A fall of ground case study – an improved understanding of the behaviour of a major fault and its interaction with ground support

I.G.T. Thin, B.J Andrew & M.J Beswick
Xstrata Copper, Mount Isa Mines, Mount Isa, Queensland, Australia.

ABSTRACT: As a result of mining induced changes in ground conditions associated with the extraction of the first stope from the Hangingwall Lens, Isa Copper Mine–South (formerly known as X41 Copper Mine), there was a need to rehabilitate part of the footwall drive adjacent to the stope void. While in the process of scaling loose material from one of the sidewalls within an area of a major fault, a fall of ground occurred which initially buried the booms of a Tamrock Jumbo. Although the failure represented a significant incident, it presented an opportunity to learn about the interactions of the ground conditions (particularly the fault zone) and the ground control systems. This paper will discuss the sequence of events leading up to the failure; the philosophy behind the selection of the original ground support and reinforcement; the philosophy and methodology behind the rehabilitation steps that were adopted once the overall failure had arrested; and the changes made to the ground control practices so as to prevent a similar failure from happening again.

1 INTRODUCTION

1.1 *Isa Copper Mine–South*

While in the process of rehabilitating the main Hangingwall Lens (HWL) access on 20B Sublevel, a fall of ground occurred. The failure took place in three stages over a period of approximately 8 hours, initiating ahead of the Jumbo and covering the booms, then progressively failing back over the entire unit. Personnel access was restricted following the initial failure, significantly reducing the risks.

With regards to the specific location of the failure, this was along P3849 SEDR on 20B Sublevel, between Q369 CO and Q36 XC (see Figure 1). The failure initiated approximately midway between the Q369 CO and Q36 XC and arrested to the north of the P3849 SEDR and Q369 CO intersection. The zone of failure encompassed the area where the J46 fault intersects the main footwall drive.

Originally developed in July 2000, P3849 SEDR (20B) was inspected in October 2001 as a result of ground deterioration in the sidewalls of the drive during the initial stages of production from stope Q369. Production firings were completed in January 2002, with the area re-inspected in February 2002 and rehabilitation recommendations issued.

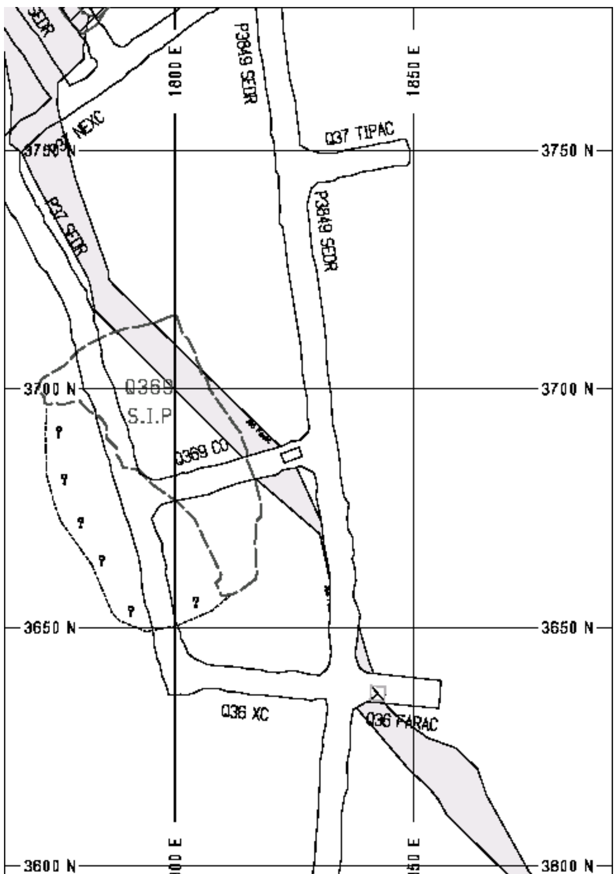


Figure 1. 20B Sublevel mine plan showing the P3849 SEDR and surrounding Q369 stope development (the shaded area represents the floor projection of the J46 fault).

1.2 *General ground conditions in the Isa Copper Mine-South*

The Isa Copper Mine-South orebodies extend for nearly 3 km north to south, up to 500 m east to west and vary in depth from 730 m to 1025 m below surface (Grant & DeKruijff, 2000). With production starting in 1966, total production to date is in excess of 160 million tonnes. The copper orebodies are hosted within an Urquhart Shale sequence (with the copper ore occurring as disseminated and massive chalcopyrite), which consists of a 1100 m thick package of thinly bedded black, pyritic and dolomitic shales that typically strike north-south and dip to the west at 65° (see Figure 2).

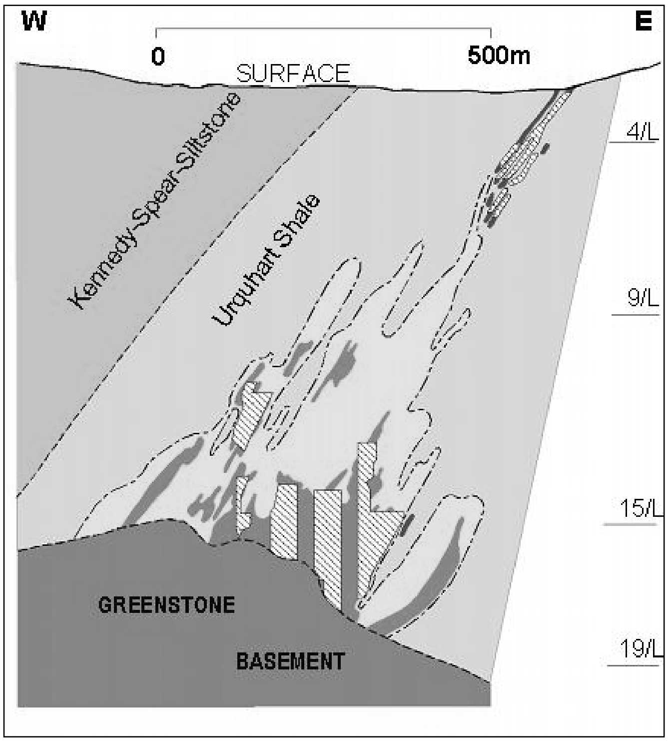


Figure 2. Typical cross section of the X41 Copper Mine mining area. The hatched area represents that part of the 1100 Orebody that has been extracted to date.

