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Geotechnical analyses for risk management of a large scale failure at Century mine, Northwest Queensland

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Abstract

The occurrence of large scale instability in open cut mines can have a detrimental impact to both safety and business of a mining company. As such it is crucial that the instability is effectively understood, communicated and managed to reduce both the likelihood and consequences of the failure and to keep the mine operational. During the period of January 2013 to December 2014, MMG's Century mine successfully operated under a large-scale progressive wall failure and recovered more than 1.8 millions of tonnes of ore; with no incidents or near misses related to the numerous failures that propagated in this area during this time. This paper briefly describes the investigations undertaken to understand the failure mechanisms, as well as the expected size and extents of the failures. It further describes how the geotechnical team used this information, in conjunction with various forms of monitoring, to effectively reduce both safety and business exposure to the risks of wall failures.

1 Introduction

When geotechnical design is inadequate for the rockmass or structure, then a hazardous working environment, resultant from unplanned rockmass movement, can lead to serious injury, and in the most extreme of cases, multiple fatalities. Adequately understanding the failure mechanisms at play and ensuring that appropriate controls are put in place will reduce the likelihood of the impending failure and as such the overall risk to an acceptable level.

The case study described in this paper will cover many aspects of the geotechnical management of the large scale failure at Century mine on a broad scale, as it is not practical within this context to cover more detail. Details of analyses and modelling processes are referenced to external papers where applicable. It presents the processes undertaken to manage geotechnical risk; including an overview of the analysis and monitoring undertaken at MMG's Century mine beneath an ongoing creeping large scale failure that intermittently failed onto operating mining benches from January 2013 to December 2014. This process enabled the successful recovery of 1.8 million tonnes of ore.

2 Background

MMG's Century mine is approximately 250 kms north-west of Mount Isa and close to the Northern Territory border in North-West Queensland. Though now closed, for the majority of mine life Century was the largest single mine producer of zinc in Australia and the third largest in the world, producing approximately 500,000 tonnes of zinc concentrate annually.

The open pit has been mined progressively in a series of cutback stages starting with Stage 1 as the first ore exposure to Stage 8 the deepest stage of the pit. Stages 9 and 10 were extracted on retreat, mining previously uneconomic ore (Figure 1).

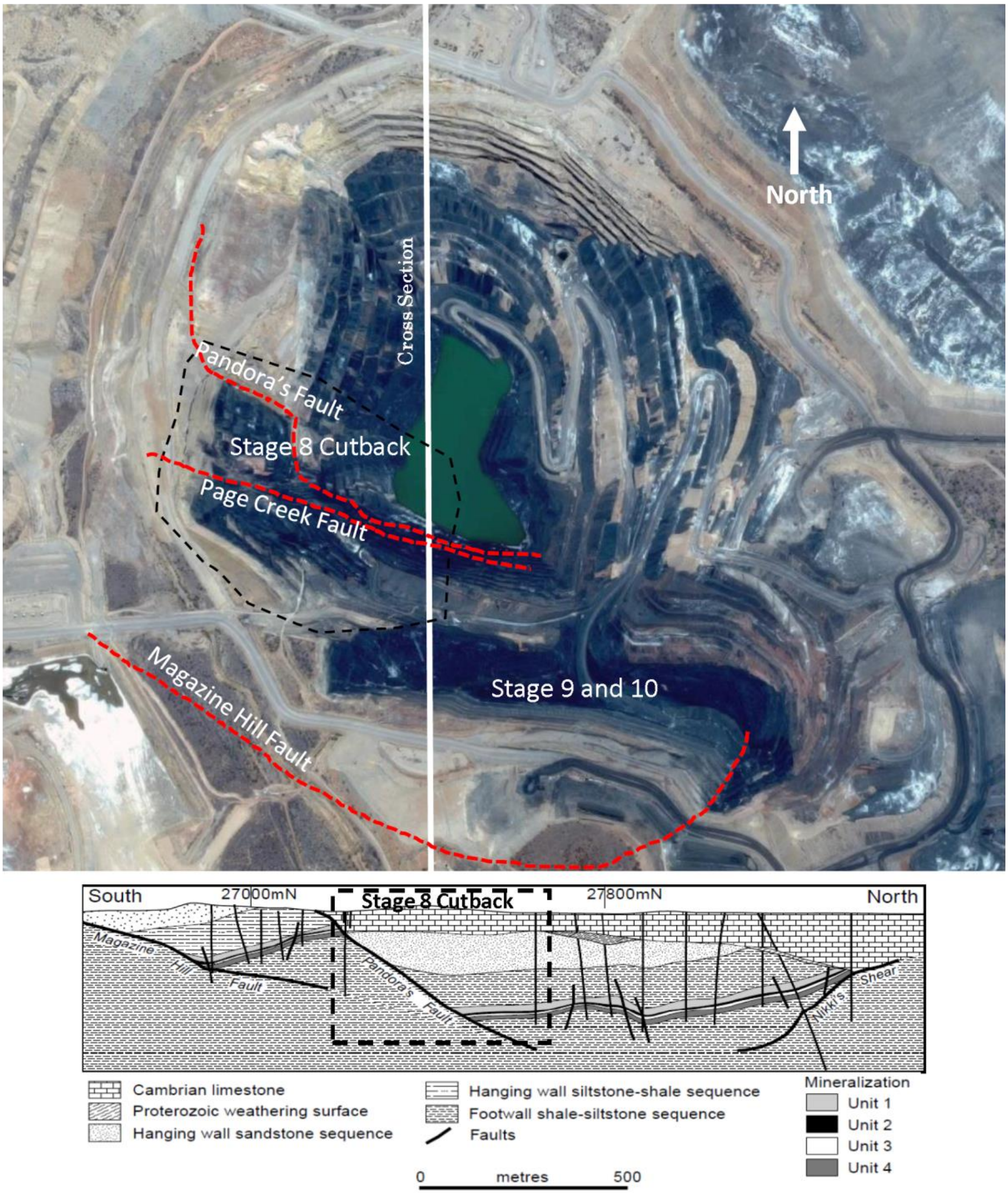


Figure 1 Century pit stages and geology (modified from Waltho & Andrews 1993)

The Century mine is a sediment hosted Zn-Pb-Ag deposit confined by numerous large scale faults (Broadbent & Zavodni 1982). The mineralisation has replaced lamellae in black shale units, which are separated by non-mineralised siderite rich siltstones. The ductile nature of these sedimentary rocks lend themselves to complex deformation around major faulting features. The Stage 8 cutback, the focus of this paper, is located in the south western corner of the main pit (Figure 1).

The Stage 8 Cutback geology sits in a basin syncline of shales with varying degrees of carbon, clay and silt content. The cutback mined through Pandora's Fault, which is a moderately northerly dipping (45° on average) large scale regional feature that bounds the orebody in the main pit. A key feature of Pandora's Fault is a Carbonaceous Breccia (CBX) believed to have been emplaced along Pandora's Fault and exposed in the West Wall of the cutback between 996RL and 936RL (midlevel pit height). This CBX unit was an unknown intrusive prior to mining in this area due to poor exploration borehole coverage.

3 Geotechnical characterisation of the problem

Significant instability issues in the Stage 8 Cutback began to emerge in 2010 during mining of the first three 12 m benches. A small block, structurally rotated, was exposed during mining. This block was bound on each side by large scale continuous shears, and had not been detected during the exploration phase. The shear structures and the rotated block were interpreted as settlement or accommodating structures associated with Pandora's Fault.

