Optimizing the life of ore passes in a deep-level gold mine

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Synopsis

Main ore pass systems should last the life of a mine, and too often expensive and hazardous remedial measures are required to repair a damaged ore pass in an attempt to extend its life. In order to maximize the life expectancy of all ore passes at Moab Khotsong, 'wearing blocks' and 'softer support' systems, combined with basic rock engineering principles, have been implemented.

Failure of an ore pass can have severe financial implications, both indirectly because the ore pass cannot deliver the broken rock either from level to level or directly in the shaft ore pass system to the required level for tramming to take place, and directly due to the cost of the repair work that is required. Several factors need to be taken into consideration so that production interruptions are eliminated or minimized.

Investigations of damaged ore passes at Moab Khotsong and surrounding mines revealed some interesting mechanisms of damage, and some innovative methods of reducing or eliminating the damage have been implemented at Moab Khotsong.

The system design was based on 30 years, experience in main shaft rock passes. The design was to counteract scaling, hang-ups and dust problems associated with main rock passes, and the objective was to increase the life of rockpasses. These problems, including the initial design aspects to try and eliminate the repair measures, are discussed in detail.

Introduction

Moab Khotsong is planned to be among the deepest shafts in the world and is the deepest shaft in the Vaal River Basin, which is situated approximately 180 kilometres southwest of Johannesburg, South Africa. The mine is designed to exploit the Vaal Reef package, which is sited at 2 400 m to 3 200 m below surface, within the Moab Khotsong lease area. Several other mines in the vicinity are currently mining the Vaal Reef at depths of 1 300 m to 2 330 m below surface. Moab Khotsong is a single bratticed shaft, with a diameter of 10.75 m and a single drop from surface down to 3 132 m, making Moab Khotsong the longest single drop shaft in the world. The sinking of the shaft had its own set of unique problems, which have been dealt with in separate publications. The tunnels towards the ore reserves traverse several different rock types ranging from hangingwall quartzite with uniaxial compressive strength (UCS) values of 200 to 260 MPa, to footwall quartzite with an average UCS of 172 MPa. Tunnels have also been mined through various formations of shale with UCS varying from a high of 155 MPa down to 83 MPa. Virgin stress levels range from 71 MPa at 85 level, which is 2 604 m below surface, to 83 MPa on 101 level, which is 3 054 m below surface. A broad-base classification of a deep-level mine is one in which the virgin stress levels approach or exceed half of the UCS of the host rock; and quite clearly Moab Khotsong can be classified as a deep-level gold mine.

Mechanisms of damage

Scaling of ore passes occurs when one of the horizontal field stresses exceeds the strength of the rock mass, and the original shape of the ore pass, typically circular, changes to an oval shape. The extent of the scaling depends on the strength of the rock mass and the ratio of the horizontal stresses. The closer the ratio of the horizontal stresses is to unity, the more even the stress damage and the greater the extent of the scaling that takes place perpindicular to the major horizontal stress direction, as shown in Figure 1.

The timing and effectiveness of the installed support also contribute to the extent of scaling. Various support types have been used, some successfully and some not so. Initially corundum wetcrete was sprayed over weld mesh and then pretensioned full column grout anchors were installed. These methods were not that successful. Investigation revealed that, although corundum was an ideal material because of its hardness, but due to its smooth nature, poor bonding with the wetcrete

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Figure 1—Stress damage

was achieved. This then meant that under impact of falling or sliding rocks the corundum fragments would easily dislodge, and then the softer wetcrete would be exposed and rapid wear would result. It was also noticed that the stiff tendons installed into the ore pass sidewalls, also contributed to the extent of damage, as these stiff tendons would vibrate when hit by falling rock. This vibration would crack and eventually break up the grout annulus surrounding the tendon, which would then be easily dislodged by falling rock. Once the grout had been removed, the immediate sidewall of the ore pass would not have any confinement, would break off, and fall down the ore pass, thus exposing more of the support tendon. Thus the cycle repeats itself.

Investigation of damaged ore passes revealed that additional factors such as impact zones and wear rate were influencing the operation of ore passes. Impact zones are areas that are constantly bombarded with ore material. Where the ore flow remained in contact with the walls of the ore pass, excessive wear occurred. The ability of the ore pass to withstand wear and abrasion determines its life expectancy. Weathering and also oxidation were also taking a toll on the ore pass.

It was also noticed that the steeper the dipping ore passes the greater the damage and the higher the velocity of the ore flow, the more potential damage to the ore pass. Damage is also influenced by the particle size: as momentum is mass x velocity, the greater the mass the greater the momentum and thus the greater the potential for damage. Uneven wear was also taking place, as some host rock would wear at a slower rate than the surrounding rock, resulting in ledges being created. Ore material would then strike these ledges and be deflected to the opposite sidewall, where it would chip away at the softer layers.