The main source of ore is the 1100 Orebody, which starts in the north and extends approximately 2 km to the south, where the orebody then splits into a Hangingwall and Footwall Lens (see Figure 3). The mining method utilised is sublevel open stoping (SLOS), which has evolved over the years to the present day design standards. Although stope dimensions are typically 40 m by 40 m in plan and extracted to the full height of the orebody (which extends to a maximum of 400 m up-dip), variations of these dimensions are becoming more common as the complexity of the orebody increases.

1.3 *Ground conditions in the Hangingwall Lens*

The predominant rock type within the Hangingwall Lens is Fractured Siliceous Shale, with the Basement Contact Zone present in the hangingwall and Silicified Greenstone beyond the contact. Five major faults intersect development at various locations surrounding stope Q369 on 20B Sublevel, namely J46, L41, W41, P41 and the Bernbourough. All the faults can be generalised as having weak rock mass characteristics.

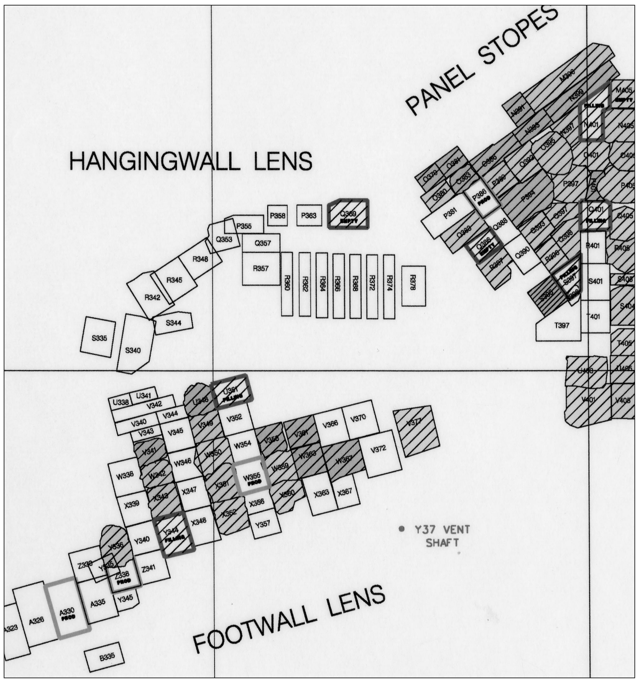


Figure 3. Schematic plan showing the southern end of the Isa Copper Mine-South (the Panel Stopes represent the southern most end of the 1100 Orebody).

Ground conditions specific to the failure zone consisted of small sized unconsolidated J46 fault material and graphitic shales. The fault material was made up of talc, sepiolite and carbonaceous rubble with buck quartz. The J46 fault strikes in a NW-SE direction, dipping at 58° towards the southwest, intersecting the P3849 SEDR to the south of Q369 CO. The graphitic shales (or bedding) also strike in a NW-SE direction, dipping at 50° towards the west.

1.4 *Background*

Initial work investigating the HWL started back in 1995 (Tyler, 1995) once diamond drilling for the HWL had been completed, after which a series of studies were performed (Li, 1997, Poniewierski, 1998a, b). The main objective of these studies was to determine an economic mining plan. The only significant reference made to development mining was the fact that the geological structural interpretation was only based on drill hole data. As such, there was limited confidence with predicting the ground conditions.

The design strategy for the HWL was to retreat the stoping block south to north, maximising the ore development and minimising secondary pillars. In order to gain some early stoping experience, Q369 stope was targeted to develop a better understanding of HWL behaviour (Q369 was the most northerly stope in the HWL, refer to Figure 3).

Two previous examples were available for review during the design stages of Q369, which had comparable geometries, changes in stress and rock mass characteristics (development on 20B for O383 adjacent to O381 stope and development of S395/S397 stopes on 15 Level). Both cases had a strike exposure of the J46 fault dipping into an open stope. In both cases, the ground conditions had been controlled using rock bolts, mesh and cable bolts. The level of de-stressing was also similar, or greater in the case of O383 development where it was surrounded by fill masses.

As the P3849 SEDR (20B) development mining advanced to the south, new geological information was being gathered and interpreted. As a result, design changes were made in order to minimise the impact and interaction of the major faults on the infrastructure (reducing the number of turnouts along P3849 SEDR and where possible, moving turnout locations away from the J46 fault).

After the development designs were finalised, numerical modelling was performed to examine the potential effects of the HWL mining and the subsequent interactions and effects of faulting on stoping, and the regional effects that the HWL mining might induce as a result of extended relaxation along the faults (Beck, 1999). Observations from the analysis were:

1 High potential for fault slip where faults were found in and near stope crowns. The area of slip was sufficiently large, that where faults intersect crowns, some instability should be expected.
2 The most significant fault damage would occur on faults that intersect stoping as opposed to faults that are undercut by stoping. The induced fault slip area was greatest on these faults.
3 In terms of regional changes, there would be regional softening associated with stoping and the de-stressing of the hangingwall faults may be associated with changes up dip and along the faults towards the X41 Shaft.
4 In terms of drive instability associated with de-stressing from the extraction of stope Q369, the Stress Damage Potential was low (Hudyma & Bruneau, 1998). As such, any ground failures induced through de-stressing were considered to be contained by the recommended support systems installed.

During the design process, and based on historical experience, it was acknowledged that there might be ground deterioration along P3849 SEDR (20B) in the area where the drive was intersected by the J46 fault. However, previous experience of mining through the fault and the subsequently installed ground control systems, had resulted in a stable access being maintained. Such experiences were utilised along P3839 SEDR (20B).

2 WHAT IS A FALL OF GROUND?

2.1 *Introduction*

At the Xstrata Copper Mount Isa Mines operations, the definition of a fall of ground is 'an uncontrolled rockfall greater than 1 tonne in size, or an uncontrolled rockfall of any size that causes injury or damage' (Mount Isa Mines, 2003a).

Whenever an excavation is made underground, the surrounding rock mass will react in such a way as to adjust or compensate for the void that has been made (where the reaction tends to relate to rock mass failure of varying degrees). As a result of the ground reactions, falls of ground or rockfalls can occur, where failures can vary in size and consequence (in both cases, this can be from insignificant to catastrophic). As such, falls of ground present a major hazard to the underground mining environment.

