Ore pass rehabilitation—Case studies from Impala Platinum Limited

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Synopsis

Ore pass systems play a critical role in moving broken rock from the workplace to surface, and the integrity of the ore pass excavations is crucial. Over the life of the mine, ore pass integrity deteriorates, which may eventually result in the ore pass no longer being fit for purpose. This paper presents several case studies of successful ore pass rehabilitation exercises.

Introduction

A successful mine must strive to maintain a constant level of production. To achieve this, rock broken in the workplace must be removed to surface on a continuous basis, with minimal interruption. Ore pass systems play a critical role in this process, and the integrity of the ore pass excavations is crucial to maintaining production requirements.

Over the life of the mine, ore pass integrity deteriorates. Ore passes are subjected to changing stress environments as a result of mining, to wear and abrasion due to the flow of broken ore, as well as to the effect of rockwall failures around and on geological discontinuities. The resulting deterioration may result in the ore pass no longer being fit for purpose, in which case remedial measures are required.

This paper briefly summarizes some of the technical issues regarding options for the rehabilitation of ore passes, and then discusses three rehabilitation case studies:

- No. 10 shaft, inter-level ore pass
- No. 10 shaft, storage silos
- No. 9 shaft, inter-level ore pass.

Finally, an Impala methodology for ore pass rehabilitation is presented.

Locality and background information

Impala Platinum Limited is the world's second largest platinum group metal (PGM) producer. The company's main mining lease area is situated some 30 km north of Rustenburg in the North West Province, along the western lobe of the Bushveld Complex (see Figure 1). The lease area measures some 12 000 hectares.

The geological sequence in the lease area dips at approximately 9 degrees to the north east. Two PGM-rich horizons are exploited; the Merensky economic horizon and UG2 chromitite layer. These two horizons are separated by an 80 to 100 metre middling. Aside from opencast operations, thirteen shaft systems are currently used for access and mining purposes, at depth of 30 to 1200 metres below surface.

Underground mining operations generally follow traditional tabular mining practice. The orebody is accessed by means of travelling ways emanating from footwall haulages and ore is extracted using scraper winch-cleaned narrow reef stoping techniques. More than 20 000 people are employed underground on the lease area to extract more than 16 million tons of ore per annum, which produces some 1.1 million ounces of platinum group metals.

Technical issues

The integrities of ore passes vary—some have to be rehabilitated before being used, others may be in service for a number of years before showing signs of deterioration, and some may remain intact and serviceable throughout their working life.

Ore passes can be developed in several ways:

- Conventional manual development with short rounds and blasting with explosives
- Drop-raising using long remotely drilled holes, then retreat blasting up the ore pass
- Raise- or blind-boring, with no explosives involved.

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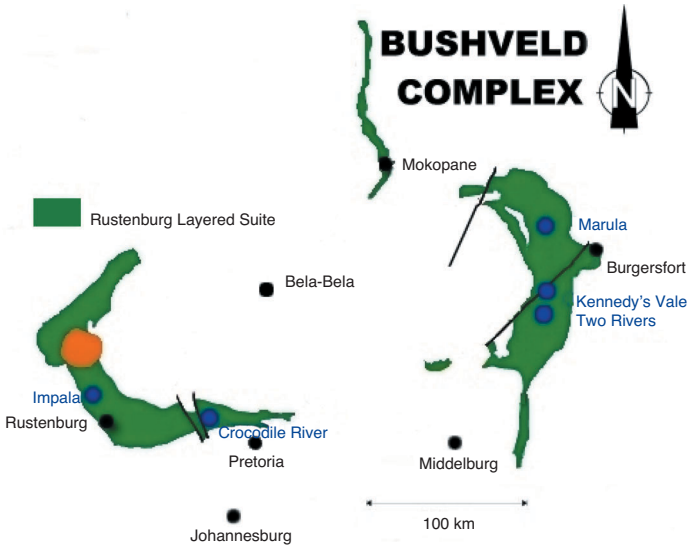

Figure 1—Locality map of the Bushveld Complex

Each method has its own problems associated with ensuring the integrity of the final ore pass excavation.