Wedge and planar failures developed consistently along a dominant and continuous structure, the Page Creek Fault, which intercepted continuous and undulating bedding planes dipping at 30–50° and oriented within 20° of the wall strike (Figure 2). These failures propagated from south to north along the west wall along these sheared and weak bedding planes. In the initial 60 m depth of wall exposure, the orientation and strike of the Page Creek Fault and bedding planes were poorly understood and the problem was thought to be localised.

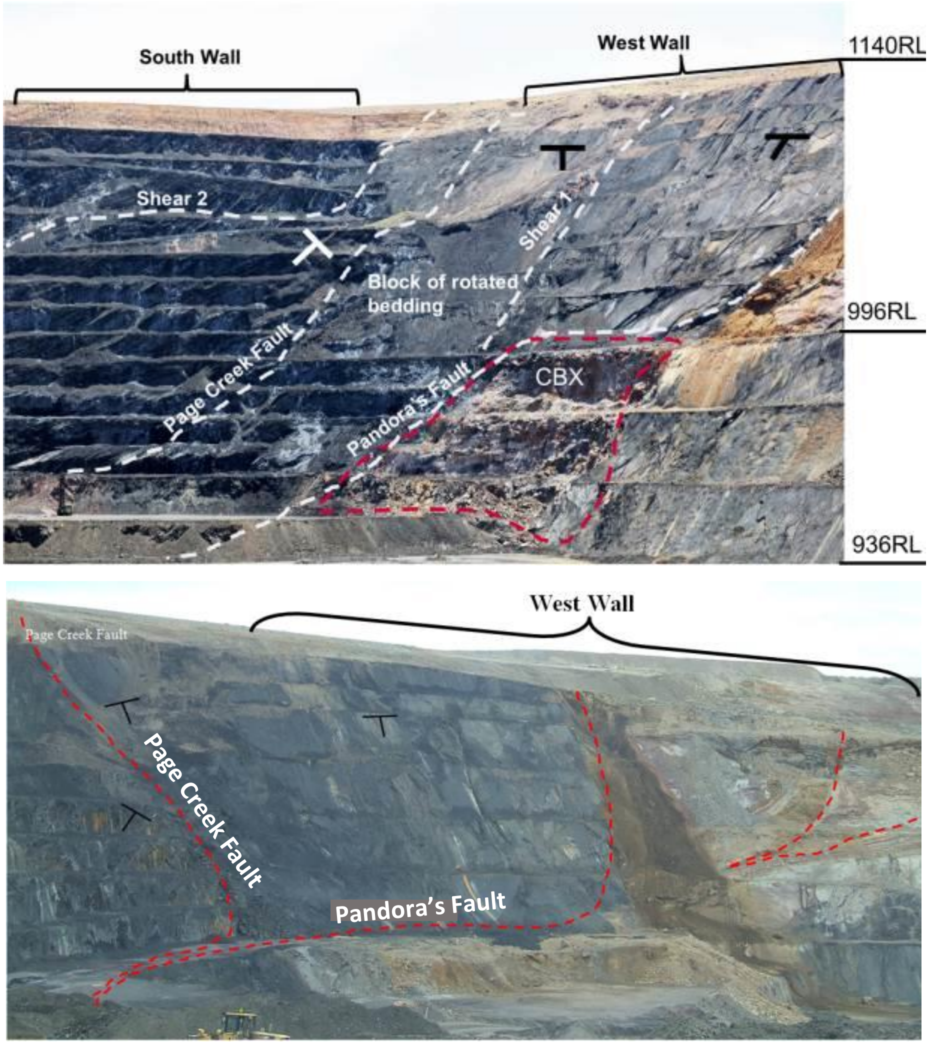


Figure 2 Bedding orientations and wall conditions in January and February 2013

In February 2012, after two months of above average rainfall, prism data began to alert the Century geotechnical team that an issue was emerging on the South Wall. A design change was undertaken to contain a large scale planar failure emerging along the Page Creek Fault on the South Wall. During the dry season it was noted that trends returned to a normal rate of movement. However, by January 2013 during the wet season the movement commenced again (Figure 3), and cracking developed on the West Wall in line with bedding strike. The seasonal acceleration trends in the prism data suggested the developing instability was highly sensitive to increased groundwater pore pressure, as seen during the wet season.

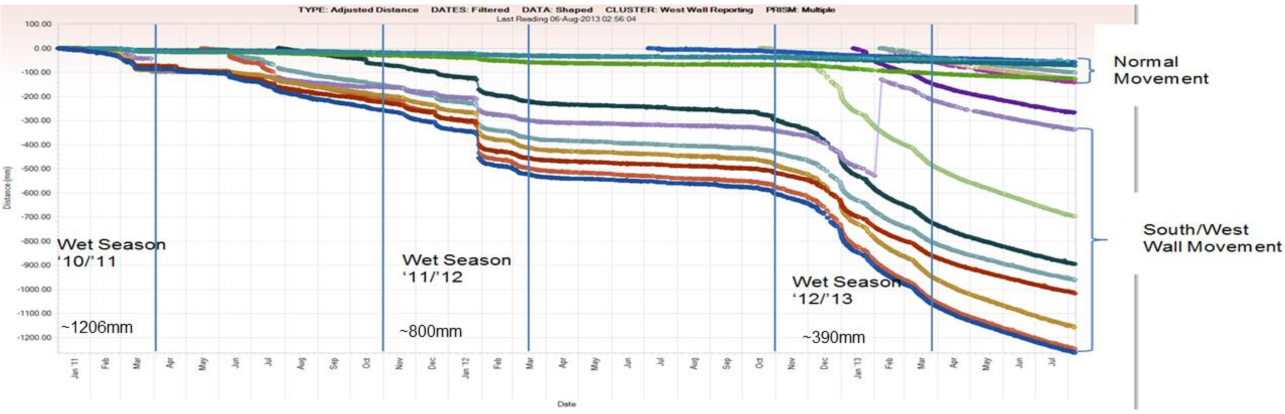


Figure 3 **Prism movement data from the Stage 8 west wall**

The raw prism data was processed using basic trigonometry functions to establish the vector and magnitude of movement over the wet season. These string files were imported into Surpac™ mine planning software, and compared with mine as-built surveys of the slope and observed tension cracking (Figure 4). The movement indicated by the vectors suggested that an active-passive block scenario was developing. The majority of the movement in the upper slope (Footwall Shales) was oriented down and easterly in RL, which was consistent with sliding along bedding planes. At the base of the slope the movement in the CBX was predominantly uplifting and easterly, suggesting it was being pushed up and out in a toppling motion and acting as a passive block or a natural retaining wall. The data also indicated that the movement was confined between both the Page Creek Fault and the Pandora's Fault.