2.2 *Fall of ground risk management*

The risk to underground personnel associated with potential falls of ground is measured in terms of likelihood and consequence (ie, what is the probability of a fall occurring in a particular instance, and what is the outcome from the fall). In order to evaluate the risk, and then ultimately reduce it to an acceptable level, four steps need to be determined and analysed (with reference to the Standard AS/NZ 4360:1999, 1999):

1 Estimate the probability of a rockfall – based on a root cause analysis (the estimation for the probability of a rockfall, whether it is small, large or dynamic, can be based on factors identified from the historical review of falls of ground over a period of time).
2 Estimate the exposure to the rockfall – based on the level of activities in a particular area (which can range from high exposure, such as a diesel workshop, to low exposure, such as a barricaded area).
3 Estimate the likelihood of a rockfall - the likelihood of a rockfall occurring and injuring a person can be estimated by combining the probability of a rockfall with the exposure. The likelihood is then expressed as either almost certain, likely, moderate, unlikely or rare.
4 Estimate the consequence of a rockfall - the consequence of a rockfall, in relation to personnel, can vary from being insignificant (no injuries) to catastrophic (a fatality). Note that determining the consequence of a rockfall will significantly influ-

ence the resultant risk rating, and will be driven by the individual (or individuals) undertaking the risk assessment. With conventional risk analysis, the most credible consequence of a rockfall should be used.

Once the likelihood (Step 3) and consequence (Step 4) have been estimated, the risk can be evaluated using a risk analysis matrix. The risk matrix will determine the resultant risk rating (being extreme, high, moderate or low), which in turn will determine the necessary action to be taken to reduce the risk to an acceptable level.

There are many definitions of what a fall of ground or rockfall is. However, there tends to be a common thread to them all, in that 'an uncontrolled failure has taken place'. A suggested common definition of a rockfall was developed as a part of the recent work commissioned by the Minerals Council of Australia and completed by the Australian Centre for Geomechanics (Minerals Council of Australia, 2003a, b) – '*An uncontrolled fall (detachment or ejection) of any size that causes (or potentially causes) injury or damage*'.

Rockfalls are an ever-present hazard in the underground mining environment, and because of their unpredictable nature, remain one of the greatest hazards to underground personnel. As such, the risk to personnel associated with rockfalls must therefore be managed, which is only possible if a detailed knowledge of the hazard is developed.

In order to assist in developing this knowledge, it is important that all falls of ground are reported. There is a need to determine why a particular failure has occurred, and then prevent a similar failure from happening again. Falls of ground provide opportunities for mine sites to learn more about their ground conditions and ground support and reinforcement, and possibly improve on individual mining practices.

2.3 *Falls of ground at Mount Isa Mines*

At the Isa Copper Mine (formerly X41 and Enterprise Mines), when a fall of ground occurs, the relevant Supervisor will complete an initial report that provides the Rock Mechanics Engineer with basic details of the incident (only after the area of concern has been made safe to other personnel). The Rock Mechanics Engineer then completes a concise 'Fall of Ground Report' (Mount Isa Mines, 2003b) which considers such information as the failure location, failure size (dimensions and tonnage), induced stress change, failure mode, rock mass quality, excavation details, and ground control details. It is also advantageous, when possible, to photograph the incident and surrounding area to compliment the report.

Falls of Ground in underground mines will continue to occur due to the complex and unpredictable nature of the geological environment in which mining activities take place. Such an environment is further complicated when consideration is given to the extent of material that is commonly extracted over a period of time, an issue which is of particular importance to the Mount Isa Mines underground operations. For this reason, it is the authors' belief that we will never eliminate rockfalls underground.

However, we will eliminate injuries and fatalities due to underground rockfalls as a result of: improved mining practices (for example, mechanised scaling and ground control installation methods); development of mine site procedures and standards in the area of ground control (for example, a Ground Control Management Plan and Ground Control Standards); a continual understanding and improvement in ground conditions and ground control systems; and an improved industry awareness (for example research studies, such as the work being undertaken by the Australian Centre for Geomechanics).

Such a belief can be seen in the industry safety statistics, which show a significant downward trend in rockfall related injuries and fatalities, particularly since 1996-97 (Potvin et al, 2001).

3 EVOLUTION OF GROUND CONTROL PRACTICES AT THE ISA COPPER MINE - SOUTH

3.1 *Evolution of ground control practices*

Each of the Mount Isa Mines operations requires its own ground support and reinforcement systems, which are tailored to the individual ground conditions and operational requirements. The most effective use of ground support and reinforcement is achieved by matching the ground support to the exposed ground conditions.

Up until 1999, ground support practices involved hand installation methods (cement-grouted rebar, dywidag, and cable bolts, including rolled mesh as a surface support). These systems were a proven and reliable practice with decades of use (Grice, 1986, Potvin et al, 1999). They were simple, robust and low cost systems. However, the practice was inefficient – three pass systems (drill the hole hand held then remove the rig, push the bolts fully encapsulating them with cement grout from a platform, then leave to cure, finally installing a plate).

In addition to the inefficiency, there were several safety issues associated with the systems – working under unsupported ground, working from height (off a platform), manual handling and arduous and repetitive tasks.

Since mid 1999, primary ground support became part of a one pass mining system. The systems adopted were fully mechanised, including the installation of sheet mesh as the surface support. The systems provided immediate support to underground personnel, with reduced residual mining risks and hazards (particularly eliminating the need for exposure to unsupported ground). An additional benefit was an improvement to productivity.

At the time of the P3849 SEDR failure, the primary ground support systems in use at the Isa Copper Mine-South consisted of split sets and mesh for short-term support requirements, and fully encapsulated cement grouted PAG bolts (or MP Bolts) used for long-term support. The PAG bolt is a point anchored dywidag bolt which provides immediate support via a specially designed expansion shell (Thin et al, 2000). With current practices, primary support has changed in terms of 3.0 metre long cable bolts replacing the PAG bolts for the long-term requirements. Secondary reinforcement remains unchanged and consists of either single or twin strand Garford bulb cable bolts. Like the primary support, secondary reinforcement is also installed mechanically, via Tamrock Cabolters.

Over the years, the use of shotcrete has evolved as a ground control system, gaining increasing acceptance across the Mount Isa Mines operations since the early 1990's. Shotcrete is predominantly used during ground rehabilitation, but has also been used as part of a primary ground control system. Investigations have been carried out looking at shotcrete as a mesh replacement, creating an in-cycle system. However, constraints with providing a constant supply of shotcrete underground (via slick-lines) has so far prohibited this to make if an efficient system (Slade & Kuganathan, 2004). Similar to the current primary support systems in use, shotcrete is applied mechanically, rather than by a hand-held process.