In theory, ore passes deteriorate due to:

- Stress-induced failure of the rockwalls
- Abrasion due to the flow of rock through the pass
- Detachment of the rockwalls inside, or alongside, geological discontinuities or weak geological horizons traversed by the ore pass.

The actual deterioration often results from a combination of these causes, which may be aggravated by factors such as unfavourable location, poor excavation practice, abrasive material and the presence of water.

Signs of ore pass deterioration include:

- Obvious increases in ore pass dimension
- Irregular ore flow through the ore pass
- Large waste rocks blocking the control chutes at the bottom of the ore pass
- Mixing of reef and waste in supposedly separate ore passes due to ore passes holing into one another.

Unless the entire length of the ore pass can be observed from its top or bottom access, deterioration (and indeed holing between ore passes) may continue undetected for lengthy periods. This is especially true for longer ore passes (50 m plus). It is thus important that ore passes are physically inspected and measured at regular intervals.

When ore passes deteriorate to the point that they are no longer fit for purpose, mine management is faced with a simple choice—the ore pass can either be rehabilitated or replaced. While this should be a simple economic decision, it is often complicated by issues such as infrastructure, logistics and time.

If rehabilitation is chosen, there are three commonly employed strategies:

- *Reinforcement of present excavation*—normally employed in cases where deterioration is detected early, or where sufficient middling exists between the ore pass and adjacent excavations to provide stability. The ore pass is reinforced to accommodate its enlarged size and shape, not restored to its original dimensions.
- *Installation of tube and backfill*—normally employed in cases where deterioration is severe or ongoing, or where the ore pass has inadvertently holed into another excavation. The use of a tube means that the ore pass is returned to a size similar or possibly smaller than its original dimensions, normally in the same position as the original ore pass.
- *Fill and redevelopment through fill*—a variation on complete replacement, this method entails filling the ore pass with cemented waste rock, followed by redevelopment through the fill, usually by raise boring.

There are no hard and fast rules in matching strategies to scenarios and, depending on circumstances, it may even be necessary to use a combination of strategies within a single ore pass.

Various materials have been used successfully when rehabilitating ore passes, including:

- Grouted tendons, with mesh and lacing rope
- Steel rings
- Andesite lava-based shotcrete
- Corundum-based shotcrete
- Concrete fill.

For the cement-based materials, a 70 MPa compressive strength requirement is normally indicated. The above materials have been used individually, but are normally applied in combination.

The working method for the actual rehabilitation process is dictated by the site-specific circumstances, but certain basic principles apply:

- In view of the hazardous nature of the work, safety is paramount
- All parties involved need to clearly understand their role, responsibility and duties
- A structured, systematic approach is essential—this is best achieved by conducting a special planning session/risk assessment prior to beginning work, as well as ongoing progress meetings during the rehabilitation process.

Case studies

No. 10 shaft, 14 – 15 level reef pass

This ore pass, which runs from 975 to 1040 metres below surface, was commissioned in early 1986 and rehabilitated in mid 1987. Although situated in noritic Footwall 16 host rock, with a UCS of over 200 MPa, the ore pass traversed very blocky replacement pegmatoid material, as well as several infilled lamprophyre (kimberlitic) dyke structures, which deteriorated due to exposure, water flow and abrasion from the ore flow.

Prior to rehabilitation, the ore pass was thoroughly surveyed to determine the extent of deterioration (Figure 2), and offsets were taken at fixed intervals down the length of the ore pass (Figure 3). The survey showed that the ore pass's original 3.5 m diameter had increased to a maximum of 24 m in one area. There was, however, sufficient clearance remaining between this and the other inter-level ore passes, and therefore a reinforcement strategy was adopted.

In determining a working method for the rehabilitation process, experience dictated the work proceed from the top of the ore pass downwards, to minimize the risk of rocks falling from unsupported areas above. Work would take place from fixed platforms established at regular intervals, rather than simply standing on a muck pile (Figure 3).

The platforms presented several advantages:

- Work could take place on more than one level simultaneously
- Additional storage place was available for material and equipment
- Each platform could be custom-built to the dimensions of the ore pass at that level
- Each platform provided additional protection from falling objects, as well as reducing the distance that an object could fall.