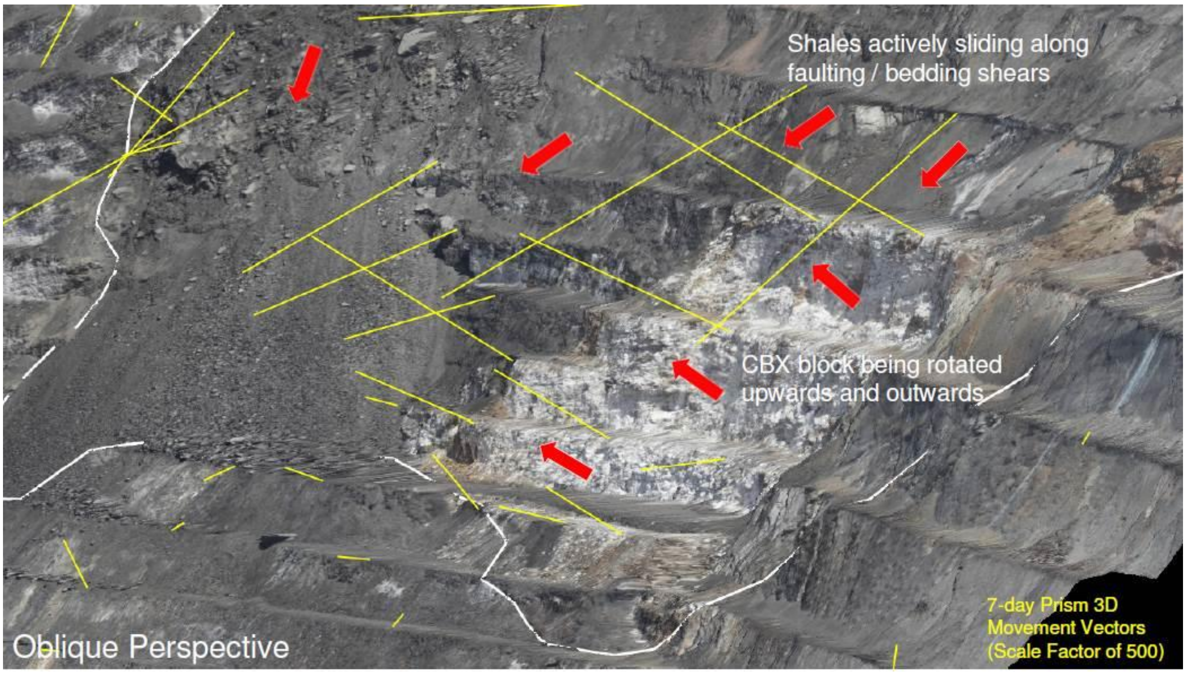


Figure 4 **Photogrammetry and prism vectors scaled to total movement of lower Stage 8 cutback wall**

In January 2013 the West Wall design was such that the previously unknown CBX unit would have been undercut. Furthermore, the design would have removed the anchored position of the CBX 'retaining wall' and initiated a large scale failure from 1140 to 936RL (approximately 204 m high × 200 m long). A failure of this size would have threatened ore continuity and production for several months as this was the only available ore source at this time. The design, at that time, steepened towards the toe based on the presumption that bedding was oriented more favourably for a steeper design in the toe. The true orientation of bedding made it likely that the bedding planes at the toe of the slope would have daylighted and initiated a second much larger scale failure (Figure 5).

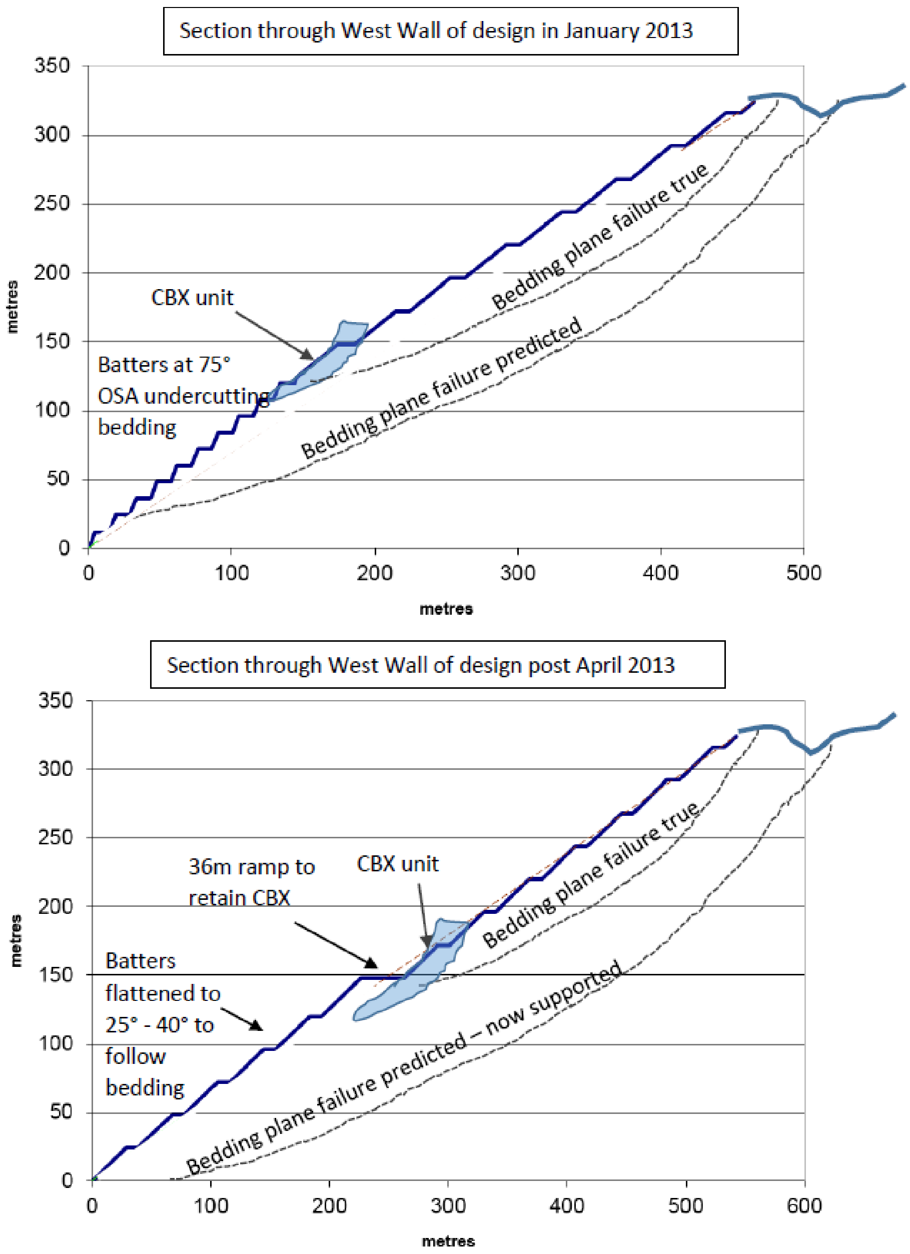


Figure 5 Simplified geomechanics of failure versus design in the west wall of the Stage 8 cutback

It was decided at this point that in order to minimise the extension of the predicted failure with depth that the passive block had to be widened so that it provided sufficient buttressing against predicted extension of failure in the active block. Mining activities in the area ceased immediately and a stringent review of the wall design was undertaken to understand the extent of the step out required to prevent the predicted deep seated mechanism from propagating further back into the wall (Figure 5).

4 Updating the rock mass structural model

In order to best represent the problem for modelling, a review of all raw drillhole data was incorporated into the analyses to further define the problem. Localised oriented drillcore data and Adamtech™ photogrammetry mapping data was interrogated for reliable bedding orientation data. This data was then used to generate 'in situ' bedding plane markers for 3D visualisation in Surpac™ (Figure 6). This enabled the Century geotechnical team to get an understanding of variation in bedding trends both at surface and at depth. The data was then used to adjust the anisotropic functions in FLAC^{3D} numerical models that were completed by mining and geotechnical consultants (Itasca Australia Pty Ltd and Mining One Consultants Pty Ltd).