3.2 *Ground control installed in the P3849 SEDR (20B) failure zone*

The original primary ground support installed along P3849 SEDR consisted of a combination of fully cement grouted PAG bolts (2.2 m long), split sets (2.4 m long) and sheet mesh in the back and down both sidewalls. The intersection of P3849 SEDR and Q369 CO was cabled bolted with 6.0 m long single strand Garford cables.

The total support system installed in P3849 SEDR where the J46 fault was intersected consisted of fully cement grout encapsulated PAG bolts, split sets and sheet mesh in the back and down the entire sidewalls. In addition, 6.0 m long single strand Garford cable bolts were installed in the backs and sidewalls. Such a system has been used many times throughout the Copper Mine, with ground stability successfully maintained in areas of drives where the J46 fault has been intersected.

Due to the unconsolidated nature of the J46 fault and the graphitic shales, it appeared that the vast majority of the rock had unravelled from around the existing ground support and reinforcement. It was seen that some elements had failed due to corrosion, with J46 fault acting as a path for ground water flow. The level of ground water in this immediate area had been limited to damp ground and not flowing water.

4 SEQUENCE OF EVENTS LEADING UP TO THE FAILURE

4.1 *Sequence of events*

P3849 SEDR (20B) was being progressively rehabilitated due to ground deterioration in the sidewalls (see Figure 1). This was initially observed during the early stages of production from the stope Q369, located 15 metres to the west of the drive (Thin, 2002). An initial inspection of the drive was made by the Rock Mechanics Engineer in order to determine the necessary rehabilitation. As Q369 stope was still an active production source, the drive was barricaded off.

Once the production firings were completed, P3849 SEDR was re-inspected by the Rock Mechanics Engineer. The rehabilitation was recommended to start back just south of the Q37 TIPAC and consisted of scaling loose ground from both sidewalls, then installing split sets and mesh down each entire sidewall. The rehabilitation was to continue along the drive moving south. Ground conditions, and subsequent deterioration, was seen to improve past Q36 XC. Cable bolting requirements were to be assessed once the bolting and meshing had been completed (it was anticipated that additional deep reinforcement would be needed in the drive, specifically in the zone of exposed J46 fault). During the last inspection, ground deterioration was not evident in the back of the drive.

Prior to the initial fall, rehabilitation had been completed to the point just south of the P3849 SEDR and Q369 CO intersection. The Jumbo operator during the previous shift had been scaling the eastern sidewall to an approximate depth of 1.5 to 2 m into the sidewall (undercutting the back). The excessive scaling was attributed to the poor ground conditions associated with the J46 fault and graphitic shales. The poor ground conditions were discussed at cross-shift between the Day and Night Shift operators.

The Night Shift operator continued with the rehabilitation. After nearly two hours into the shift, the operator contacted his Supervisor, concerned with ground conditions on the eastern sidewall adjacent to the Jumbo. The Supervisor inspected the area, which had already been rehabilitated with mesh and split sets. The Supervisor told the operator to pull the Jumbo back and bar down the previously meshed area, after which re-installing mesh and split sets to the floor. The Supervisor then left the area.

The operator returned to the Jumbo and was in the process of moving the booms into a position to move the unit back. While moving the booms, scats started to 'shower' down. Approximately 2 seconds later the initial rockfall occurred. The operator saw mesh and rocks coming towards him, at which point he took cover behind the console. Once the rocks stopped falling, the operator hit the Stop button and climbed over the right hand side of the steering console and left the unit. The area was then barricaded off.

Various technical personnel inspected the area during the remainder of the Night Shift to discover the second fall of ground had covered the Jumbo. The third and final fall was discovered just prior to the end of the shift, where the failure was found to have progressed to the P3849 SEDR and Q369 CO intersection (see Figures 4 and 5).

For a period of approximately 36 hours after the initial failure, localised rock noise was heard in the immediate failure zone (the rock noise consisted of cracking and popping). No further rock noise was heard after this time.

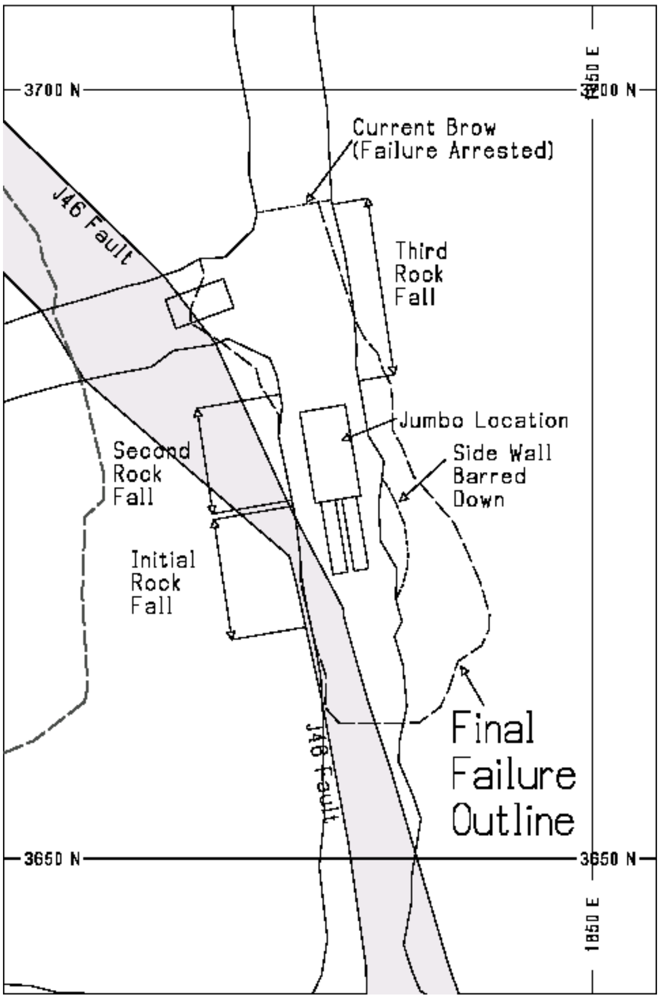


Figure 4. 20B Sublevel mine plan showing details of the sequence of failures and final failure outline (the shaded area represents the floor projection of the J46 fault).

Figure 5. Looking south at the fall of ground at the point of arresting, at the intersection of P3849 SEDR and Q369 CO, 20B Sublevel.