To establish the platforms, the ore pass was filled to the top with rock. The ore pass was then bled until the rock level had dropped by between 3 and 5 metres. A safety net was placed above the rock and secured to the sidewall by means of pigtail eye bolts. However, a muck pile plug would be left at the bottom of the ore pass as an additional safety measure.

The following services were provided in the ore pass (See Figures 4 to 6):

- Ventilating air was supplied by means of a 406 mm force ventilation column, as the muck pile plug prevented the flow of through ventilation
- A 570 mm pipe column was installed for transporting material down the ore pass using a 'sky climber' mini-hoist that was certified by the Inspector of Machinery
- Compressed air and service water were supplied in 50 mm diameter flanged pipes
- Vertical ringback ladders allowed for travelling between the top of the ore pass and the different working platforms. The longest ladder measured 7.2 metres. In view of their steep angle of installation, the ladders protruded at least 1.0 m above the top working platform. Additional coverage of the ringback section was provided by nylon netting
- Telephones were installed at the top of the ore pass and the material discharge point.

The actual reinforcement consisted of 1.8 and 2.2 metre long, 16 mm diameter grouted tendons, installed radially

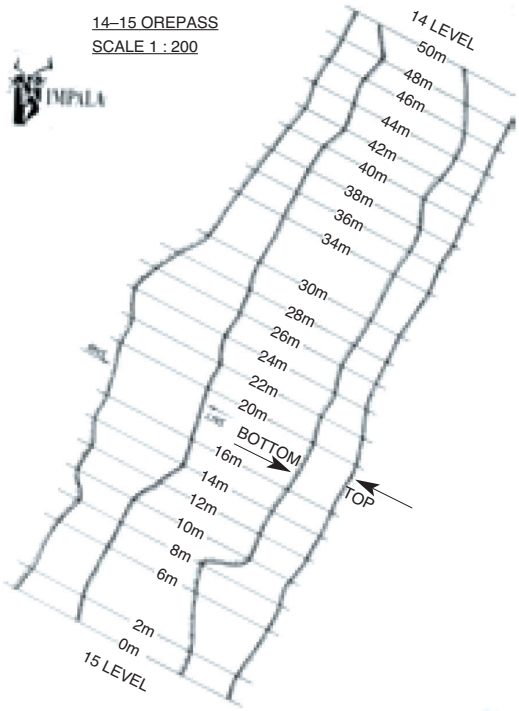

Figure 2—Sections through ore pass

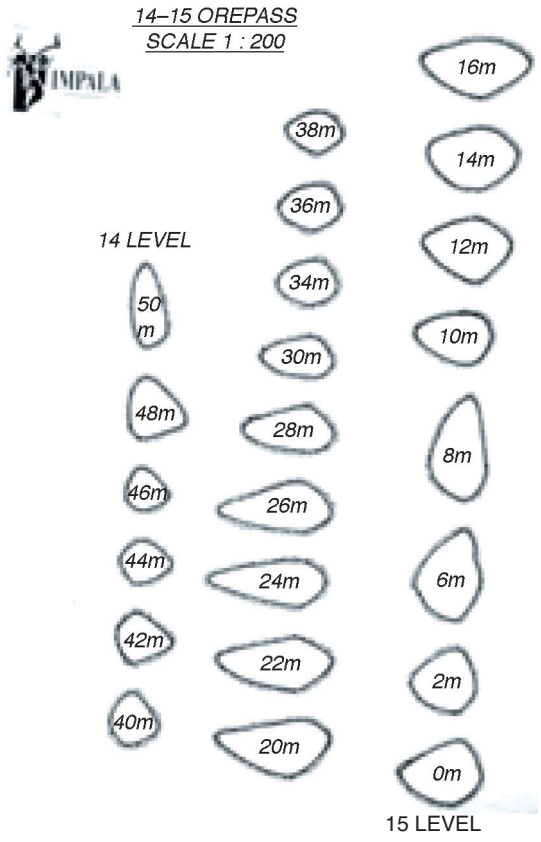

Figure 3—Offsets down ore pass

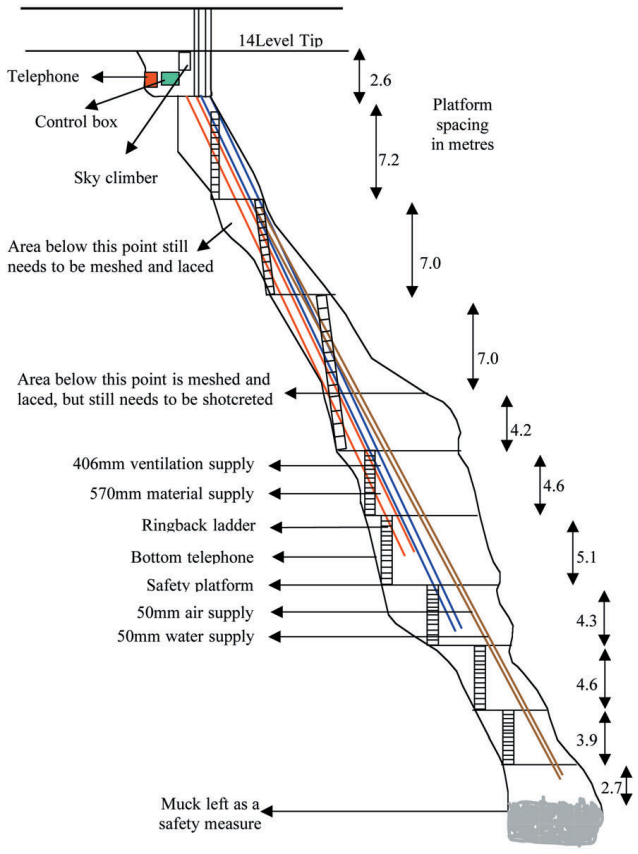

Figure 4—Section through ore pass during rehabilitation process

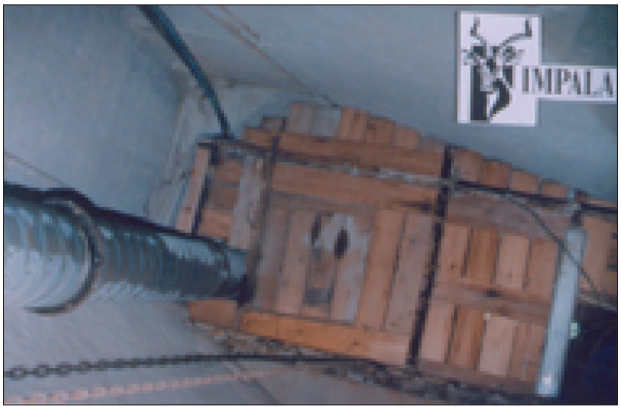

Figure 5—Typical working platform

Figure 6—Typical ringback ladder installation

around the ore pass on a 1.0 metre pattern. These would be supplemented by meshing and lacing to improve areal coverage and rigidity. This system would be covered with a 100 mm thick layer of high strength (70 MPa) andesite lava-based shotcrete, which would provide abrasion resistance.

It was originally intended to begin all work at the top of the ore pass and work downwards, stripping from the top as work progressed. This proved logistically impossible due to the difficulty of removing all the material and equipment through the ore pass chute on 15 level. Instead, the grouting, meshing and lacing work progressed downwards (Figure 7), after which the shotcreting was done in reverse (Figure 8), with stripping taking place from the bottom upwards behind the shotcreting operation.