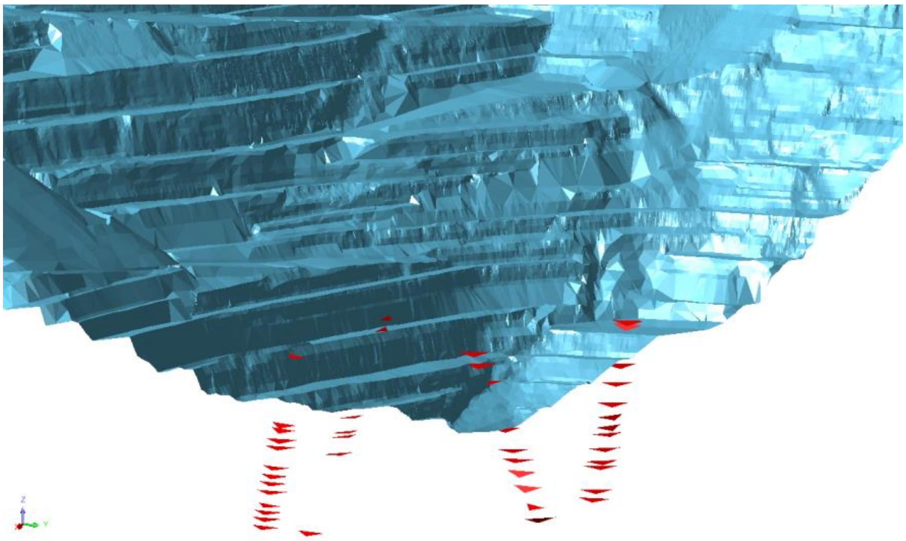


Figure 6 3D visualisation of drillhole data

5 Initial stability assessments for determining wall redesign

The design changes that were considered for numerical modelling focused on understanding the design change that would be required through the lower, not as yet mined, wall to prevent propagation of the current failure into a more deep seated failure over time. While it was understood that the problem was three dimensional, initial analyses of likely failure mechanisms were undertaken in *SLIDE* (RocScience™) to establish an appropriate buttress width. While it was found that *SLIDE* tended to provide a conservative result that was not compliant with the required Factor of Safety, it was useful in eliminating the six potential design options down to two that could then be analysed more comprehensively through FLAC^{3D} numerical modelling (Itasca). FLAC^{3D} models tend to be computationally demanding, and can take several days to set up and run. In the initial design option elimination stage, a lot of time and expense can be avoided by using basic geotechnical modelling programs to filter options. A more appropriate initial alternative would have been 2D numerical modelling, however this software was not available to Century at the time.

The FLAC^{3D} model was built by Itasca engineers (Sainsbury 2012) and more comprehensive numerical analyses were undertaken to understand the extents of instability. In order to simulate the effects of anisotropic rock mass strength and deformation behaviour on stability, Itasca has developed a Ubiquitous Joint Rock Mass (UJRM) modelling technique (Sainsbury et al. 2008). The ubiquitous joint constitutive model was developed to simulate well-defined strength anisotropy due to embedded planes of weakness within a Mohr–Coulomb material. When used to simulate rock mass strength and deformation behaviour under unconfined compression, the UJRM model represents the progressive degradation of matrix cohesion and ubiquitous joint failure at various stages of loading (Sainsbury et al. 2008).

Bedding discontinuity strength was estimated by Barton–Bandis theory (after Barton 1976) applied to field observations. Cohesion of 80–88 kPa and friction angle of 28° was estimated for the bedding planes in shales. These estimates are consistent with large-scale back-analysed shear strength properties of filled discontinuities.

Due to the heavy computational loading in FLAC^{3D}, Itasca calibrated the UJRM into a rockmass matrix in 3DEC to simulate the required anisotropic behaviour. A series of computational UCS and triaxial (σ^3 = 2 MPa) tests were simulated with β angles from 0 to 90° on the shale UJRM sample.

The model indicated a significant amount of strain (>0.5%) and 100% joint cohesion degradation would occur with depth along the Page Creek Fault and bedding with a high likelihood of failure from surface 1140RL to the 936RL behind the CBX intrusive dyke (Figures 7 and 8). Further predictions garnered from this model suggested that, as mining progressed past 900RL, failures would continue to propagate along the Page Creek Fault and the Pandora's Fault within the intact rock buttress.

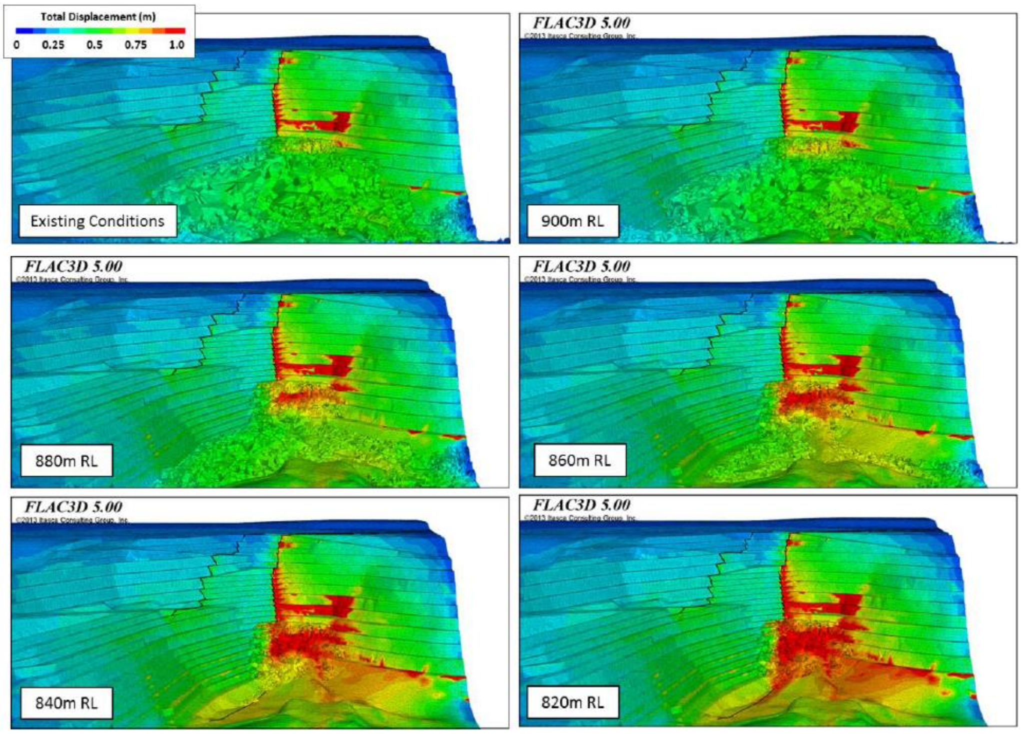


Figure 7 First stage 3D numerical modelling of the west wall instability (Sainsbury 2012)

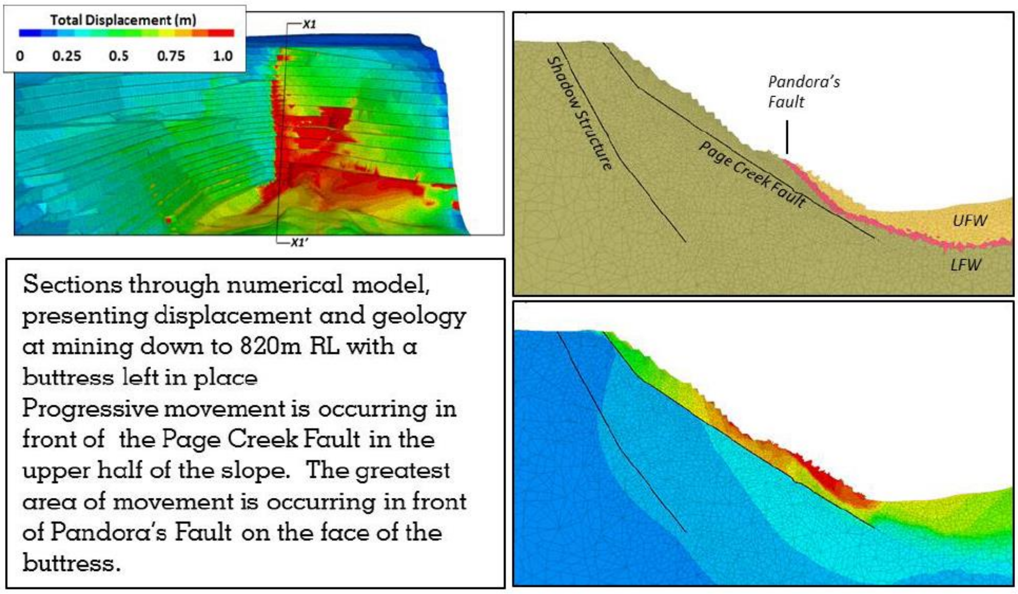


Figure 8 Section through FLAC^{3D} numerical model (Sainsbury 2012)