Stress orientation, fracturing, excavation shape and size and method, as well the rock strength influence the life of an ore pass.

Design considerations

Geological factors

The more homogenous the outer walls of the ore pass then the more likely the ore pass will be stable. Imperfections such as bedding planes, faults, dykes and geological horizons of varying strength (such as shale and siltstone), will probably result in inconsistent wear, which in turn results in impact and deflections zones. The thickness of and cohesion between bedding planes, as well as the varying mechanical properties of the strata layers, affect the wear rate and pattern in an ore pass. Softer strata will wear out more rapidly, which compromises the original design shape and interrupts the flow of ore. (see Figure 2.)

The dip of the strata in relation to the ore pass is critical to the durability of the ore pass. (see Figure 3.)

Rock engineering factors

The magnitude and direction of the principle stress will influence the extent and mode of failure. The closer the horizontal stresses are to being equal, the less the extent of spalling or dog-earing. Dog-earing, which is the spalling of rock that occurs under high stress, takes place at 90 degrees to the direction of the major stress. (see Figure 4.) This scaling process (wear) will take place regardless of the chipping and scouring of the ore material; however, the flow of ore material will aggravate this wear process. Mining in the vicinity of ore passes will also cause stress changes and a stable ore pass could turn into an unstable ore pass in a short period of time. Flat angles, or low angles of intersection between the ore pass and the strata layers create wedges, which break under impact or wear, thus resulting in uneven ore pass walls, causing more impact and deflection zones. (see Figure 5.) Diameter, shape and excavation method are obvious methods affecting the stability of ore passes.

Inclination

Local experience and inspection of vertical ore passes have found some unusual wear patterns, which indicate profound