5 PERCIEVED CONTRIBUTING FACTORS WITH THE FALL OF GROUND

5.1 *Perceived contributing factors*

In order to better assess the immediate failure zone, a 150 mm thick shotcrete curtain was sprayed on both sidewalls to the floor and in the back (in affect, creating a shotcrete arch), to a distance of approximately 6.0 metres back north from the point were the failure arrested (see Figure 6). Deep reinforcement was then installed in the back and sidewalls of the drive, from the Q37 TIPAC moving south, with the installation of 9 m long Garford cable bolts. Once this was completed, the unstable brow was then mechanically (and thus remotely) removed, after which there was some limited mucking of the failed material. The immediate failure scar and fall material were then visually inspected and assessed.

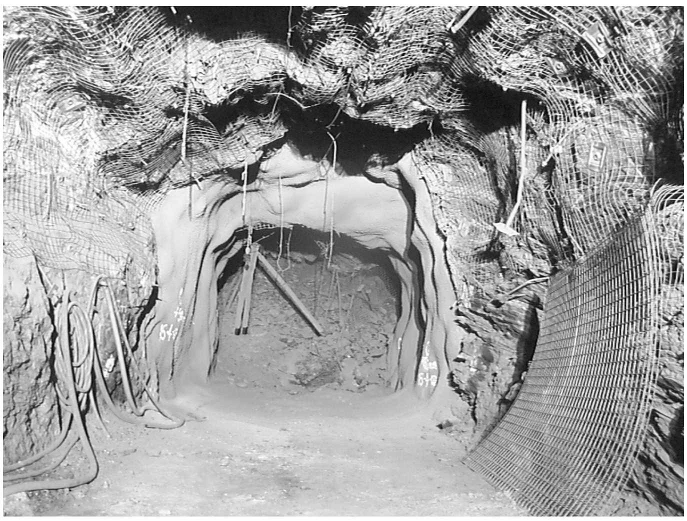


Figure 6. Looking south along P3849 SEDR (20B) at the first stage of the initial rehabilitation process, with the spraying of shotcrete (150 mm) and prior to the installation of the reinforcing cable bolts.

As a result of this initial rehabilitation and discussions with the relevant Supervisors and Operators, several contributing factors were identified which were attributed to the failure. These factors were:

1 Under-cutting the back of the drive through deep scaling of the sidewall (initially triggering the failure).
2 Continued and progressive mechanical scaling in poor ground.
3 A stress window (created by the southern end of the 1100 Orebody and the Footwall Lens), which was subsequently de-stressed due to extraction from Q369 stope.
4 J46 fault (and its unconsolidated material properties) and heavily graphitic-coated ('greasy') shales.

The decision as to how to progress with the situation (either full-scale rehabilitation or develop a by-pass) was dependent upon the outcome of the installation of the additional support and reinforcement, and the success of collecting physical facts relevant to the fall.

6 POST FAILURE REHABILITATION PHILOSOPHY AND METHODOLGY

6.1 *Philosophy and methodology*

Having safely completed the initial stage of the rehabilitation process, a risk assessment was undertaken in order to determine the next stage of rehabilitation. Access along P3849 SEDR (20B) had to be re-established south of the failure as this represented the production-drilling horizon for the HWL.

As part of the risk assessment process, the decision to develop a by-pass around the failure zone was discussed and assessed. While the risks associated with such an action would be lower than those associated with rehabilitating the drive, the question that could not be answered was where did the failure stop in a southerly direction along P3849 SEDR (20B)? The risk of creating an intersection with the by-pass and P3849 SEDR while still in the failure zone proved to be too high, and as such, the option of developing a by-pass was discounted at this time.

With the collection of the physical facts and the level of personnel experience associated with ground rehabilitation, the risk assessment focused on rehabilitating the drive.

Management of weak, friable and unconsolidated failure material drove the basis for the philosophy and methodology behind the rehabilitation (see Figure 7). The resultant risk assessment identified several hazards associated with a full rehabilitation process of the drive. From this, new controls were identified and a risk management action plan developed. The agreed rehabilitation consisted of:

1 Adopting an incremental rehabilitation process, which would limit the amount of exposed and unsupported ground within the failure zone at any one time.
2 Adopting a 'project' approach, using Operators with extensive ground rehabilitation experience. Two Supervisors were selected and removed from their respective Crews. By having these two dedicated personnel, changes in ground conditions would be captured and managed more effectively, than if different and rotating personnel were involved. At least one of the Supervisors was present whenever any work was carried out.
3 Regular inspections by the Rock Mechanics Engineer and updates from the two dedicated Supervisors. Digital pictures were taken of the rehabilitation as it progressed.
4 Adopting a rehabilitation cycle, that was flexible and that would be continually assessed during the rehabilitation process (dependent on the exposed ground). The cycle was made up of: remote muck no more than a 4 m advance, then assess; remote spraying of 150 mm thick fibre reinforced shotcrete (mechanical scaling was not used, any loose material was 'scaled' as a result of the impact from the shotcrete on the exposed ground); install 9 to 12 m long single strand Garford bulb cable bolts (length dependent on ground during drilling) on a 1.5 m bolt spacing and a 1.0 m ring spacing - cables installed remotely with the Tamrock Cabolter; cables left to cure, then manually plated and jacked; then repeat the cycle.
5 Communication presentations to the Isa Copper Mine-South workforce. This was an important part of the rehabilitation process as it presented the facts behind the failure, the steps being taken to recover the situation, and the changes that would take place to avoid a similar failure from happening again.

Figure 7. Typical size of the failure material from J46 fault exposed on P3849 SEDR, 20B (note that the unit mucking from the failure zone is an Elphinstone R1700).

7 GROUND CONTROL BACK ANALYSIS

7.1 *Introduction*

The design of ground control systems used for development that exposes a major fault has been based on judgement, which has evolved with historical experience over time. This judgement has worked well over the years with drive stability being successfully maintained on many occasions – indeed, there has never been a failure similar to that experienced along P3849 SEDR (20B).

Given consideration to the perceived contributing factors and the experience gained during the rehabilitation, it is believed that the failure has initiated as a result of increasing the effective span in the back of the drive due to the mechanical scaling of the eastern sidewall – exceeding the capacity of the installed ground control systems. Due to the nature of the rock mass in the failure area, the initial failure mechanism would have been that of unravelling in the area of the under-cut back, which then continued and propagated out into the drive.

7.2 *P3839 SEDR (20B) ground control back analysis*

Empirical design methods exist for assessing drive stability based on rock mass classification, with the Q–system (Barton et al, 1974) being one of the common methods used at Mount Isa Mines. The Q-system is a useful first-pass tool for the design of mine openings. However, it has limitations that need to be appreciated and understood. If any of the Q system input parameters are incorrectly selected (due to many reasons), the resulting bolting recommendations can be misleading (Misich, 2003).