As it was apparent that the hazard, the failure in progress above the 936RL, could not be stabilised without additional external support, a cutback option was contemplated but found to be uneconomic. It was determined that ore below the failure would either have to be written off or operational activities in the area below this failure would have to be closely and carefully managed so that they accounted for the additional high level hazard that was present.

In April 2013 a decision was made to reduce the likelihood of failure below the 936RL, by stepping out the design and flattening the overall slope. Stepping out into an intact rock buttress design; effectively locking the CBX dyke into the wall, allowed this hard brittle CBX block to continue to act as a retaining wall. This gave the opportunity to continue mining without having to immediately remediate a failure, and allowed for time to consider other mining options.

Using interpretations of monitoring data and modelling it was determined that the west wall exposed operations to the risks of five types of failures as seen in Figure 9.

- Shallow rockfalls associated with degradation of the slopes over time (Type 1).
- Relatively shallow, but extensive, multi-batter failures from surface to the 936RL (Type 2).
- A new failure that may emerge on Pandora's Fault — introduced through the wall redesign to encompass and intact rock buttress (Type 3).
- Propagation of the shallow failure through the intact rock buttress (Type 4).
- Deep Seated failure of the overall slope as mining progressed towards final bench (820RL), (Type 5).

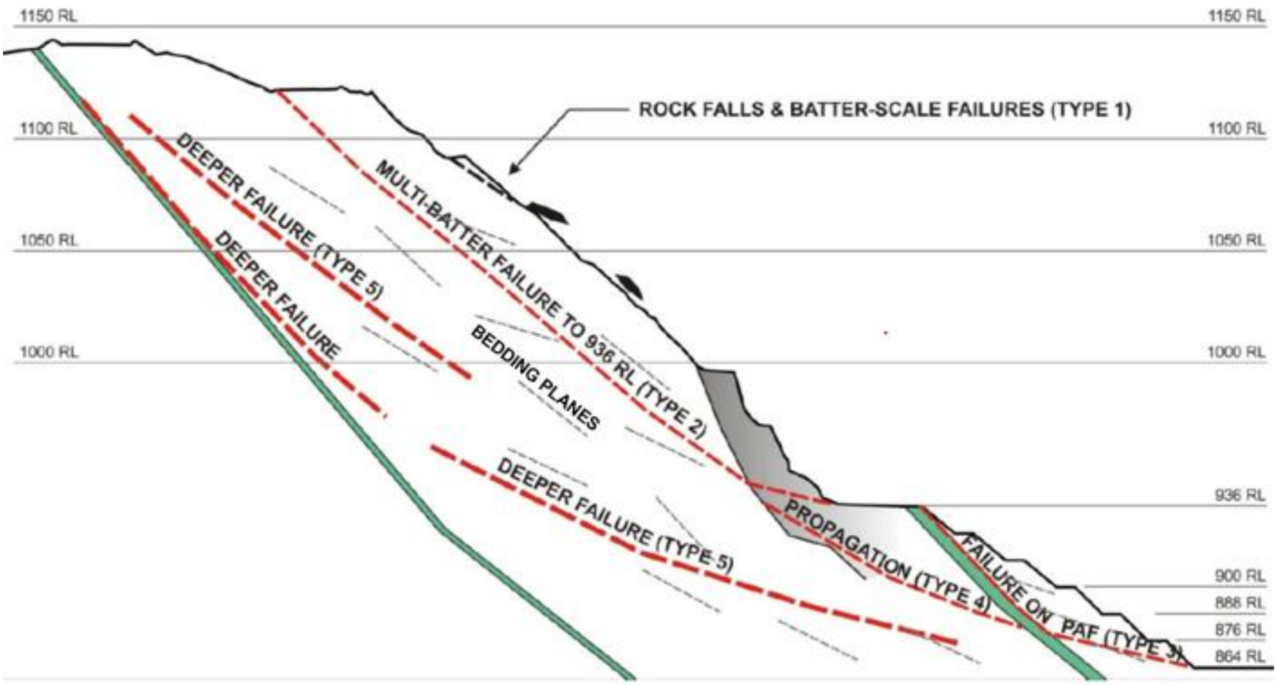


Figure 9 Anticipated failures of the Stage 8 cutback west wall (modified from Lucas 2013)

6 Working in areas of increased geotechnical risk

Century mine manages geotechnical risk escalation through a Trigger Action Response Plan (TARP) within the Geotechnical Management Plan (GMP). The GMP dictates in general terms the level of control that is required to address the wide range of geotechnical issues within the mine. The high level TARP is more qualitative than quantitative, as it defines the geotechnical risk relative to expected design performance and potential for impact on safety (Table 1).

Table 1 Ranking geotechnical risk at Century mine

Geotechnical risk rating	Description
Low	Normal operating conditions
Moderate	Conditions are outside specification, but can be managed by appropriate controls
High	The risks that may result from ground movement require extensive and or specialised risk reduction strategies
Extreme	The risk that may result from ground movement is beyond what can be managed by appropriate controls other than exclusion from the area

Once an area has been identified as having increased geotechnical risk it must be delineated, and communicated to all pit personnel. At Century there are specific hazard cones that are used to isolate areas of increased geotechnical risk. It is a 'golden rule' of the mine site that to cross these cones an individual must have received the permission from a site Registered Professional Engineer of Queensland Geotechnical Engineer or their delegate. Under the GMP, management of these zones centres on the need to complete a Risk Assessment and a Job Safety Analysis to undertake work in the hazardous area that mitigates the risks. These areas are referred to as Geotechnical Control Zones (GCZ).

GCZ are implemented as a control to reduce the inherent risk of a particular pit section. In most cases GCZ are used in areas with an inherent risk of Moderate to High. The purpose of the GCZ is to alert mining personnel that a particular pit section has potential geotechnical issues and that review of a Job Safety Analysis could be required before entry to the delineated area. The GMP dictates that determination of Exclusion Zone distances based on the following:

- Potential failure mechanisms.
- Available catch capacity.
- Material type.
- Steepness and quality of wall.
- Exposure of personnel and equipment.

The analysis of the west wall instability issues, described in the above sections, identified that the risk(s) associated with a large scale failure ranged from Low to Moderate for rockfalls and small batter scale failures, to extreme for large scale/multi-batter wall failure. However, slope stability risk is a dynamic function, as the risk of failure is closely correlated to changes in environmental factors over time such as pore pressure. The modelling and analysis phase clearly indicated a trend for acceleration and active deformation during the wet season, and a trend for deceleration and creep during the dry season.