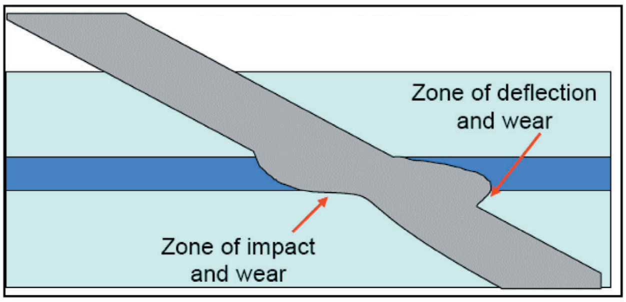

Figure 2—The effect of 'soft' seams

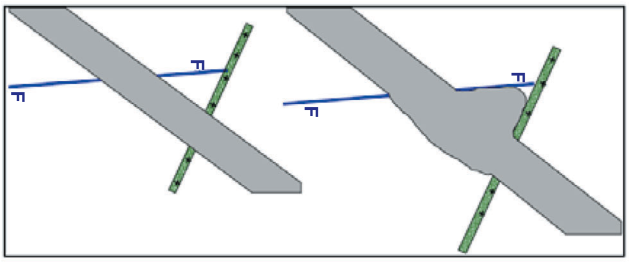

Figure 3—Dip of the strata in relation to the ore pass

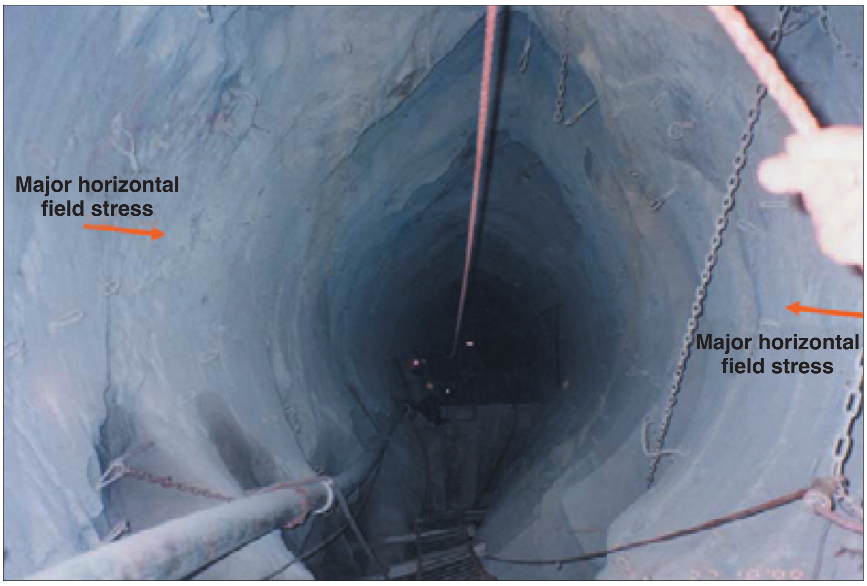

Figure 4—Dog earing

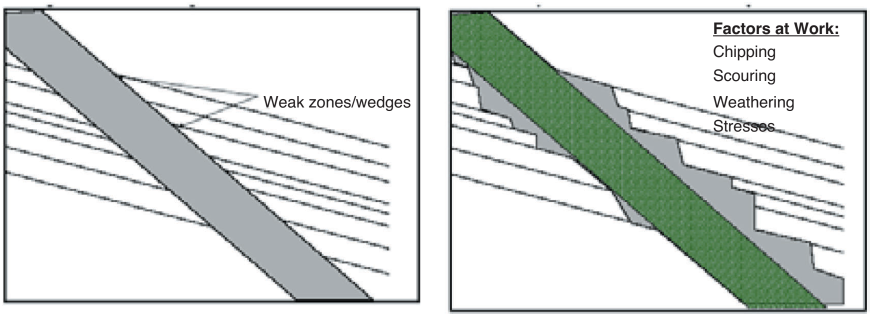

Figure 5—Wedge creation

dynamics at work. When ore is tipped into a vertical ore pass, the 'plug' of ore compresses the column of air below it. As this air forces its way up, through the ore material to the low pressure above the plug of rock, it shifts the falling ore fragments laterally with sufficient energy to chip away at the permanently exposed walls. The side walls of the ore pass are struck with the full momentum of the falling ore, which will be close to terminal velocity. (see Figure 6.) A second aspect of the inclination of an ore pass is that the one side of the ore pass will be exposed to the flow of ore, and excessive wear will be experienced. The natural walls of an ore pass, or the artificial skin as well as any support members or civil construction that are exposed to the flow of ore, must withstand the abrasive nature of the ore material.

Rock hardness

As mentioned previously ore passes traverse rock of varying strength, and it is typically in areas of lower rock strength that excessive wear occurs. Concrete on its own is much softer than rock and would offer no protection to the ore pass sides, therefore the ideal lining material should have a Mohs rating of 5 and should contain a good spread of fragments of a material harder than the ore being transported over it. The Mohs scale was devised in 1812 by German mineralogist Friedrich Mohs, and is use to compare the relative hardness of minerals. Quartz has a Mohs rating of 7, and Corundum has Mohs rating of 9. (see Table I.)

Andesite is much harder than concrete and has been used to improve the durability of concrete, however its suitability for use in an ore pass is severely limited as it is much softer than the ore material rubbing against it. Corundum due to its hardness would appear to be ideal, but because of it smooth and almost polished nature, it bonds very poorly to the concrete, and is easily dislodged, thus exposing the concrete to the ore material. A concrete mix utilizing Andesite is still the preferred mix for use at Moab Khotsong. Ore pass wearing blocks are constructed in the 'footwall' of inclined ore passes. This is discussed in detail further on.

Support type

Previously high tensile support tendons were installed in ore passes, to provide protection for the mining crews working below and also to prevent the sidewalls from being damaged once the ore pass was commissioned. While the initial support resistance was suitable, it was soon noticed that these high tensile steel tendons were too stiff as, once struck