Due to safety concerns with the exposed ground during rehabilitation (with regard to exposing personnel to the ground conditions), a rock mass classification was not done prior to shotcreting the fault zone. An estimate was however made based on observations during the rock mechanics inspections and geological mapping carried out during the original development stage (Milne, 2003). As such, the following parameters were used:

1. Rock Quality Designation (RQD) = 10 (minimum value used)
2. Joint Set Number (J_n) = 9 (three joint sets)
3. Joint Roughness Number (J_r) = 2.0 (smooth, undulating)
4. Joint Alteration Number (J_a) = 5.0 (alteration between 4.0 and 6.0; 1-2 mm of clay, chlorite, graphite, and clay less than 5 mm respectively)
5. Joint Water Reduction Factor (J_w) = 1.0 (dry, minor inflow)
6. Stress Reduction Factor (SRF) = 2.5 (single weakness zone containing clay, depth of excavation > 50 m)
7. Excavation span = 5.5 m (original development span) and 7.5 m (final failed span)
8. Excavation Support Ratio (ESR) = 3-5 (temporary mine opening)

From these parameters, a Q of 0.178 was determined. Then with reference to Figure 8, it can be seen that the empirical estimation of support requirements for a drive with a 5.5 m span equates to bolts and fibre reinforced shotcrete with a thickness of approximately 50 mm. For a drive with a 7.5 m span, this equates to bolts and fibre reinforced shotcrete with an approximate thickness of 90 mm.

Based on this empirical back analysis and engineering judgement, the proposed changes to ground control systems used to maintain drive stability with future exposures of the J46 fault (or any other of the major faults), are to consist of mesh reinforced shotcrete (with an approximate thickness of not less than 100 mm), followed with cable bolts (the length of which will vary from between 6 and 9 m). A cyclic approach of installing this ground control system is certainly preferred over a campaign approach, so as to minimise exposure.

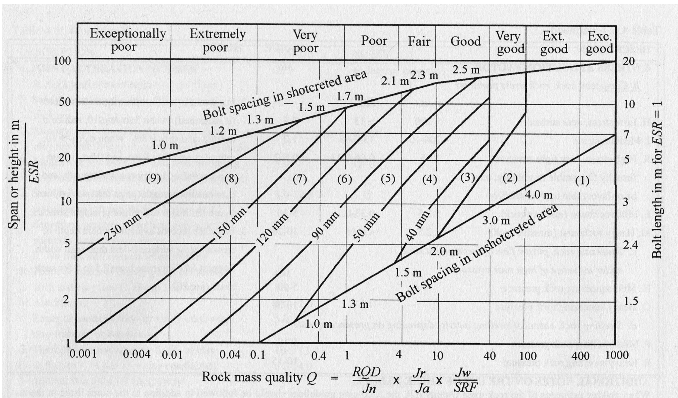


Figure 8. Estimated support categories based on the Q-system (Grimstad & Barton, 1993).

8 ESTABLISHING LONG-TERM HANGINGWALL LENS ACCESS

8.1 *Long-term access*

Having implemented a practical rehabilitation cycle to allow for the re-establishment of access along P3849 SEDR (20B), the issue of long-term drive stability had to be addressed. Although the effects of future stoping on drive stability were acknowledged, they were not considered as part of the rehabilitation process – both processes were felt to be incompatible with each other due to the complexity of the situation, and had to be dealt with separately.

Extraction of the HWL in a retreating sequence was inevitably going to create stress changes on the failure zone, with a progressively increasing stress path moving towards the zone (the failure zone being located at the end of the retreating sequence). Although the rehabilitation of the failure had created a safe and stable environment, maintaining its stability for the life of the HWL was unknown – would the shotcrete and cable bolts continue to create a stable environment during the retreating sequence? It was felt that further work would be needed to ensure the long-term stability.

As such, several options were proposed. These consisted of: development of a bypass around the failure zone; installation of an Armco tunnel through the failure zone, then filling the void between the tunnel and failure profile; installation of a shotcrete/concrete arch through the failure zone, then filling the void between the arch and failure profile; and backfilling the failure zone, then mining through the fill.

These options assumed that the level of ground control (shotcrete and cable bolts) installed during the rehabilitation would be insufficient for the future stress changes. Conversely, consideration was also given to the fact that the rehabilitation would remain stable. This gave one further option, which was to monitor the stabilised failure zone through instrumentation, and address any deterioration only if it occurs. However, installation of such instrumentation would have limited value, as there was no guarantee that the area would be adequately monitored. In addition, there was no confidence in establishing magnitudes of movement in the installed ground control that if exceeded, would lead to further ground failure.

Having given consideration to the various options in terms of ensuring a safe long-term travel way, while minimising the risk of production delays and cost, the preferred option was the development of a bypass. Although this option was originally discounted during the investigation as part of the initial rehabilitation process, circumstances changed with the re-establishment of the drive – the extent of the failure was seen to have followed the strike of the J46 fault (see Figure 9). With such information, the bypass could be designed so as to intersect the drive away from the failure. In addition, it was discovered that the bypass could be utilised for future access requirements for the Lower Footwall Lens, information that only became available with the completion of the 2002 Copper Business Study – approximately 9 months after the failure took place (Mount Isa Mines, 2003c).

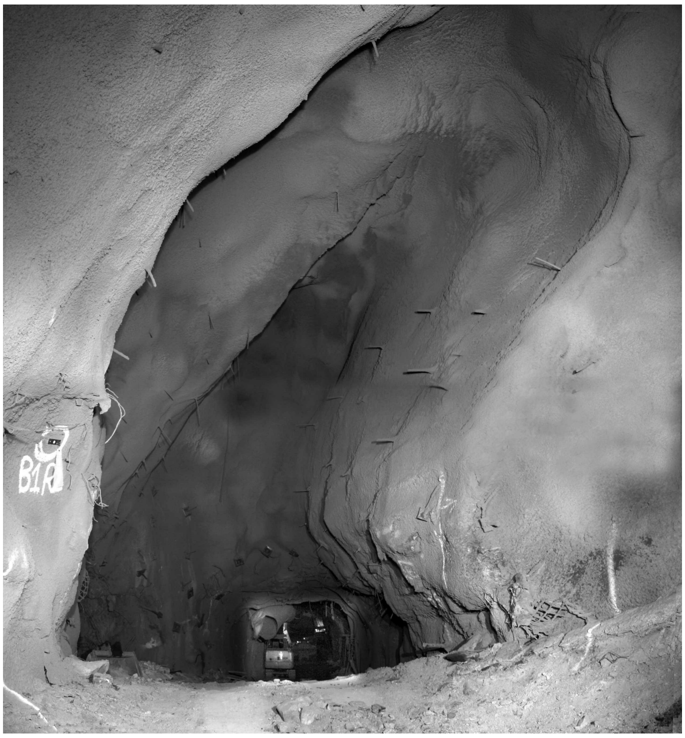


Figure 9. Looking back north along P3849 SEDR (20B) at the failure profile, dominated by the strike of the J46 fault (the photograph has been taken from the top of a 4 m high ramp used during the rehabilitation – notice the vent bag in the top left hand corner of the original drive profile).

