walls and reduce waste dump costs. This material provides lateral support pressure to the sidewalls of the caved zone, inhibiting the continuous damage and movement of the surrounding rock.
2. Thickened and filtered tailings or filter cake: to mitigate the risk of liquefaction and mudrush, tailings placed above active caves must be dewatered to a high density, such as thickened tailings or filter cake. If tailings are to be used, it is critical to maintain a self-draining surface to prevent water ponding, which is a major safety risk in active caving environments – see detailed discussions in following sections. Tailings can also be amended with the addition of cement.
3. Co-disposal: strategies involving the mixing of tailings and waste rock can be employed to utilise void space. This approach can improve the stability of the stacks by allowing tailings to fill the voids between waste rocks, optimising discharge space.
4. Cemented paste backfill (CPB): CPB can be utilised to improve the mechanical properties of backfill and reduce permeability, often using binders like Portland cement, slag, or fly ash.

4.2 Placement timing considerations

4.2.1 Option 1: subsidence column filling commencing before breakthrough

Refer to Figure 2 – in this case, the projected subsidence area is prepared and instrumented ahead of cave breakthrough. This option requires fill to be placed before or very soon after breakthrough of the cave to surface, and then continuously added to constrain lateral expansion of the crater. This approach allows for the active management of the subsidence zone and ensures that filling can be implemented safely while caving subsidence continues in a controlled manner.

Filling continues and positive water drainage is managed during the entire mine life (Figure 2). Based on the instrumentation and risk assessment, filling may need to be done by remotely controlled equipment for safety.

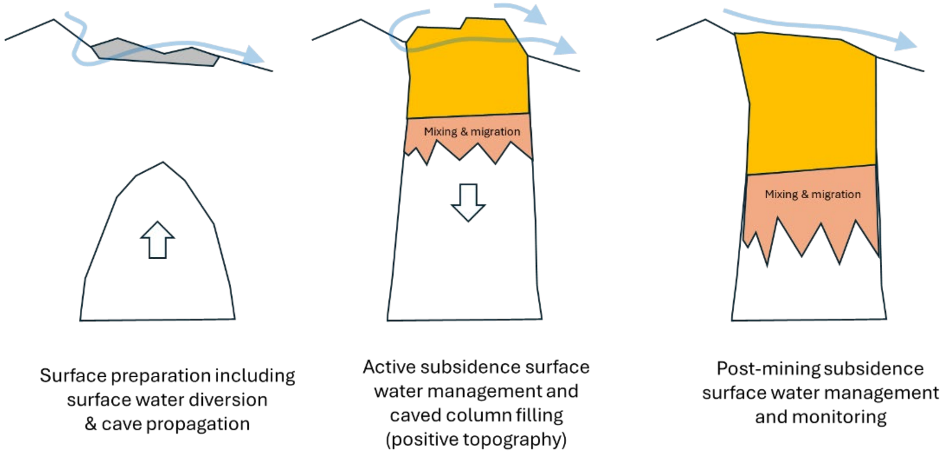


Figure 2 Schematic example of subsidence column filling commencing before breakthrough

The example of pre-filling using waste rock is Telfer mine, where the bench was preloaded with waste rock prior to the cave reaching the surface. This strategy provided confinement to the pit walls, limiting the size of the subsidence crater and minimising wall sloughing upon the cave's breakthrough to the open pit.

4.2.2 Option 2: subsidence column filling start after breakthrough when crater is formed

Refer to Figure 3 – this option involves backfilling after surface breakthrough to manage subsidence progression and surface water drainage, as seen at Padcal mine. Delaying the start of backfilling until breakthrough provides certainty on where backfilling is required but comes with higher safety risks until the backfill surface can be established.

