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Geotechnical and operational risk management planning for a long ore pass

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Abstract

The use of long ore passes for ore handling presents an appealing alternative to offset the energy burden and safety risks associated with trucking solutions for underground extraction. In particular, where orebody shape and infrastructure arrangement presents an opportunity to place and utilise a long ore pass, inclusion of a geotechnical and operational risk assessment during the planning stage becomes imperative to eliminate potential fatal flaws or severe impediments to the operation.

Several recent studies have been concluded within the broader industry to review and benchmark geotechnical and operational risk management issues associated with the use of long (300-500 m) and ultra long (>500 m) ore passes; however, knowledge and data in the public domain specific to geotechnical and operational risk assessment for long ore passes remains limited. Specific questions that remain unanswered include the cumulative risk effect of known hazards – both geotechnical and operational – as a function of ore pass length, and strategies to successfully manage a long ore pass.

This paper presents a single case study in which a detailed, albeit qualitative, risk management assessment was carried out to determine the feasibility for utilising a long ore pass in a caving operation. As an outcome of the risk assessment, decisions were enabled regarding planned risk mitigation interventions, ore pass maintenance and replacement strategy, and ore handling solutions required to ensure a feasible and sustainable operation. These included planned placement ofa replacement pass, column height monitoring, the use of continuous column feed, water management, access points for hangup release, and a split pass system. Results of this case study may assist in expanding the current knowledge base, and solution management for similar industry challenges.

Keywords

Long ore pass, Risk management, Geotechnical, Operational, Planning.

1 Introduction

In a caving operation, the target orebody shape and orientation frequently lends itself to options where macro infrastructure layouts can be designed, meaning widely separated infrastructure connected through long drives or shafts. In a case where “top of mine” and “bottom of mine” infrastructure separated 300-400 m vertically, for establishment of sublevel caving extraction levels, and materials handling infrastructure, this presented an attractive potential to benefit from direct materials transfer

through a series of single long drop pass systems (Fig. 1). In this case, the planning of an ultra-long ore passes transfer system was employed to optimise on development and production throughput.

However, while the operational case was strategically self-evident, input from multidisciplinary stakeholders was required to ensure against the potential for system failure that may result in severe consequential rehabilitation requirements (Hadjigeorgiou 2013). Dependencies for successful operability of such an ultra-long pass system are a function of several contributing conditions, accounting for, amongst many others, the prevention of, and controlled release of hangups, ore pass stability and longevity, safety, and reliable throughput (Stacey 2005), discussed further herein. Careful consideration must therefore be given to assess critical infrastructure vulnerability, the consequence to operational sustainability, ensuring against potential failure, suspension of production, either temporarily or more long term, and serious safety risks.

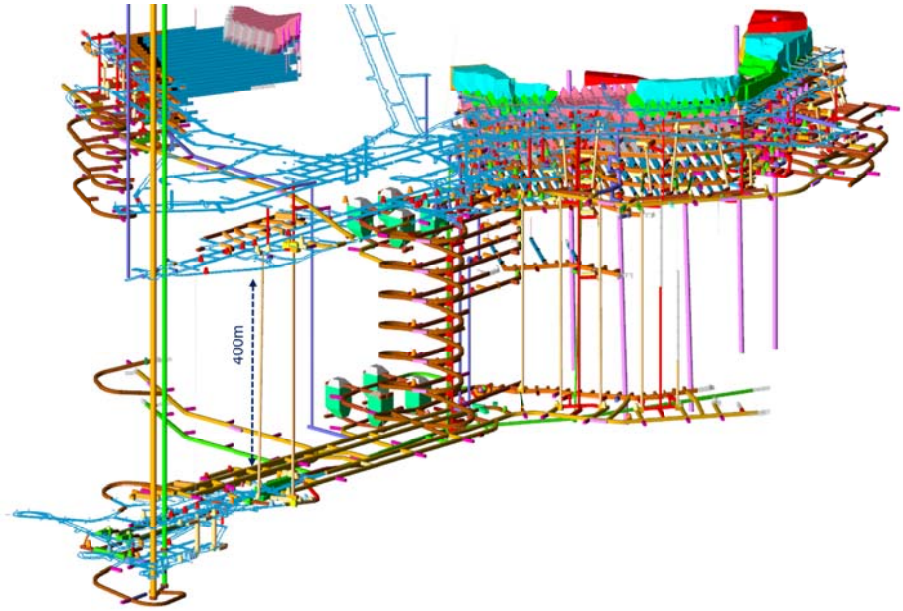


Fig. 1 Macro infrastructure layout for a sublevel cave operation showing ultra long ore pass location (400 m).