To effectively manage the risks associated with mining under the west wall the challenge for the geotechnical team was in developing a quantitative and clear TARP for managing the transitions between High and Extreme Risk that would reflect the changes in acceleration. The analyses that were undertaken to establish this TARP and the effective boundaries of the control zones are described in the sections below.

7 Establishing a safe working distance

Working around landslides and large scale failures has serious implications for safety. To adequately manage the risks it is important to understand:

- The area that will be impacted in terms of failure volume and run-out distance so that adequate controls can be put in place to establish safe work areas and manage the risks.
- The rate of failure, so that an appropriate TARP can be set up.

To understand this, the Century geotechnical engineers followed the approach recommended by Hungr et al. (2005) to estimate the geometrical angle of reach (Figure 10). This theory is commonly referred to as the Fahrbòschung angle. Initially described by Scheidegger (1973), this angle has also been called the reach angle, the travel angle and the travel distance angle. Under this theory the run-out length (how far a failure will travel laterally) is proportional to the height of the slope. It is also described as the distance the failing mass needs to travel for the kinetic energy to dissipate (height of the drop over the length of the drop).

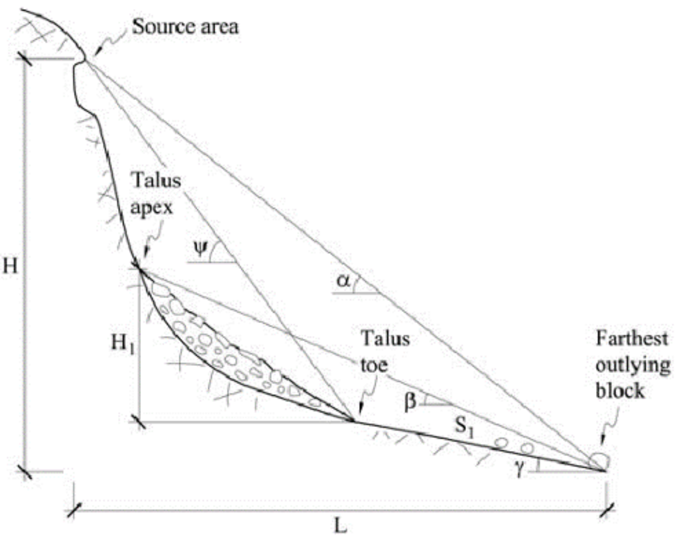


Figure 10 Geometric variables: vertical drop (H), travel distance (L), reach angle (α) shadow angle (β), source-talus angle (ψ), substrate angle (γ), and shadow distance (S1), (from Hungr et al. 2005)

Three key approaches were followed for calculating expected reach angle extents for the failure model. Initially the engineers looked at historical large scale slope failures at Century mine in similar rockmass and measured the height, slope angle, reach angles and travel distances for each event. Two historical failures were deemed to be of suitable size and of the ravelling/sliding type mechanism to be applicable. Utilising imagery and survey laser scan data of the failures, actual reach angles (α) of 29–31° were substantiated (Figure 11).

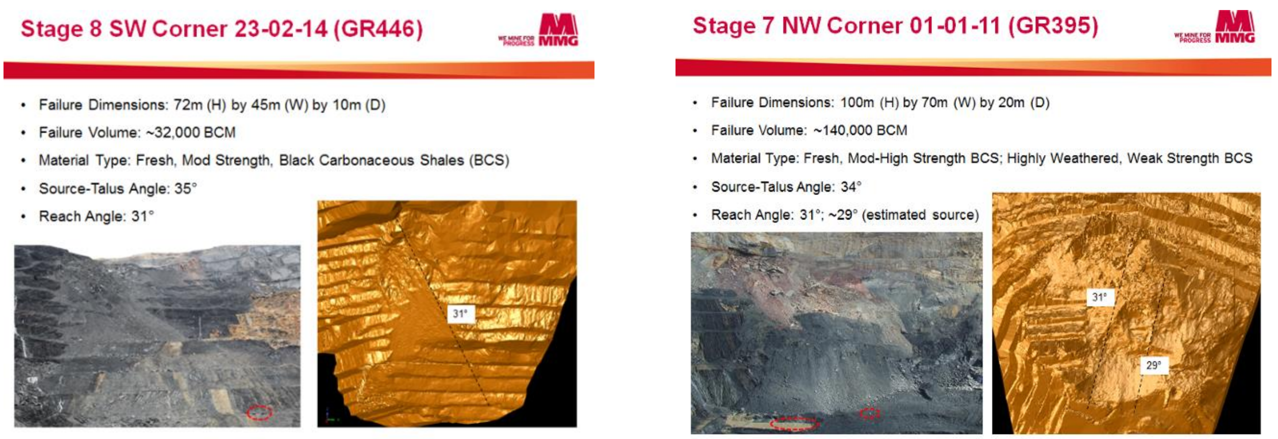


Figure 11 Reach angles from historical large scale slope failures at Century mine

Empirical equations derived by Finlay et al. (1999) are represented in Figure 12. Using the known extents of the Stage 8 failure, i.e. H = 190 and Slope Inter-Ramp Angle /δ = 39°, the Engineers applied these parameters to the upper 95% confidence interval in Finlay's work, previously established as the most appropriate of the formulas for the rockmass and failure size. Applying this 95% confidence interval formula to the Stage 8 west wall failure it was established that the predicted travel distance (L) may be 400 m, corresponding to a reach angle (α) of 25.3°.

Dependent variable		Equation
Cut slope	LCI	$\text{Log } L = 0.062 + 0.965 \text{ Log } H - 0.558 \text{ Log } (\tan \delta)$
	Mean	$\text{Log } L = 0.109 + 1.010 \text{ Log } H - 0.506 \text{ Log } (\tan \delta)$
	UCI	$\text{Log } L = 0.156 + 1.055 \text{ Log } H - 0.454 \text{ Log } (\tan \delta)$

Figure 12 Equations for landslide travel distance of a cut slope for Hong Kong slope failures (Finlay et al. 1999)

The final approach was to use an empirical formula from Corominas (1996) for an obstructed translational landslide/rockmass failure (Figure 13). Using the calculated likely Stage 8 west wall failure volume extents of 2.2 million cubic metres, a reach angle (α) of 25.4° was determined as a prediction for the Stage 8 Failure.

$$Log\ tan\ \alpha = A + B\ Log\ V \tag{3}$$

Where A and B are constants and V, the volume. In Table 3 there are several suggested expressions for this relationship which correspond to the equation of the regression line.

Landslide type	Paths	A	B	R^2
Translational slides	All Obstructed Unobstructed	-0.159 -0.133 -0.143	-0.068 -0.057 -0.080	0.67 0.76 0.80

Figure 13 Empirical regression equation for a translational landslide (Corominas 1996)

The approaches utilising separate empirical equations ascertained near-identical reach angle results, and correlated well with historical failures at Century mine. This provided a level of confidence that the placement of the exclusion zone would be sufficient in the event of large scale slope failure. As such, from these analyses, it was determined that the maximum predicted reach angle (α) was 25° (Figure 14).