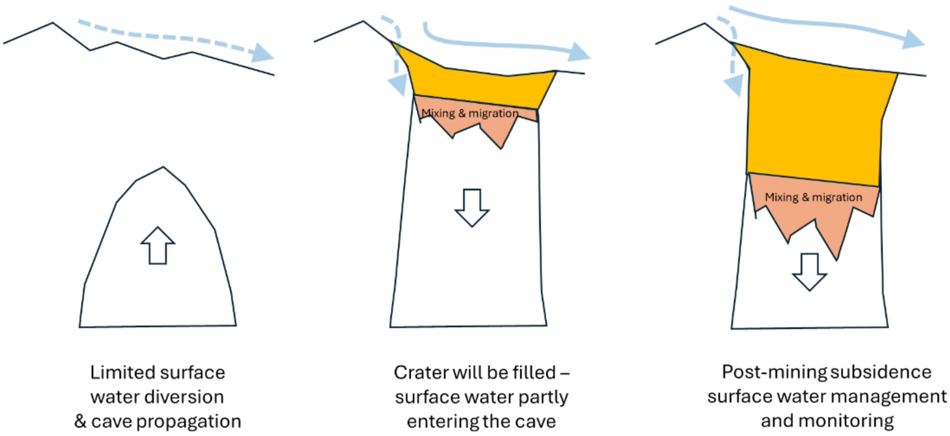


Figure 3 Schematic example of subsidence column filling start after breakthrough

4.2.3 Option 3: subsidence column filling commencing after crater is formed and mining completed

Refer to Figure 4 – this option involves filling the subsidence crater during or after the mining is completed. The distinction between option 2 and option 3 is that option 3 does not necessarily require active management of the crater surface and water drainage. Scarps and crater walls may require that material be tipped similar to waste rock dumps or pit backfilling. The muckpile surface will be more stable if done after mining which reduces safety concerns on surface, and the cons of potential resource sterilisation and dilution.

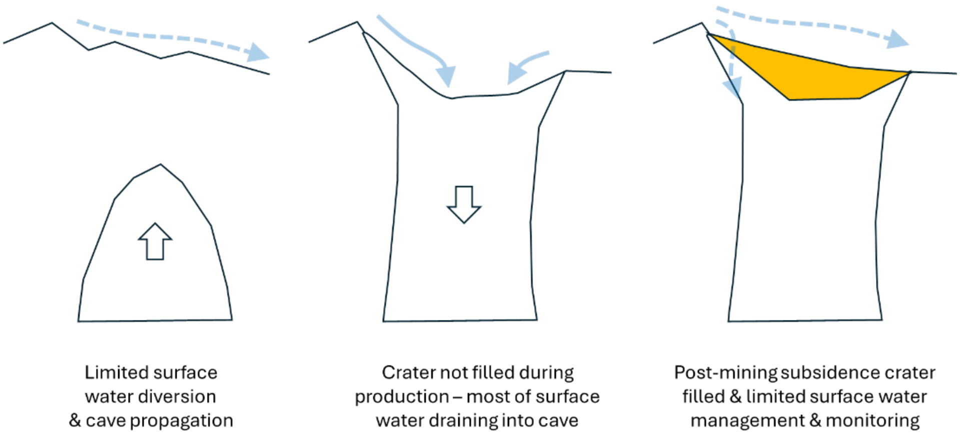


Figure 4 Schematic example of subsidence column filling start after breakthrough

4.3 Hydrology and water management

A major safety risk with subsidence above active caves is the accumulation of surface water, which contributes to mud rush risk into the underground workings. Ensuring a surface water diversion and preventing ponding is critical.

4.4 Monitoring and early warning

Even with backfilling, effective management of subsidence is required, combining surface monitoring (e.g. radar, prisms, photogrammetry) with subsurface data (e.g. time domain reflectometry [TDR], microseismic sensors, extensometers). Monitoring of the subsidence influence on surface will be more challenging with backfilling, and maintaining reliable materials volume balance is essential.

Trigger action response plans (TARPs) must be developed to set backfilling activities' exclusion zones and evacuate areas when specific surface deformation thresholds are breached. Using remotely operated equipment will eliminate the safety risk to personnel.

5 Critical risks

A risks register specific to subsidence and backfilling options under consideration must be developed for every stage of the design. Some of the key risks include:

- failure to control lateral expansion
- slope stability of the surrounding terrain
- subsidence breakthrough location
- uncertainty about the cave shape
- fines migration and dilution
- dust generation
- noise pollution
- traffic disturbances
- water management and ponding
- liquefaction and mudrush.

This process will help identify and trade-off if there are critical risks associated with subsidence that could be effectively addressed via backfilling.

6 Case studies

6.1 Padcal block cave mine, Philippines

The Padcal mine is located in the mountains of Luzon island in the Philippines, some 15 km south of Baguio city. It has been in operation since 1958, initially as an open pit, and in 1963 as an underground block cave mine. The Sto. Tomas II orebody is associated with various porphyry stocks. Mechanised load–haul–dump block caving was introduced in 1996 at the 908 level. Padcal mine was the first underground block cave operation in the far east. Since the mine started commercial operations, it has been producing copper concentrates, with gold and silver as by-products and it is owned by Philex Mining Corporation.