A case in point is discussed herein where a detailed, albeit largely qualitative, risk assessment and risk management strategy were carried out through the collective and engaged input of multidisciplinary stakeholders, to determine conditions under which the ultra-long pass system might be feasible for the duration of the mine's production needs.

2 Industry references

A key challenge to assess the likelihood for success or failure of an ultra-long pass system, aside from the obvious rock-wall stability, muck flow and handling constraints, is obtaining examples of similar cases against which to benchmark. In the case under consideration, successful boring of the raise was ruled out as major risk on the basis of proximal passes and geotechnical analysis for shaft construction already completed in the same host environment – i.e. siting in terms of rock mass conditions and local stress state was not a principal concern (Walls 2019, McCracken and Stacey 1989). However, the probable longevity of the pass, and sustainable operability was more difficult to define given the nature of muck that would pass through the shaft (Bartlett 2020, Bartlett 2022, Bunker et al 2015), and uncertainties in operability for the length of the ore pass system (Salmi 2024).

Recent work (Salmi 2024) presents an effort to compile and compare known cases of rock passes > 300 m previously implemented in the industry (Table 1). These cases highlight dominant problems encountered, however while the cases include significantly long ore passes up to 500 m and longer, information to relate the problems to the length of the passes is less clear. For example a dominant problem described as "hang ups due to feeding wet muck" may be encountered in any length of ore pass when poor or incorrect operational conditions are exercised. Additionally, consequences of associated components such as the host rock conditions, duration of pass operation, and column control are not clearly related to the length of the pass, but merely cases where long ore passes have encountered difficulties. The relationship of air blast risk increase as a function of ore pass length is acknowledged (Salmi 2024), with numerical assessments to evaluate impact from uncontrolled release

of hangups having found that discharge height is a major contributor to safe ore pass management (Wang 2021); however, each of these findings affirm the requirement to consider the effect of ore pass length on the risk management requirements to ensure feasible operability as a function of ore pass length.

Table 1. Industry examples of ultra-long passes > 300 m (Salmi 2024).

Operation	**Location**	**Maximum ore pass length (m)**	**Method of excavation**	**Dominant problem**
Rio Blanco Division, Adina, Codelco	Chile	516	-	Hang-ups due to feeding wet muck
Brunswick	Canada	325	Raise-boring	Structural failure, Stress-induced failure
Grasberg	Indonesia	500 to 650	-	Severe air blast/back blast, dust mitigation issue and serious wear which resulted in significant widening of some passes in the system
Henderson	Colorado, USA	Currently 200 in full length. Mine may use passes with lengths beyond 300 in the future	Raise-boring	Flow dynamic issues and preferential draw in the ore passes' system, significant piston effect, and dust propagation in the system
Kiirunavaara	Sweden	Around 350	Raise-boring	Significant wear and deterioration, stress and structural induced failures, issues with oversized fragments blocking ore passes
Finsch Mine Petra Diamonds	South Africa	350	Conventional drill and blast methods	Extensive wear and deterioration, resulting from prolonged scaling, rendered one of the long ore passes irreparable and necessitated its abandonment

The intuitive recognition of cumulative potential for failure as a function of increasing ore pass length one may consider to be self-evident. By contrast, quantification of this cumulative increase is yet to be explicitly defined and did not form part of the case under consideration.

Additionally, while there is a clear thread throughout the available source material to account for the influence of multidisciplinary components, from geotechnical through to construction, operational, maintenance and monitoring (Salmi 2024, Hadjigeorgiou 2013, Bunker et al 2015, Bartlett 2020, Bartlett 2022), a particular practical consideration was encountered as a challenge for the case in this paper, which was ultimately overcome through considerable leveraging of geotechnical risk reporting to gather a multidisciplinary stakeholder engagement and carry out a risk review for the ore pass plan. The outcomes of the risk review, albeit largely qualified rather than quantified, enabled a considered approach, the outcome of which was to define alternative arrangements, and minimum ore pass management protocols.

3 Geotechnical conditions

Specific to the case in question, the departure point to motivate for a risk review arose through geotechnical assessment of the probable ore pass longevity based on rock conditions hosting the planned ore pass system. As indicated, reasonable confidence for overall wall stability was determined through rock mass characterisation (Roberts 2011, Peck and Lee 2008), and scanning of an adjacent completed ventilation raise (operational data). However, three vulnerable locations were identified where the pass intersected dolerite intrusions (Fig. 2, Fig. 3, Fig. 4), and where initial unravelling had the potential to exacerbate with wear. Stress-induced failure was ruled out as a potential contributor, based on the scanned images, and rock mass analysis. While the potential unravelling against dolerite presented a concern, the regional persistence of the dolerite intrusions precluded alternative siting. As a result, the likelihood for increased wear in these locations was accounted for in the risk review, together with the cumulative effect of decreased lifespan for the ore pass system as a function of the ore pass length, and vulnerability to critical failure for the infrastructure design.