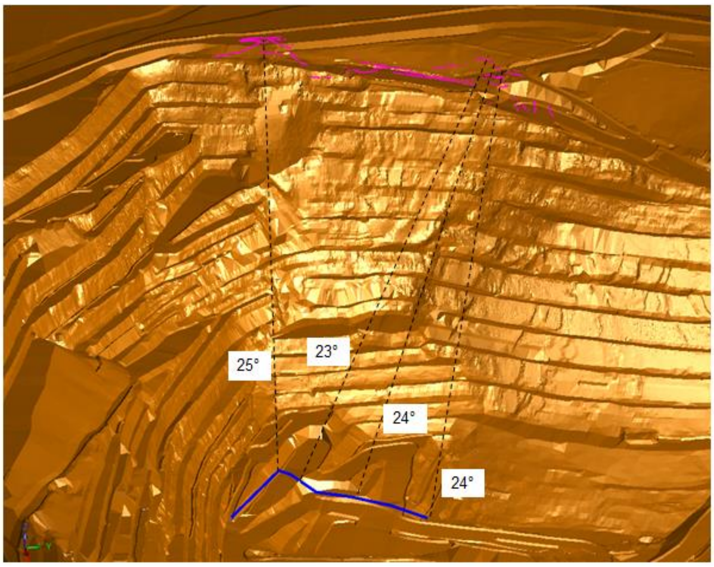


Figure 14 Measured 'reach angles' from the extents of surface tension cracking to the delineated exclusion zone boundary

8 Managing rockfall potential

In order to understand the controls required to manage the risks associated with the west wall failure it was prudent to understand how the extents of the impact of a failure from a single rockfall through to an overall slope failure would impact safety.

To understand the impact of the rockfall zone the program TRAJEC3D was used. The program requires an understanding of:

- Size, weight and shape of the rockfalls predicted.
- Coefficient of restitution of the rock falling.
- The static friction angle of the rock.
- The dynamic friction angle of the rock falling.

The data was obtained through both estimations of known parameters, field observations of blocks hanging up, and back-analysis of rockfalls that had already occurred following the process described by Graf et al. (2013). Over a thousand rockfall scenarios were run using blocks of various size, shape and weights. The TRAJEC3D software (Basrock) allowed for various catchment bund positions and heights to be tested to understand the capacity for rockfalls to be contained (Figure 15).

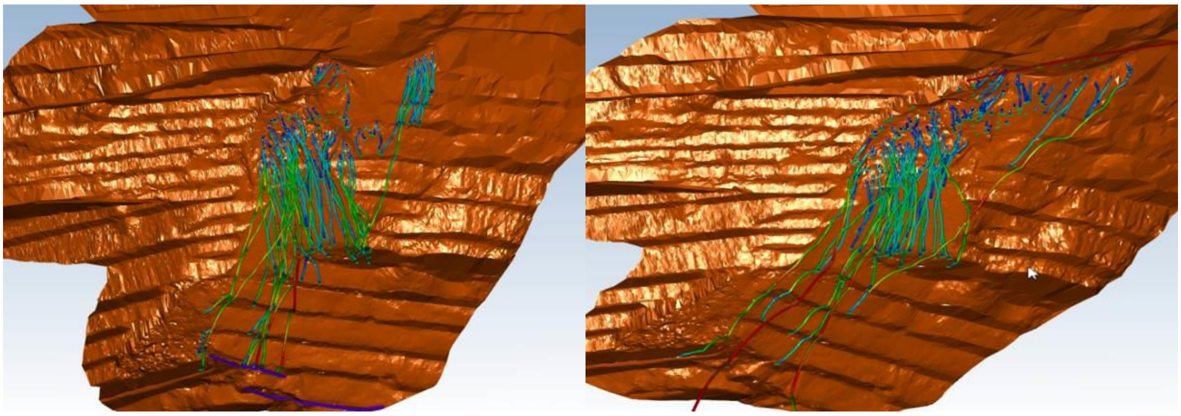
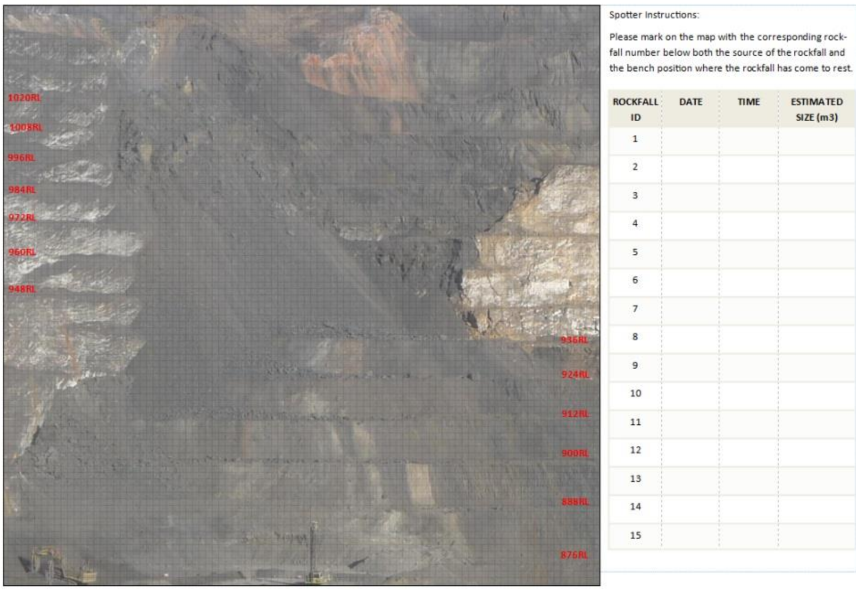


Figure 15 Bunded (left) and unbunded (right) TRAJEC3D rockfall simulation

Spotters trained in geotechnical hazard awareness were strategically placed as mining on the bench continued, under strict Job Safety and Environment Analysis (JSEA) communication standards. Spotters were issued with a rockfall plotting sheet to note any rockfalls observed (Figure 16). Information collected included source and final position locations and approximate size and shape of the rockfall. This information was then fed back into the TRAJEC3D model to further validate and improve it.



Stg 8 High Control Zone—Rockfall/Rilling Plotting Sheet

Spotter Instructions:

Please mark on the map with the corresponding rock-fall number below both the source of the rockfall and the bench position where the rockfall has come to rest.

ROCKFALL ID	DATE	TIME	ESTIMATED SIZE (m3)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			

Figure 16 MMG Century mine rockfall plotting sheet

9 Monitoring movement with the radar

It is widely understood that for a rockmass to fail it must move past the state of elastic behaviour and into plastic deformation; and not all rock that moves into this state will fail to the point of collapse. However, for those that do move to a state of collapse, the rockmass can transition from creep to progressive movement and back again through multiple cycles before the onset of failure occurs and the rockmass moves to ultimate collapse (Broadbent & Zondni 1982).

At the time of publication, the most effective tool for monitoring a large scale failure is through synthetic aperture radars; or as they are more generically known, slope stability radars. In order to manage operations around the west wall instability it was determined that mining would be allowed during the creep phase of movement under stringent controls, the foundation of which was a slope stability radar monitoring system. If movement accelerated above acceptable creep phase velocities an alarm would trigger in the dispatch control room, and the area specific TARP would be activated. A low level increase would call for alerting the geotechnical engineer to investigate the data to see if there is a sustained trend of acceleration; whilst higher thresholds dictated pit evacuation.

The rate of movement that would trigger this response was of critical importance as noise in the dataset would trigger 'false' alarms that would result in an unnecessary evacuation. As failure can be time dependant, extending the length of time it takes to mine in this area meant extending exposure to geotechnical risk across a larger portion of time. The rate of movement of the rockmass as it approaches instability is highly dependent upon the properties of the rock itself, the geometry of the structures within the rockmass, the geometry of the slope face, and the influence of environmental factors such as rainfall, and pore pressure. The geology and structure of the rockmass in the west wall was variable; as such by April 2015 there were nine different zones moving at different rates. Some of these zones posed higher risk than others, if they accelerated towards failure.