Padcal mine complies with the Philippines *Mine Safety and Health Standards* rule 328, Section C: "regular backfilling of the subsidence shall be undertaken to maintain a minimum of 4% gradient over the subsidence area to drain off rainwater" (Department of Environment and Natural Resources 2000). Padcal mine had a dedicated subsidence management crew backfilling and grading the subsidence in order to divert the surface water away from the subsidence zone and minimise the infiltration into the caved zone (Figure 5).

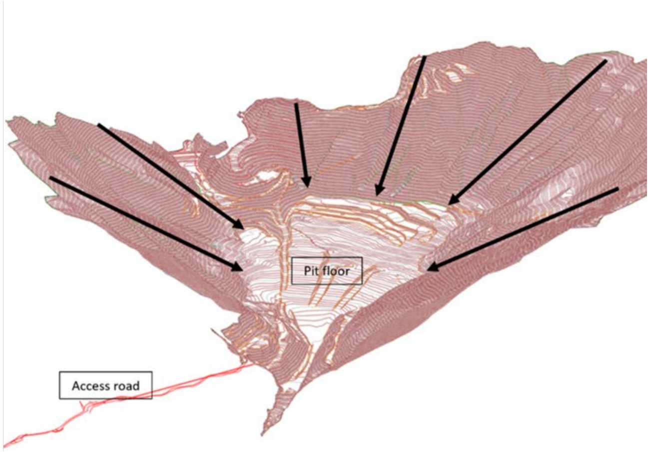


Figure 5 Managed subsidence backfill at Padcal mine (after Monis 2026)

Monis (2026) stated, “the six-decade operational history of the Padcal mine demonstrates that subsidence backfilling is not merely a surface restoration task but a fundamental geomechanical requirement for mature block caves operating under high-precipitation conditions. By systematically integrating waste rock backfilling with rigorous draw control, the operation has successfully established a ‘buffer zone’ that suppresses fines migration and mitigates hydraulic connectivity between the surface crater and the extraction horizon”.

Padcal mine is a good example of successfully managed subsidence using backfill placement timing option 2 – backfilling after the breakthrough. Additional cost was offset by safety benefits and reduced cost of pumping. It should be also noted that subsidence is so well managed that the mine allowed local public transport routed through the middle of the subsidence.

6.2 San Manuel block cave mine, USA

The San Manuel porphyry copper mine is located near San Manuel, Pinal County, about 50 km northeast of Tucson, Arizona in the USA. It was mined by both open pit and block caving mining methods. The mineralisation was discovered in 1879, but the main body of the deposit was discovered in 1942. The first major production began in 1955. The mine and smelter were permanently closed in 2002. Over 700,000,000 short tons of ore were extracted using the block caving method.

The original orebody was cylindrical, but the San Manuel fault caused the division into 2 main parts, called the upper San Manuel orebody and the lower Kalamazoo orebody. The Kalamazoo caving operation was separated from the San Manuel cave by a pillar in which 5 shafts some 900 m deep were located. Kalamazoo was shut down shortly after the cave broke through to surface and did not develop a subsidence crater, only tension cracks. San Manuel crater was very complex. The subsidence was influenced by local faulting (San Manuel fault) and the presence of a Gila conglomerate caprock (Blodgett 2002). On the southeast side of the subsidence, it is bounded by steep escarpment and in the northern part of the subsidence the San Manuel open pit was developed.

According to Cori Hoag (pers. comm. 2026), backfilling the south side of the San Manuel open pit with the No. 4 Waste Rock Dump was an ingenious move on the part of the Magma Copper Mine engineers. They simultaneously stabilised a significant portion of the subsidence escarpment, which had developed as a near-vertical topographic feature with safe access issues on the southern edge of the overall subsidence zone, and sited a new waste rock dump with essentially zero haul distance in an otherwise space-challenged location (pit was expanding close to eastern property boundary).

Open pit mining of the San Manuel oxide copper deposit occurred from 1985 through 1995. Underground sulphide copper mining and production occurred in the immediately adjacent, underlying area from 1955 through 1999. During the years of concurrent mining, the waste rock materials were dumped into the active, subsiding crater.