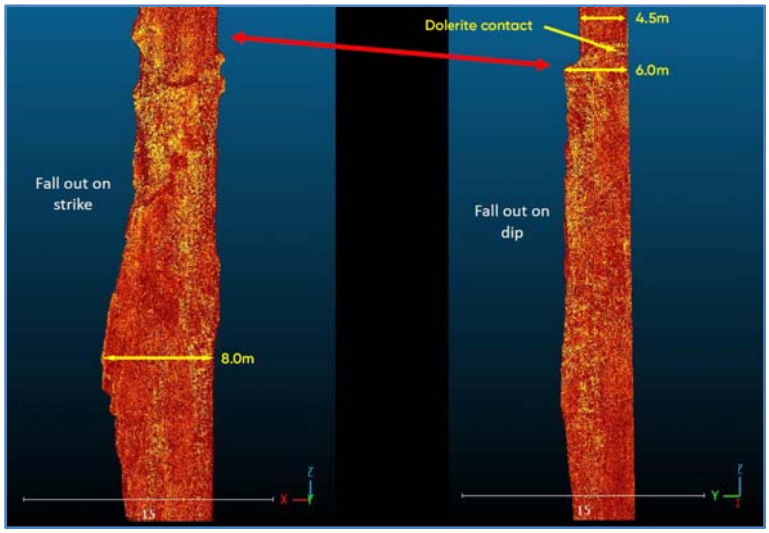


Fig. 2 Scanned adjacent ventilation pass perimeter (operational data).

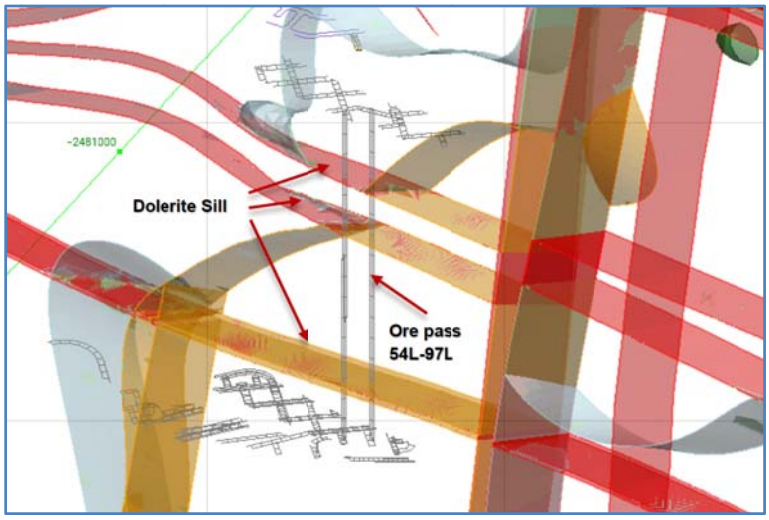


Fig. 3 Lithological section showing dolerite intersection through ore pass system.

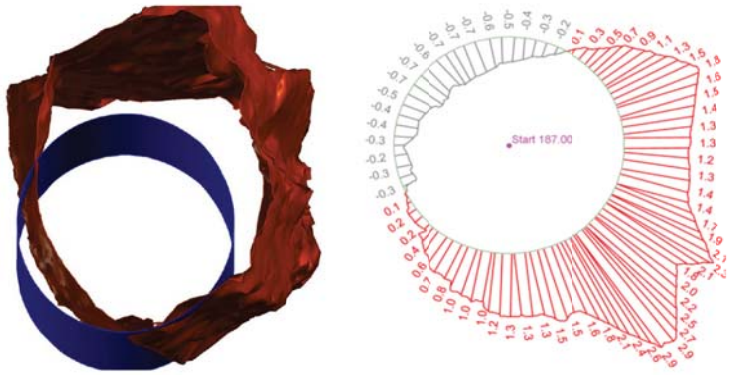


Fig. 4 Cross section showing diameter and perimeter change through dolerite intersection.