The bypass (Q37 SEXC and Q36 NEXC) was developed within Fractured Siliceous Shales, intersecting the J46 and L41 faults at its southern end (see Figure 10). The bypass was designed so as to intersect the fault normal to its strike (improved stability when compared to an intersection striking parallel). The development profile through the faults was maintained without any problems, with the installed ground control consisting of split sets, mesh in the back and down both sidewalls to the floor, 100 mm of shotcrete, and cable bolts. The ground control as a whole was installed as a complete system before the next advancing cut was taken.

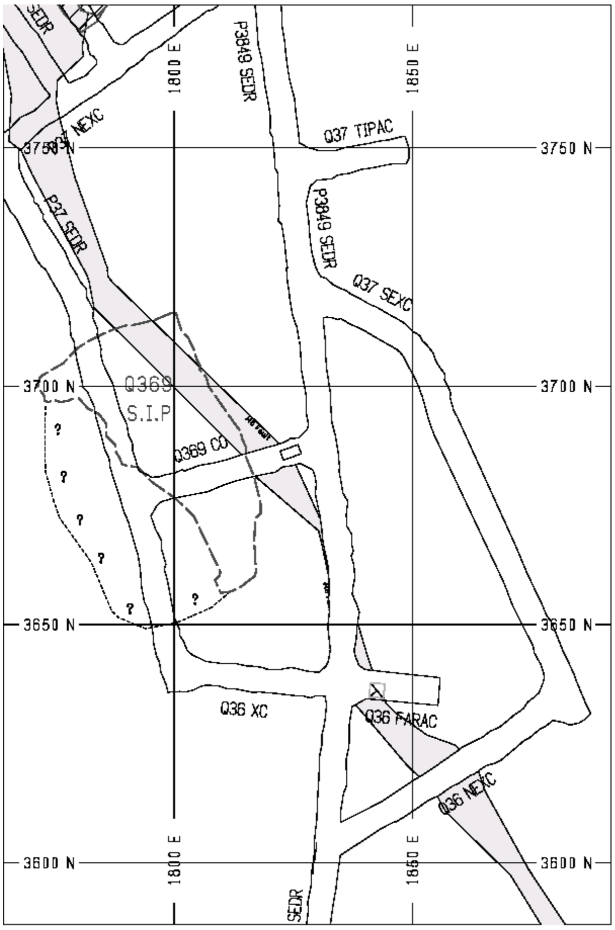


Figure 10. 20B Sublevel mine plan showing the Q37 SEXC and Q36 NEXC Bypass in relation to P3849 SEDR (the shaded area represents the floor projection of the J46 fault).

9 LESSONS LEARNT FROM P3849 SEDR (20B)

9.1 *Key learning's*

Successful development of fault intersected drives has been achieved many times before, where ground and induced conditions have been similar (if not worst) than those associated with P3849 SEDR (20B). With such cases, stability was maintained with the installation of bolts, mesh and cable bolts in the back and down both sidewalls. Historical experience indicated that such a combination of ground control systems would be appropriate for the ground conditions exposed along P3849 SEDR (20B). However, a significant fall of ground did occur, despite all the correct procedures being followed. So what has been learnt from this failure, so as to prevent a similar failure from happening again?

An extensive and documented design process had been followed for the HWL development and stoping, with a number of group meetings with relevant operational and technical personnel providing input. As a result, several modifications were proposed and implemented prior to development and the start of stope extraction (Grant, 2000).

Poor ground conditions had been recognised in the original development stage, with ground support adjusted to reflect previous experiences of successful development through the J46 fault. Inspections of the drive during stoping resulted in the area being barricaded for personnel safety. The area was then subsequently identified as requiring rehabilitation and a plan developed to undertake this task. The rehabilitation commenced and progressed successfully to the event area.

Change-of-Shift communications between operators and supervisors discussed a change in ground conditions seen during the rehabilitation process (this was also documented in the Operator Ground Condition Assessment Sheets). Just prior to the event occurring, the operator had recognised a change in ground conditions and after discussing the situation, decided to adjust the support system being installed.

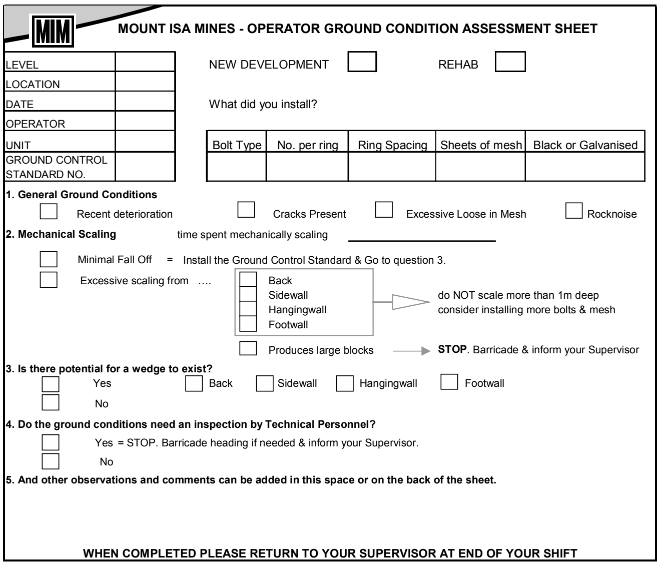
Given the friable ground conditions where the ground 'fell around the bolts' and the overall weak nature of the ground in the failure zone, the question of effective mechanical scaling needed to be addressed. The power of today's bolting rigs in poor or weak ground could allow such equipment to loosen and remove an infinite amount of material with no real improvement in the ground conditions. Is mechanical scaling in poor or weak ground the most suitable option to take?