The open pit equipment operators learned to work safely around the large tilted and subsided blocks of San Manuel Formation and to push material as needed to build safe access ramps and expansion pushbacks. The ramp roads were groomed frequently to fill in subsidence features, and the pit topography was surveyed monthly. The subsidence of the open pit was non-uniform in that the north side of the pit was sinking 2–5cm/month and the south side was sinking 15-30cm/month (roughly but noticeably more). This deposition was specifically targeted at the south side of the subsidence crater, adjacent to a steep escarpment (Figure 6).

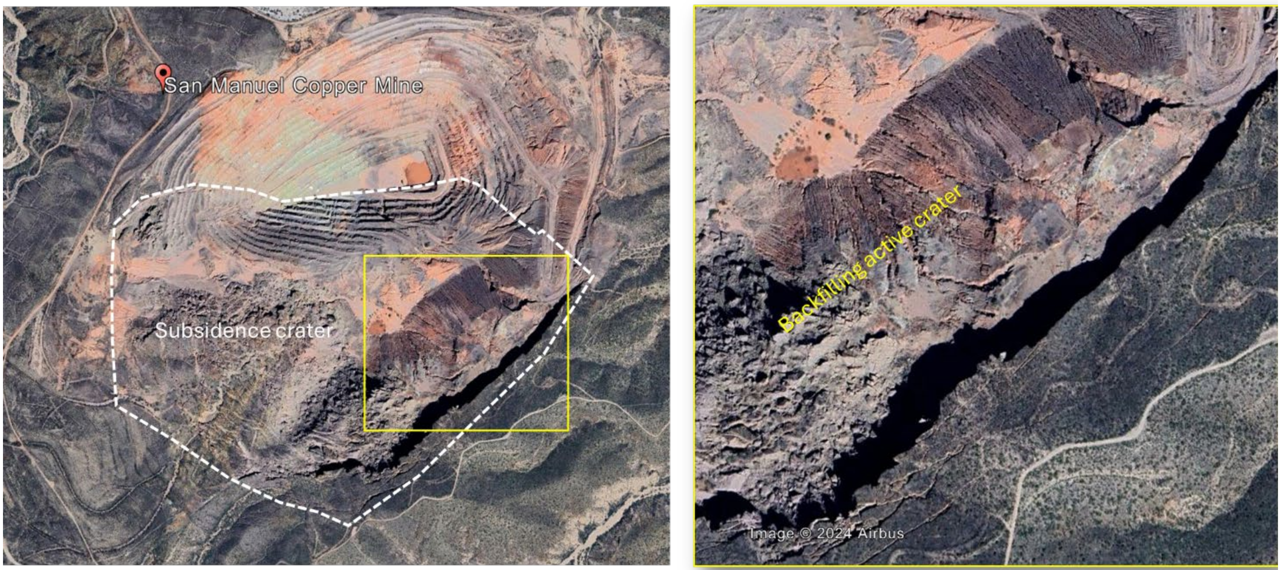


Figure 6 Waste rock backfill deposited in the San Manuel subsidence (Google map)

San Manuel is a good example of multiple concurrent activities within the subsidence zone, including open pit mining and waste rock deposition into the subsidence crater. It is an example of backfill placement option 3 and safe operating practices.

6.3 New Afton block cave mine, Canada

New Afton mine is a block caving operation with multiple caving blocks at various elevations due to the inclination of the orebody. It is located approximately 10 km outside of Kamloops and 350 km northeast of Vancouver in British Columbia.

New Afton is mining copper-gold porphyry deposit which extends along a southwesterly plunge from immediately beneath the Afton Mine open pit, which operated from 1977 until 1997. The principal commodities are copper and gold in copper concentrates.

New Gold Inc (now Cour Mining) began construction and development of the New Afton underground block caving mine in 2007. The open pit was dewatered and accumulated mud and sediments removed from the bottom of the pit. Block caving reached commercial production in July 2012, following the first drawbell blast in September 2011.

Initial production was from the Lift 1 caving block with West and East Cave blocks approximately 600 m below the pit. In 2021, the production from Lift 1 was completed as Lift 2 B3 block was reaching full production. A schematic section through the mine is illustrated in Figure 7.

The abandoned open pit and completed East and West Cave Lift 1 subsidence offered logical space for tailings deposition. New Afton mine conducted a comprehensive multi-disciplinary study and risk analysis to ensure that thickened tailings (approximately 60% solids) will not migrate into the previously caved rocks of Lift 1 and will not pose any risk to underground operation in terms of mudrush or excess water inflow. The deposition commenced in 2022 (Figure 7).