4 Mining risk management

To ensure a sustainable ore pass utilisation plan, a multi factor analysis was undertaken with input from multiple disciplinary stakeholders, including mining, safety, engineering and operators (Table 2). Consideration was given to:

- Air blast risk potential as a function of hangup height
- Potential severity of consequence as a function of hangup height release
- Practicalities for hangup release
- Increased complexity of hangup release requirements as a function of pass length, and therefore hangup height

- Potential for increased wear from bombing for hangups
- Potential for uncontrolled release, and severity as a function of hangup height
- Practicalities of column height monitoring
- Practicalities and dependencies of ore pass functionality through sustained continuous ore flow
- Critical production dependencies
- Water ingress management

A series of six alternative arrangements was compiled, with consideration for schedule impact on construction, practicalities for execution, maintenance, replacement strategies and safe throughput management. The completion of a quantified decision matrix provided a significant breakthrough for planning a replacement system and a mid level transfer, which previously had been regarded as superfluous. In the short term, the planned 400 m ore pass system was agreed and elected as the most pragmatic early startup approach, simultaneous to the establishment of mitigation measures including the mid level and replacement passes.

Table 2 Multi-factor analysis applied to determine ore pass design and operation risk management constraints for ultra long pass arrangement.

Option	Features	Longevity	Operability	Hangup management	Constructivity	Scheule	Contingency/Mitigation	Safety	Opex	Capex	Score
	Weighting %	10%	15%	20%	5%	10%	10%	15%	5%	10%	100%
Option 1 – Base case mid level transfer with LHD loading	54L crusher chamber 54L ore pass 3500mm 74L loading area with LHD 94L-97L transfer pass 97L bulkhead with apron feeder and CNV belt	5	7	8	8	5	5	5	2	3	5.7
Option 1a – 54L mid level transfer with apron feeder	54L plug 3500mm 54L-74L ore pass 3500mm 74L transfer feeder 74L-94L ore pass 4500mm 94L-97L transfer pass	5	6	6	4	2	2	6	5	4	4.8
Option 1b – mid level transfer with Hagg loader	54L - ring beam 3500mm (20m) 54L-74L ore pass 3500mm 74L Haggloader feeder 74L flexible conveyor train (FCT) 74L-94L ore pass 4500mm 94L-97L transfer pass	5	3	7	7	5	5	5	4	2	5.0
Option 1c – mid level transfer gravity feed	54L – ring beam 3500mm (20m) 54L-74L ore pass 3500mm 74L transfer pass 74L-94L ore pass 4500mm 94L-97L transfer pass	2	1	4	1	5	5	4	8	6	3.8
Option 2a – mid level transfer gravity feed with finger passes	54L – ring beam 3500mm (20m) 54L-74L ore pass 3500mm 74L transfer pass 74L plug on main ore pass 94L ore pass 450mm	2	7	4	1	5	5	4	6	6	4.6
Option 2b – single 400m vertical pass	Single 400m ore pass from 54L OPA to 94L dead box, with mid-level access for identification and unblocking hang ups	2	8	6	10	7	5	3	7	8	5.9

5 Conclusions

A key outcome for this case study was the pragmatic approach of multidisciplinary stakeholder engagement to determine a resolution for the ultra long ore pass system that would enable short term efficiency, while ensuring long term mitigation strategies. The engagement of multidisciplinary input

for ultra long ore pass risk management is well understood within the realms of industry experience. However, the practicalities of bringing together the professionals for collective engagement require additional effort. It is considered a significant achievement of this case that the collective risk review was accomplished, with the outcomes for significant planning and design adaptations, while still utilising the benefit of ultra long ore pass development in the early stage of the operation.

Ultra-long passes have great economic benefit potential and as such will continue to be planned within mine designs wherever possible. However, an additional finding while conducting this case study was that the cumulative increase in risk management requirements associated with an increase in pass length is intuitively and qualitatively self-evident, whereas there remains the need to provide quantitative relationships between risk elements as a function of ore pass length. As described, for example, if the rock walls are situated in good ground, the "spot" likelihood for stability is similar to that for a shorter pass. However, the length of the pass increases the number of locations at which poorer zones will occur, and therefore cumulatively increases the likelihood for failure somewhere within the pass. As such the frequency for rehabilitation, release of hangups, and more severe events including air blasts continue to render a long pass system vulnerable.

Commensurate risk mitigation and management must therefore be explicitly built into the design and management plan to mitigate against potential failure, which is likely to occur sooner rather than later. To achieve the required risk mitigation measures, collective engagement must be driven, usually as an outcome of geotechnical assessment, to bring together the multidisciplinary stakeholders in the ultimate risk management decision making outcomes for a successful ultra long ore pass operation.

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