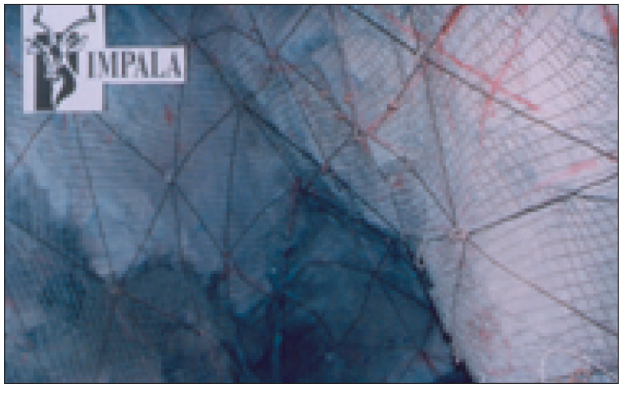

Figure 7—Completed meshing and lacing operation

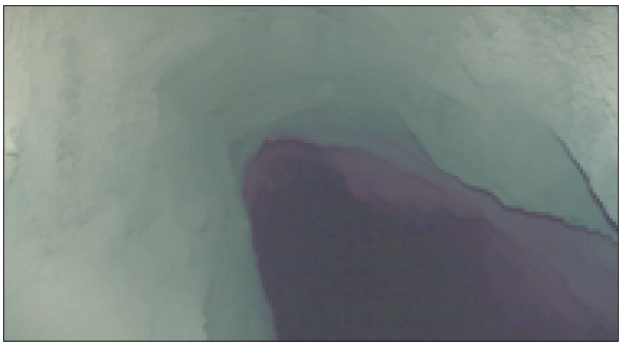

Figure 8—Ore pass after completion of rehabilitation process

Despite the trial-and-error nature of the exercise, the rehabilitation progressed smoothly with only minor delays due to material shortages and excessive working heights. No accidents or injuries occurred during the rehabilitation process, which took approximately 6 months and cost R1.2 million. To date, no further significant deterioration has occurred and the ore pass continues to operate.

No. 10 shaft, decline silos

The 10 shaft decline system was one of five similar projects begun in the early 1990s to sustain production levels. Given the depressed state of the platinum market at the time, it was decided to extend the life of existing vertical shafts via sub-level decline systems, rather than sink new vertical shafts. Each decline system comprised separate major tunnels for transporting men by chairlift, material by rail, and rock removal by conveyor, as well as ancillary excavations such as connecting travelling ways and ore passes.

The original 10 shaft decline system design proposed three large (30 m long x 7.0 m diameter) vertical bunkers to provide buffer and storage capacity for ore delivered from the decline section via the conveyor. The bunkers would be situated close to the shaft, in the same geologically-disturbed area as the 14–15 inter-level ore pass that had recently required rehabilitation, and would extend from 15 level (1040 mbs) to a loading inter-level 30 m below.

Analysis of the local *in situ* stress regime and orientation of local geological structures showed that even if supported, the long-term stability of the bunker could not be guaranteed. This analysis, together with the historical evidence and adverse ground conditions encountered in the horizontal development ends, prompted a design change. The single bunker was replaced by seven smaller (3.0 m diameter) vertical silos, which were developed by raise-boring, and then fully supported prior to commissioning. As the silos would be fully supported, the middling between adjacent silos was reduced to 9 m, half of the accepted industry norm.

The support for the silos consisted of welded mesh, pinned into place by 1.8 m long mechanically-anchored rockstuds. The rockstuds were subsequently full-column grouted for long-term corrosion resistance. No lacing was used due to the small diameter of the silos. The tendons and mesh were covered by a 100 mm thick layer of 70 MPa UCS andesite lava-based shotcrete. All work was conducted on a mini-stage, which was lowered from a skyjack arrangement installed on top of the ore pass. Support operations progressed down each silo in 2–3 m stages, with both grouting and shotcreting being completed before lowering the mini-stage.

The support of the seven silos, which was conducted by contractors, took approximately 9 months to complete, with no serious incidents being recorded. Following their commissioning in 1996, the silos have functioned successfully to date, with the only significant deterioration in the lining having occurred along the lamprophyre dyke zone (see Figures 9 to 12).

No 9 shaft, 16–17 level ore passes

This rehabilitation exercise was well documented in a paper entitled 'An engineered solution to multiple ore pass repairs at Impala Platinum Ltd, Wildebeest South mine' by van der Linde and Moolman (1995).