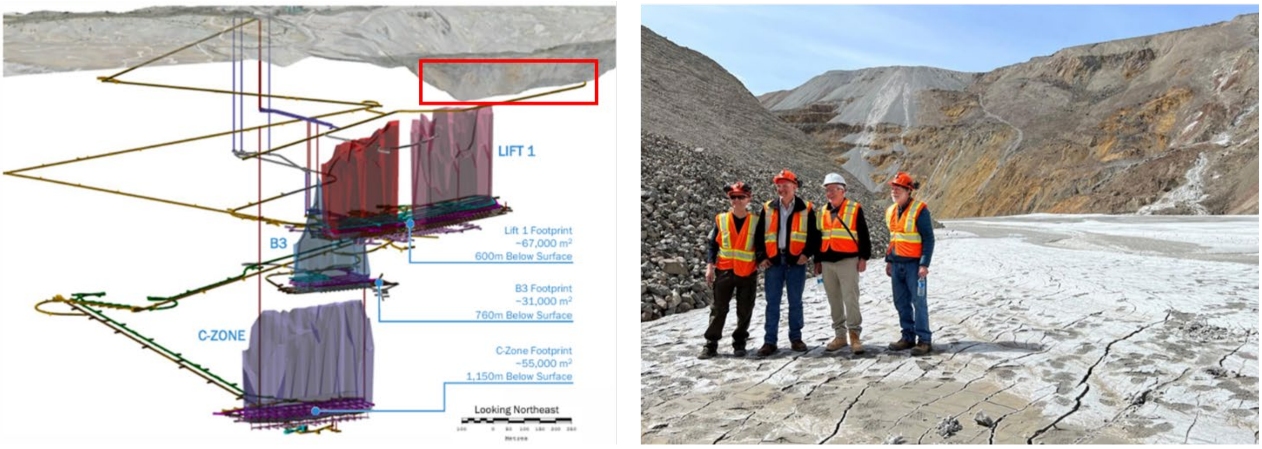


Figure 7 Schematic section through the New Afton mine and in-pit thickened and amended tailings (New Gold Inc 2023)

The New Afton mine is a good example of comprehensive subsidence monitoring to protect surface infrastructure (Davenport et al. 2022), and standard operating procedures (SOPs) including TARP and risk assessment processes. These are all necessary for the safe deposition of the tailings into previously active subsidence with continuous caving in adjacent blocks. This is an example of backfill placement option 3 and the first case of using tailings as backfill media.

6.4 Telfer sublevel caving mine, Australia

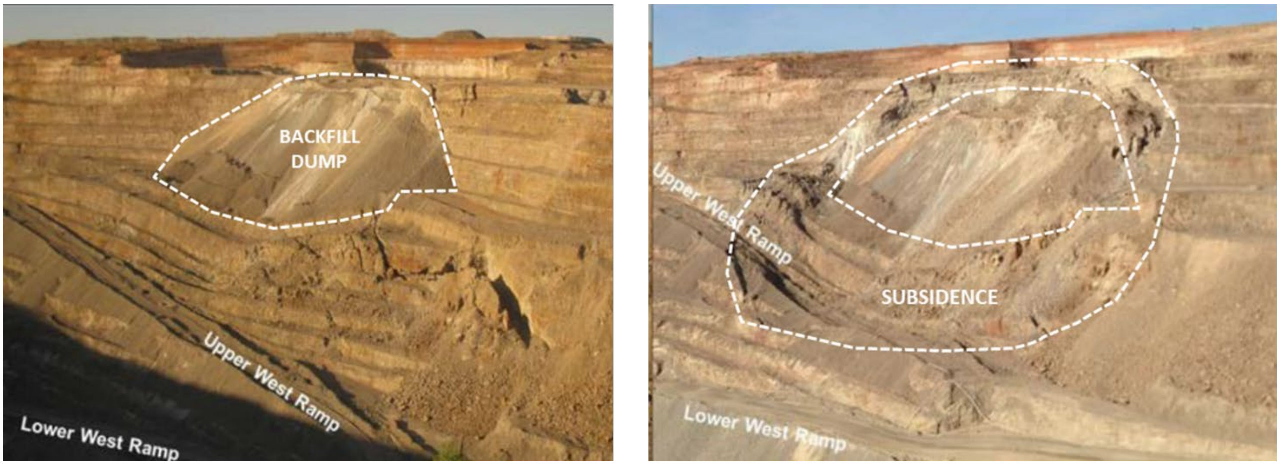
The Telfer mine is a gold, copper and silver mine located at Telfer in the Great Sandy Desert in Western Australia, approximately 420 km south of Broome. It is owned by Newmont, having acquired the previous owner, Newcrest Mining.