Figure 17 shows the daily chart generated from Century geotechnical engineers to assist the production team in understanding the current magnitude of risk. The figure uses the TARP rates for the majority of zones. It should be noted that zone 4 (CBX) had a much lower range of acceptable movement but rarely exceeded it. Although the rate of creep in the CBX block was very low, failure of this block was likely to trigger a much larger failure of the rockmass behind it; (zones 2 and 7) as such, alarm triggers were tighter in this zone and larger control zones were appropriate.

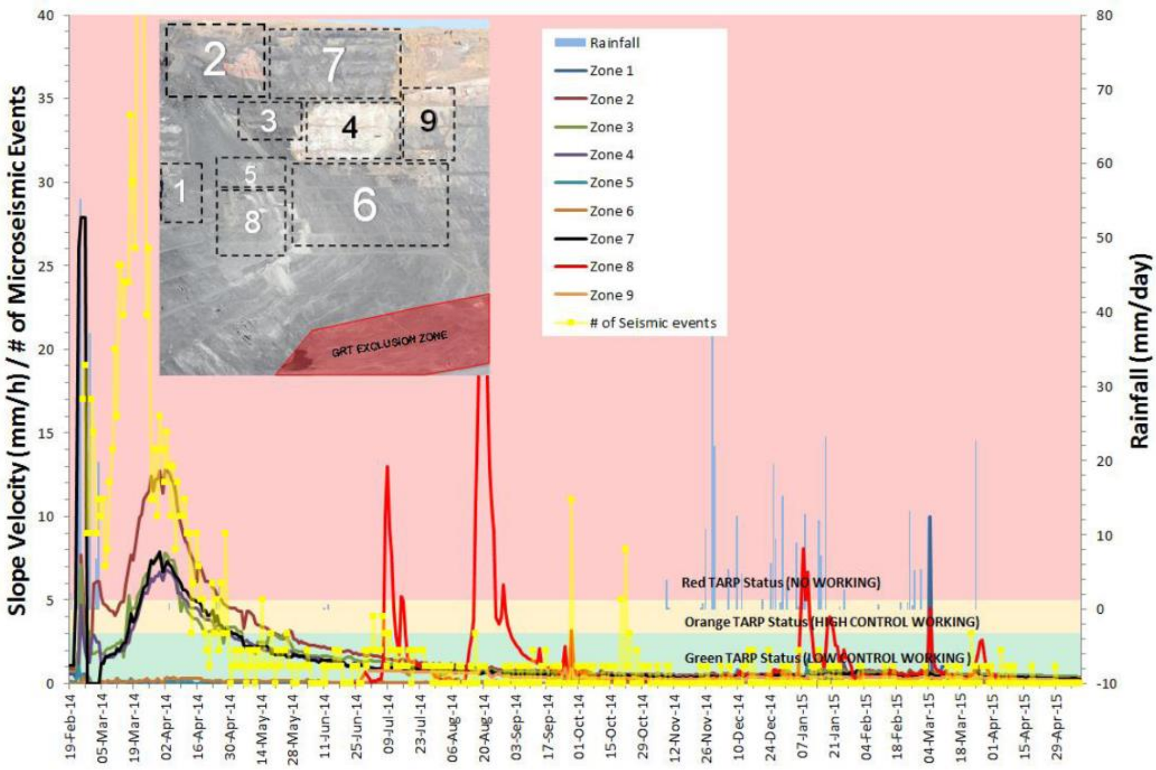


Figure 17 TARP and zone rates of movement in the west wall

By appropriately alarming zones individually, the appropriate risk controls could be put in place at the working face. For example, the isolated failure observed in zone 8 typically moved at 15 mm/hr but posed little threat to operations within a 20 m radius.

It should be noted that having many zones does tend to slow down scan run times and a judgement call is required to be made by the geotechnical engineer on the required scan time needed.

The rate of movement per zone was re-evaluated over time, with careful analysis of both the creep phase and failure phase data, as failures progressed over the two year period. Figure 17 shows the rate of movement thresholds that dictated the transition from acceptable rates of creep into rates of movement where acceleration could occur faster than a reaction time could be managed.

10 Conclusion

In November 2014 Century successfully recovered of 1.8 million tonnes of ore inside the impact zone of the Stage 8 west wall failure. The capacity for the mine to be successful in this endeavour with no incidents and minimal disruption to the schedule was in large part due to the time and effort put in by the geotechnical engineering team to adequately define the failure mechanism as well as the size and extents of the failure. It allowed them to understand the differences between normal acceptable movement and movement that would escalate to failure. The analyses provided critical insight to the expected rockmass behaviour from a rock fall to a large multi-batter failure that allowed adequate controls and TARPs to be put in place to protect the workforce.

The operations crew successfully evacuated the control zones 48 hours prior to the two large scale multi-batter failures (1–2 million tonnes). While this paper describes the backbone of geotechnical work done to ensure all safety measures were taken, this area could not have been successfully mined without the full cooperation and engagement of the pit personnel. Critical to this is effective and open lines of communication between the workforce, the engineering team and a supportive management structure.

References

Barton, N 1976, 'The shear strength of rock and rock joints', *International Journal of Rock Mechanics and Mining Sciences and Geomechanics Abstracts*, vol. 13, no. 9, pp. 255–279.

Broadbent, CD & Zavodni, ZM 1982, 'Influence of rock structure on stability', *Stability in Surface Mining*, Society of Mining Engineers, vol. 3, Chapter 2.

Corominas, J 1996, 'The angle of reach as a mobility index for small and large landslides', *Canadian Geotechnical Journal*, vol. 33, pp. 260–271.

Finlay, PJ, Mostyn, GR & Fell, R 1999, 'Landslide risk assessment: prediction of travel distance', *Canadian Geotechnical Journal*, vol. 36, pp. 556–562.

Graf, CC, Peryoga, T, McCartney, T & Rees, T 2013, 'Verification of Trajec3D for use in rockfall analysis at Newmont Boddington Gold', in PM Dight (ed.), *Proceedings of the International Symposium on Slope Stability in Open Pit Mining and Civil Engineering*, Australian Centre for Geomechanics, Perth, pp. 1231–1242.

Hungr, O, Corominas, J & Eberhardt, E 2005, *State of the Art Paper #4 — Estimating landslide motion mechanism, travel distance and velocity*, viewed 10 June 2016, ftp://www.eos.ubc.ca/pub/ohungr/Support/OH_Recent_Papers/SOA-4_Hungr.pdf

Lucas, D 2013, 'Century Mine Geotechnical Review May 2013', *Report no.* 3585, Internal Report, Mining One Consultants, Melbourne.

Sainsbury, B 2012, 'Assessment of the Long Term Stability of the Stage 8 West Wall Cutback at MMG Century, Original Slope Design with Version 6 Buttress', *Report no. 13003*, Itasca Consulting Group, Inc., Melbourne.

Sainsbury, B, Pierce, M & Mas Ivars, D 2008, 'Analysis of Caving Behaviour Using a Synthetic Rock Mass (SRM) - Ubiquitous Joint Rock Mass (UJRM) Modelling Technique' in Y Potvin, A Dyskin & R Jeffery (eds), *Proceedings of the First Southern Hemisphere International Rock Mechanics Symposium*, Australian Centre for Geomechanics, Perth, pp. 243–254.

Scheidegger, AE 1973, 'On the prediction of the reach and velocity of catastrophic landslides', *Rock Mechanics*, vol. 5, pp. 231–236.

Waltho, AE & Andrews, SJ 1993, 'The Century zinc-lead deposit, northwest Queensland', in IJ Duncan (ed.), *The Australian Institute of Mining and Metallurgy Centenary Conference*, Australasian Institute of Mining and Metallurgy, pp. 41–61.