To summarize briefly, in August 1994 it became apparent that, after some 10 years of service the Merensky reef pass and the waste pass had holed into one another between 16 level (975 mbs) and 17 level (1030 mbs), as reef tons were being lost to waste. The holing was initially estimated to measure 2 m x 3 m. An attempt was made to seal the holing, but this had to be abandoned due to dangerous ground conditions encountered in the ore pass. The ore passes were continually blocked by large rocks scaling off the ore pass rockwalls, and it became evident that a proper rehabilitation exercise would have to be conducted to ensure long-term ore pass stability.

The selection of an optimal rehabilitation method was hampered by uncertainty regarding ground conditions and the extent of failure. After assessing the available options, the following methodology was proposed:

- Both ore and waste passes would be filled with rock from 16 to 17 level

Figure 9—General view of condition of supported silo

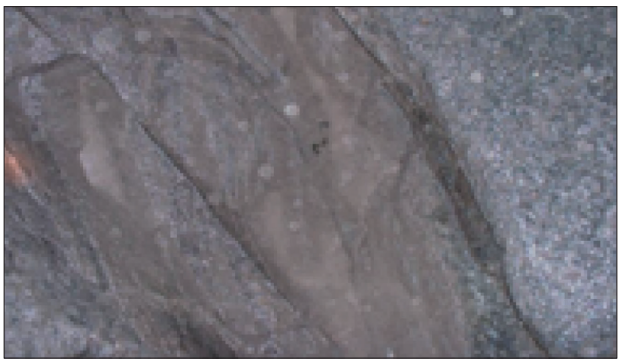

Figure 10—Lining eroded on lamprophyre dyke exposure

Figure 11—Shotcrete eroded to partially reveal weld mesh

Figure 12—Minor exposure of lamprophyre dyke in silo

- The broken rock would be used as a base for making safe and support operations, covered by a safety net and wooden platform
- Work would begin on 16 level and proceed downwards, with rock being bled from the passes when necessary to lower the working level
- Support would consist of grouted tendons, with meshing and lacing for areal coverage, supplemented by shotcrete when considered necessary
- Once the passes had been supported, they would be backfilled from the bottom up by low-strength concrete, with steel shuttering used to keep the intended pass voids open
- Finally, the voids would be lined with high (80 MPa) strength concrete rings to create the new rockpass excavations.

The job required extremely complex logistical arrangements—the tip cross-cuts had to remain accessible for rock being removed from the affected levels, which were still producing, and rock tipped on the shaft's upper levels had to be moved through the single remaining ore pass without mixing Merensky and UG2 ore. In addition, the 3 ton mass of the assembled concrete rings meant that they had to be lowered into place by means of a specially-installed Fulton winder and associated headgear.

Serious delays were experienced during the initial making safe and support phase as the reef pass emptied faster than the waste pass when bled, preventing simultaneous work from taking place until such time as the holing point had been reached. When the holing cavity was finally exposed, the damage was found to be more severe than initially anticipated.

The semi-elliptical shaped holing had occurred in the layered footwall 16 horizon (see Figures 13 and 14). The area was traversed by a 45 degree-dipping reverse fault, together with near-vertical jointing, which resulted in blocky ground conditions. It was also likely that the situation could occur in the newly developed adjacent UG2 ore pass, which intersected the same features.

After assessing the extent of the damage, it was concluded that the waste pass, being the lower of the two, was unlikely to migrate further towards the footwall as a substantial 'dead box' of muck had already formed. Provided its hangingwall was properly supported, further deterioration was unlikely.

A change of project scope was proposed—a brattice wall would be constructed in the holing cavity to separate the two passes, then the waste pass would be recommissioned (see Figure 15). Once the waste pass was in use, the reef pass would be rehabilitated as originally proposed, while simultaneously rehabilitating the UG2 ore pass. This would have both time and cost advantages, as well as ensuring the future stability of the UG2 ore pass.

Following the change of scope, the rehabilitation process was completed successfully, although problems were experienced with the workability and transport of the concrete used for the backfilling operation. The project overran its planned time frame, with delays experienced with the making safe and concrete pouring operations, and cost R2.47 million. The emphasis placed on safe working practices resulted in only two dressing cases being recorded during the 15 000 shifts worked.