The mine was discovered by Newmont in 1972 and developed initially as open pit. In the 2019–2020 financial year, the Telfer mine produced 393,164 troy ounces of gold, 35 million pounds of copper and 164,000 troy ounces of silver. Telfer was concurrently mining from open pit and from sublevel caving (SLC) located approximately 600–1,000 m below the pit.

In order to minimise and defer initial subsidence expansion, the open pit bench was backfilled with 1.1 million tonnes of rockfill (Figure 8). The life of concurrent open pit and SLC operations was anticipated to be a further 5 years. SLC mining commenced operation in 2006, and subsidence broke through to the surface in 2009. Surface deformations within the subsidence zone continue at a rate of 500–2,000 mm per month. Underground and open pit operations have continued concurrently with the progressive enlargement of the SLC subsidence zone (Figure 8).

Risks were monitored by understanding the cave propagation mechanism through modelling, comprehensive real-time surface and subsurface deformation monitoring instrumentation and the use of TARPs. In addition to the instrumentation and TARP implementations, the risk of subsidence was further managed by continued backfilling of the developing subsidence crater with waste rock from the western wall over the life of the SLC operation.

Telfer mine is a good example of option 1 (proactive backfilling of the subsidence) and concurrent operation of SLC and open pit. The program of pre-filling was very successful, and because the main objective was to limit lateral expansion of the subsidence while operating open pit, after pit mining ceased, the filling was discontinued and subsidence crater gradually increased.



(a) (b)

Figure 8 (a) Waste rock buttress at the Telfer mine shortly after sublevel caving cave breakthrough; (b) Expanding subsidence crater (Nicoll et al. 2017)

6.5 Diavik sublevel retreat mine, Canada

The Diavik Diamond Mine is located in the Northwest Territories, Canada, 200 km south of the Arctic Circle and 30 km from the Ekati mining complex.

The operations include 4 kimberlite bearing pipes, mined by both open pit and underground mining methods. Kimberlite pipes were located under the lake, and impermeable dykes must be designed and constructed around the pipes before mining can be implemented (Figure 9). Open pit mining of all 4 kimberlite pipes transitioned to underground mine. Three out of 4 pipes were mined by the sublevel retreat (SLR) underground mining method without backfilling. Because the fourth pipe was located in the pit walls in close proximity of the dyke separating the lake from the mining area, the sublevel open stoping with backfill was implemented.

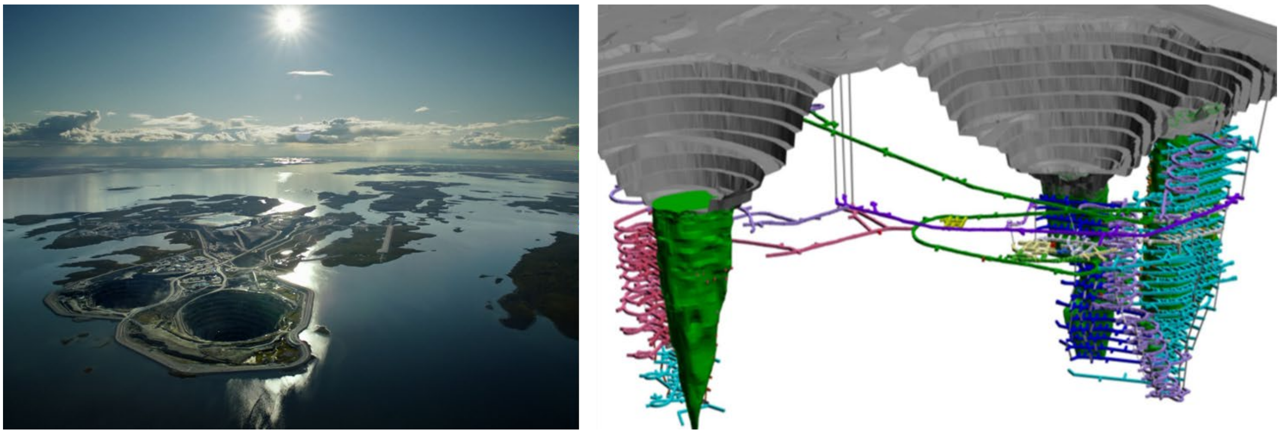


Figure 9 Diavik mining complex with 2 sublevel retreat and one sublevel open stoping mine (Jakubec 2018)