With material that has graphitic-coated surfaces, loose and friable, and likely to move as relatively small blocks, stability should be maintained with tight surface restraint/support – bolt and mesh and/or shotcrete. With loose material of a similar description, should consideration be given to not 'bleeding' mesh that has bagged due to a build up of loose material – more loose material is potentially allowed to move, initiating/propagating a failure? Another layer of appropriate surface support maybe more beneficial.

Such questions, although obvious, are not easily answered and may well be specific to individual sites and situations. In order to help address such questions at the Isa Copper Mine-South (and indeed at all the Mount Isa Operations), changes were implemented to several design and operational procedures:

1 Modifications were made to the Operator Ground Condition Assessment Sheets – OGCAS (Figure 11, Mount Isa Mines, 2003d). The OGCAS is part of the management of ground control risks, and is a simple process that assists the operator in assessing the ground conditions for their work area, identifying potential ground condition hazards and suggesting necessary action to control them. The sheets are completed for each development or rehabilitation cut advanced. The modifications that were made related to mechanical scaling in poor ground, instructing the operator not to scale more than 1 metre deep, but rather stop and contact their Supervisor. Additional modifications

consisted of keeping the sheets in a duplicate book which could be kept on individual rigs, passing on information to the cross shift in terms of what has been installed and what issues have been encountered (providing documented history for particular areas).



MIM MOUNT ISA MINES - OPERATOR GROUND CONDITION ASSESSMENT SHEET

LEVEL	
LOCATION	
DATE	
OPERATOR	
UNIT	
GROUND CONTROL STANDARD NO.	

NEW DEVELOPMENT ☐ REHAB ☐

What did you install?

Bolt Type	No. per ring	Ring Spacing	Sheets of mesh	Black or Galvanised

1. General Ground Conditions

☐ Recent deterioration ☐ Cracks Present ☐ Excessive Loose in Mesh ☐ Rocknoise

2. Mechanical Scaling time spent mechanically scaling ____________

☐ Minimal Fall Off = Install the Ground Control Standard & Go to question 3.

☐ Excessive scaling from .... ☐ Back ☐ Sidewall ☐ Hangingwall ☐ Footwall → do NOT scale more than 1m deep consider installing more bolts & mesh

☐ Produces large blocks → **STOP**. Barricade & inform your Supervisor

3. Is there potential for a wedge to exist?

☐ Yes ☐ Back ☐ Sidewall ☐ Hangingwall ☐ Footwall

☐ No

4. Do the ground conditions need an inspection by Technical Personnel?

☐ Yes = STOP. Barricade heading if needed & inform your Supervisor.

☐ No

5. And other observations and comments can be added in this space or on the back of the sheet.

WHEN COMPLETED PLEASE RETURN TO YOUR SUPERVISOR AT END OF YOUR SHIFT

Figure 11. An example of the Operator Ground Condition Assessment Sheet (OGCAS).

2 Development of the Isa Copper Mine Primary Development and Rehabilitation Checklist – PDD (Mount Isa Mines, 2003e). The PDD is a procedure that outlines the steps involved in checking the engineering details of planned primary development and rehabilitation designs in all the copper orebodies, including the recommendation of the most appropriate ground control for the ground conditions to be exposed. The PDD has input from the relevant Planning Engineer, Geologist, Rock Mechanics Engineers, Ventilation, Development Superintendents and Mine Manager. In addition to the PDD, a separate checklist was developed for areas considered as high-risk rehabilitation (Mount Isa Mines, 2003f).
3 Use of risk ratings for existing mine access-ways, entry areas and infrastructure as part of the rehabilitation plan for individual areas, covering a total of 275 km of underground development across the lease. The risk ratings were developed through a process of analysis and evaluation of risk, which considered assessing the probability of a rockfall and exposure of personnel to these falls, followed by an evaluation of the consequences of such events.
4 As has already been stated, in order to maintain the stability of development that has intersected the J46 fault or other major faults (assuming that the development can not avoid the fault), changes were made to ground control practices in such circumstances. Areas that expose major faults are now supported with a combination of bolts, mesh, shotcrete and cable bolts in the sidewalls (floor-to-floor), and back – an upgrade on the level of ground control that has historically been installed.
5 Use of numerical modelling to predict fault displacement or changes in mining induced stress in faults zones, associated with stope extraction (Slade, 2003).

Two questions to consider that are pertinent to the use of the upgraded ground control: would the failure have occurred if shotcrete had been applied as part of the ground control system during the original development? And if shotcrete had originally been installed, would it have deteriorated to a point that would have necessitated rehabilitation? Difficult questions to answer. However, with the development of the by-pass comes the opportunity to further improve our understanding of the behaviour of the J46 fault and its interaction with this upgraded support system.

9.2 *Proposed ground control instrumentation*

As the bypass has intersected the J46 fault, there is the opportunity to install instrumentation internally and externally to the fault. The proposed instrumentation will have two purposes. It should allow for a better understanding of the mechanisms of fault deformation, and also enable drive stability to be monitored with future mining activities (determining how effective the upgraded ground control system actually is).

The proposed instrumentation will consist of (Milne, 2003):

1 Borehole Camera Holes, for visual monitoring within the fault.
2 Closure stations, installed to determine if ground movement is occurring and if it is being transferred to the shotcrete. The stations can also be used to measure the distance between closure stations (across the drive) to give an indication of shear movement.
3 SMART cables, installed to determine if the cables are loading (the SMART cables, coupled with the closure stations, should determine if the cable bolt/shotcrete ground control system is behaving as expected).

10 CONCLUSIONS

Despite the length of time that mining has been in existence, the behaviour of a rock mass in a producing environment still remains unpredictable. This behaviour is then exacerbated when a mine has been an active source for a long period of time (as is the case with the Isa Copper Mine-South).

The failure in P3849 SEDR (20B) was no exception to the unpredictable nature of a rock mass. Such a degree of ground reaction had never been experienced before at the Isa Copper Mine. However, with the work that has been undertaken as part of the rehabilitation process (and the planned future instrumentation program), a significant amount of knowledge has been gained, which will only aid in the overall understanding of the behaviour of our rock mass and its interaction with ground support. Changes have been made to our design process and Development practices, including modifications to ground control systems in areas with exposed faults, that represent a significant move forward to prevent a similar failure from happening again.

For as long as excavations are created underground (both at a development and production scale), falls of ground will continue to occur. The challenge that the industry faces is the effective management of such a hazard.

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