Impala methodology

The success of the reinforcement approach used at No. 10 shaft led to it being adopted as the preferred means of ore pass rehabilitation on Impala. The approach was refined by trial and error during other rehabilitation exercises, and was eventually written up as a method statement by one of the contracting companies. This method statement was incorporated into a set of guidelines issued by Impala's rock engineering department in late 2003, which can be customized to suit different situations.

The methodology incorporates most of the steps used in the original 14–15 level ore pass on No. 10 shaft, but with a few refinements:

- Platforms are limited to a maximum of 3 m apart—this has been found to be optimal in terms of working height and accessibility
- Accelerator has been added to the shotcrete mix to provide better binding, faster setting and less rebound.
- Fluorescent lighting has been included for better visibility.
- Safety belts have been replaced by full-body harnesses.

In the majority of cases on new capital projects, ore passes are supported prior to commissioning. Rehabilitation of a typical 65–70 m long ore pass (55 m level intervals at 55 degrees) takes between 4 and 6 months, at a cost of between R600 000 and R1 200 000. Although this approach delays the commissioning of the ore pass, it ensures its long-term stability.

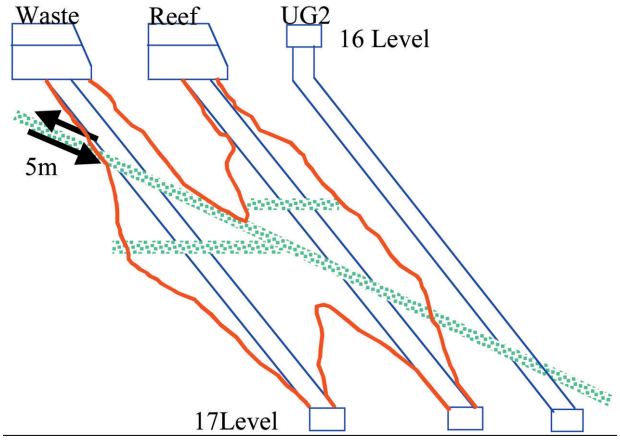

Figure 13—Holing between passes and reverse fault position

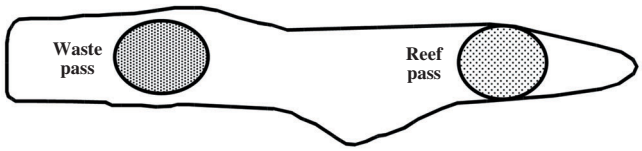

Figure 14—Plan view showing profile of holing between passes at widest point

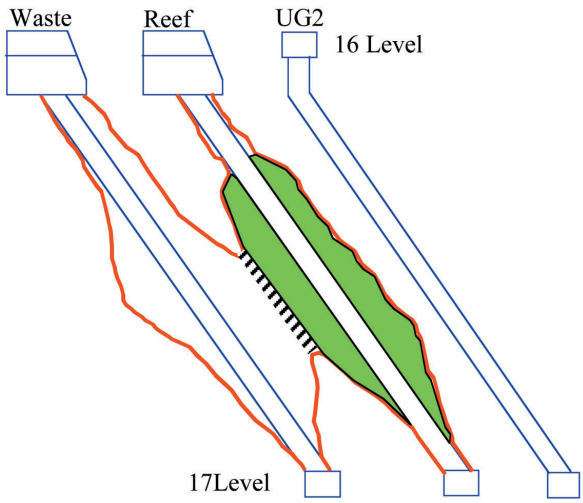

Figure 15—Position of brattice wall and filled area in reef pass

Conclusions

The Impala experience has shown that at present depths in the Bushveld environment, ore pass deterioration occurs due to failure along geological structures, rather than stress-related issues. The extent of such deterioration can be extensive, and can result in the loss of the ore pass as a functional excavation.

While the case studies presented above comprise only a small number of the ore passes rehabilitated on Impala to date, they showcase typical engineered approaches to ensuring ore pass stability and continued functionality.

Experience on Impala has shown that, for Bushveld conditions, a strategy of ore pass reinforcement ensures long-term ore pass stability. Adopting a formal rehabilitation methodology also reduces the risk associated with the actual ore pass rehabilitation process.

Acknowledgement

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