The cylindrical nature of the diamond deposits and the strong country rocks meant that mining by the SLR method generated steeply dipping subsidence. This was reported from other diamond mines such as Ekati, Finsch or Koidu (Jakubec et al. 2018). As the pits are surrounded by a lake, excessive subsidence instability cannot be tolerated and any empty stope would need to be filled with waste. As a mitigation measure, the Diavik mine proactively designed a waste deposition ramp that would enable trucks to dump the waste rocks into the void. This operational readiness with extensive monitoring system, TARPs and SOP allowed to safely manage the subsidence. No backfilling was ever needed since instability was limited to localised sloughing of the crater walls.

6.6 Kirunavaara sublevel caving mine, Sweden

The Kirunavaara SLC mine, recognised as the world's deepest iron ore mine, is located in Kiruna, northern Sweden, and is owned and operated by the mining company LKAB. The orebody is approximately 4 km long and between 80 and 160 m thick, reaching depths of up to 2 km. The deposit strikes approximately 12° northwest and dips 55–60° to the southeast; crucially, it dips directly towards the city of Kiruna. Iron ore extraction has been ongoing for over 100 years. Ground deformations caused by mining activities, particularly on the hanging wall side, began affecting residential areas as early as 1970. By 2004, the severity of these deformations necessitated the relocation of parts of the town, including the historic town centre. The subsidence also impacts the footwall side, which houses critical mine infrastructure.

To mitigate these deformations, LKAB initiated a project to evaluate the effects of backfilling the subsidence crater with waste rock (Figure 10).

(a) (b)

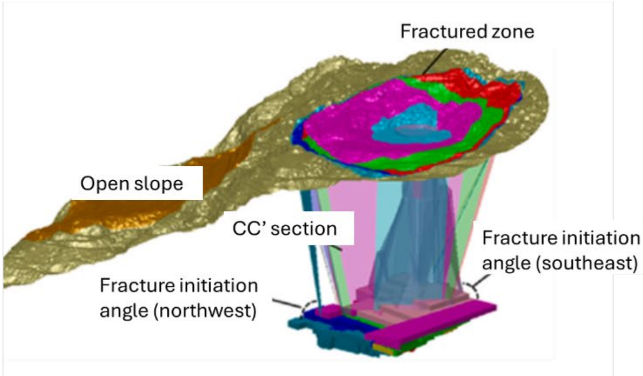
Figure 10 Waste fill of subsidence at Kiruna sublevel caving mine indicated by (a) yellow rectangle on Google image and (b) view from the local road (photo by Jakubec)

Numerical analyses, conducted using RS2 software and calibrated with GPS monitoring data, revealed mixed results regarding the effectiveness of this practice (Carlsson 2025). Backfilling the crater effectively stabilises the hanging wall by increasing the 'break angle'; this effect is most pronounced at shallower depths. Conversely, backfilling does not improve stability in the footwall. Simulations indicated that footwall deformation actually increased by approximately 2 cm when backfill was applied. This adverse effect is attributed to the self-weight of the backfill material. The added mass increases the vertical load on the collapsed material and the surrounding rock mass, thereby inducing further deformation in the footwall region.

6.7 Various sublevel caving mines in China

The authors are not directly involved with backfilling projects for caving-related subsidence in China; however, we recognise that SLC is a common mining method there and have worked on several SLC projects within the country. The following section presents a selection of representative case studies identified through a literature review of relevant projects in China.

Case study 1: the Dahongshan Iron Mine is located in Yuxi City, China. The mine extracts 2 ore veins: the shallow orebody is mined via open pit (5.5 million tons/year), while the deep orebody is extracted using SLC (4 million tons/year). Underground mining at the 480 m sublevel began in 2006 and, as of 2022, had deepened to the 340 and 370 m sublevels. The open pit and underground mining areas are horizontally separated by only 250 m. As underground caving progressed, it posed a stability threat to the open pit slope (Figure 11). A defining geological feature is the presence of magma intrusion-type faults, especially the F2 fault. Characterised by dense gabbro-diabase rock formed from cooled magma, the F2 fault acts as a massive dyke separating the open pit from the underground workings. The surface fractured zone developed in stages, initially appearing as a unilateral collapse before expanding asymmetrically due to the constraint of the F2 fault. While the fault inhibited deep rock movement, it could not prevent shallow rock damage from migrating and connecting with surface fractures. To mitigate these issues, the mine began continuous waste rock backfilling into the surface collapse pits in 2017, utilising waste rock stripped from the open pit operation (Figure 10b). Monitoring confirmed that the backfill successfully restrained the expansion of the surface fractured zone, maintaining a fracture initiation angle of approximately 79° on the open pit side.



(a) (b)

Figure 11 Dahongshan iron mine. (a) Isometric view of the surface fractured zone due to sublevel caving mining; (b) Backfill treatment to the collapse pits on the open slope surface (Ma et al. 2024)

Case study 2: the Hemushan SLC iron mine is located in Anhui province, China. Surface subsidence was first observed in 2008. The operation faced strict safety constraints due to the proximity of surface construction projects, which were situated less than 80 m from the subsidence zone (Figure 12). To mitigate the risk of slip failure at the caved space wall, the mine implemented a strategy of backfilling the caved space with excavated waste rocks. Subsequent monitoring confirmed that following the backfilling, no large-scale extension of the subsidence occurred, allowing nearby surface constructions to maintain safe working conditions.

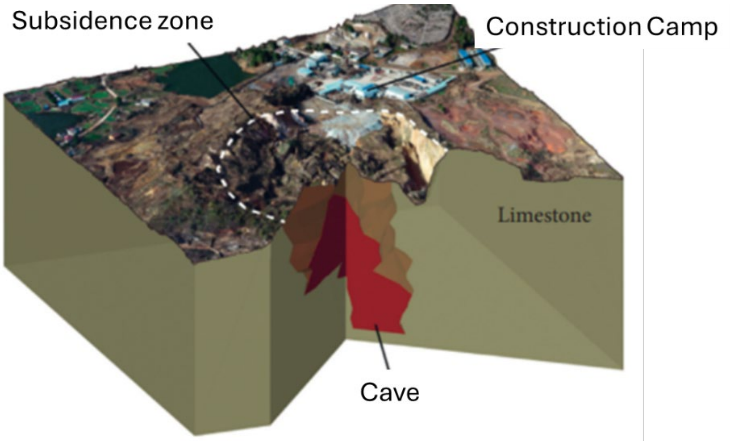


Figure 12 Isometric view 3D view of the deposit and associated surface subsidence at the Hemushan mine (Ding et al. 2020)

Backfilling practices at other SLC sites in China, such as the Dagushan iron mine and Tongkeng Mine, are noted but not detailed here due to the scope of this work.

7 Conclusion

Backfilling is no longer viewed solely as a waste disposal method but as an engineered solution to manage caving-induced subsidence and stabilise the surrounding rock mass. Backfilling could have significant benefits during the mine production, chiefly reduction of water inflow and minimising the mudrush risks as it was demonstrated at Padcal mine (Monis 2026). It can also have significant positive impact for mine closure and environmental and social impact. The most critical safety consideration is the surface water management and prevention of tailings mobilisation if tailings is used as backfill. Maintaining a self-draining gradient is essential to mitigate the risk of inflow and inrush into active underground workings. In fact, proper managed subsidence backfilling will reduce the risk of inrushes as clearly demonstrated at Padcal mine. The most critical economic consideration is prevention of tailings mobility and preferential migration through the muckpile to the mining areas resulting in excess dilution. For any project where subsidence filling is being considered, the authors recommend progressing from conceptual assessment through focused trade-off studies before committing to pre-feasibility or feasibility level design (Jakubec et al. 2026). The safety of concurrent surface backfilling and underground mining relies on integrated monitoring systems (radar, prisms, TDRs) and clearly defined TARPs to manage episodic subsidence and protect personnel.

Case studies presented in this paper demonstrate various backfilling strategies resulting in various degrees of success. Except Telfer mine, none of the other existing cases of subsidence backfilling were part of original mine design and strategy, but they still represent experiences that could encourage more a serious look at this opportunity. Authors are aware of confidential projects where backfilling of caving subsidence will be one of the conditions of obtaining a mining permit.

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