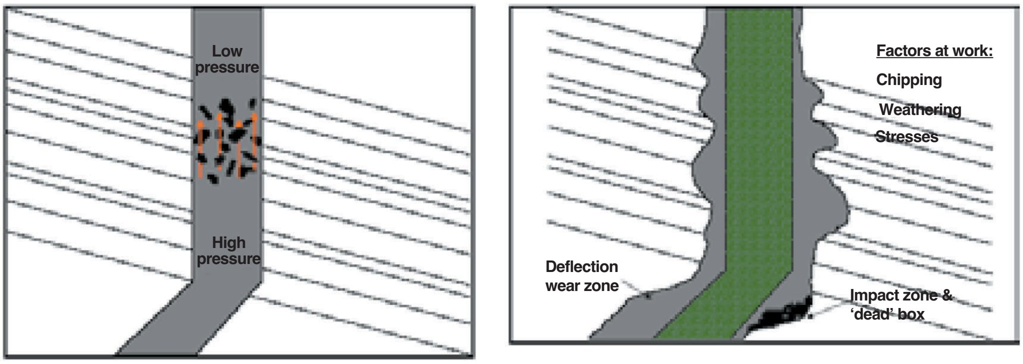

Figure 6—Damage in vertical ore pass

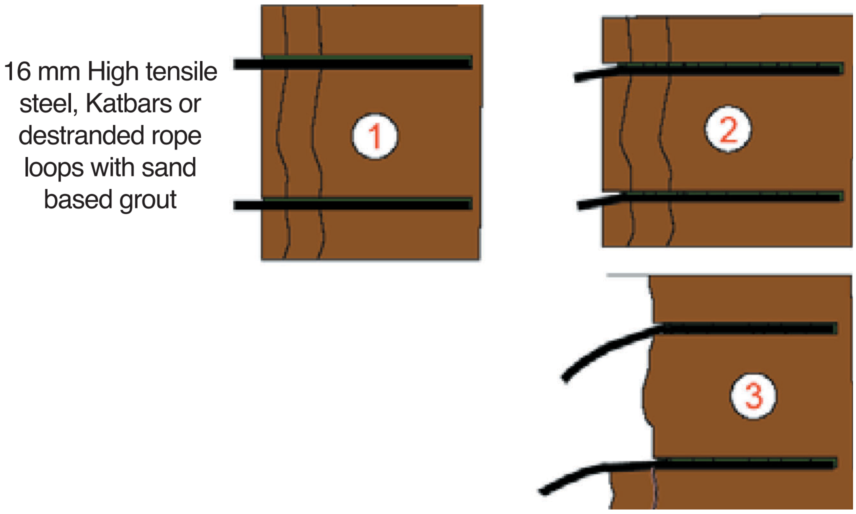

Figure 7—Effect of using high-tensile support tendons

Table I

Relative hardness of minerals (Mohs scale)

Hardness	Element	Description
1	Talc	
2	Gypsum	
3	Calcite	
4	Fluorite	Concrete?
5	Apatite	Andesite 5.5
6	Orthoclause	
7	Quartzite	Reef and footwall
8	Topaz	
9	Corundum	
10	Diamond	

by falling rock, shock waves were transmitted to the surrounding grout annulus and the host rock. The shock waves would then crack the grout and eventually cause the grout annulus to break up, thus exposing the unprotected ore pass sidewall to impact damage from falling rocks, as illustrated in steps 1 to 3 in Figure 7. These support tendons would not easily bend or wear, and thus would transmit the shock waves as the rocks passed by until the grout material was providing no function at all. The scaling process would then continue uncontrolled. The current support tendons used at Moab Khotsong in ore passes are 10 mm diameter mild steel unit, of length to suit the ore pass diameter, and the grout mix is based on pure cement mix containing condensed silica fume, which helps to increase workability and pumpability while reducing shrinkage.

Moab Khotsong ore pass wearing blocks

As mentioned previously, ore passes inclined at approximately 50 degrees, experienced excessive scaling and wear on the 'footwall' of the ore pass. To reduce or eliminate this excessive wear, the installation of 'wear blocks' was implemented. The spacing between the wear blocks was determined by the dip of the ore pass, the angle of influence and the angle of repose. Typical spacing between wearing blocks is 3.5 metres to 4.5 metres. The main purpose of the wearing blocks is to reduce the contact between the bare sides of the ore pass and the ore material, while maintaining the momentum of the ore flow below the rate at which it becomes airborne.

As seen in Figure 8, cubbies are excavated in the footwall of the ore pass, and manganese steel units combined with andesite based concrete are cast into these cubbies. All steel is covered with the andesite concrete mix. Depending on the dimensions and the dip of the ore pass, wearing blocks can be installed in varying configurations, as shown in Figure 11.

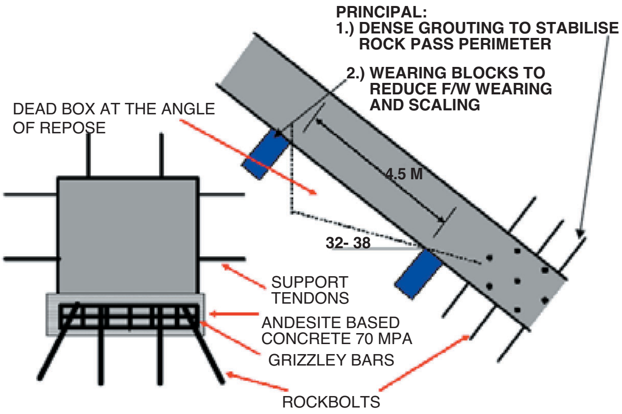

Figure 8 —Moab ore pass wearing blocks

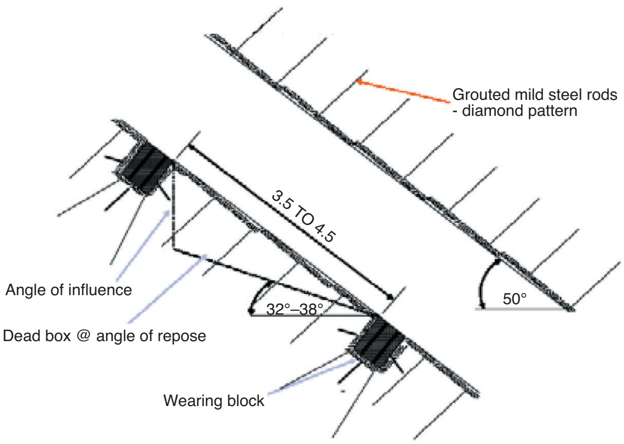

Figure 9—Wearing block layout

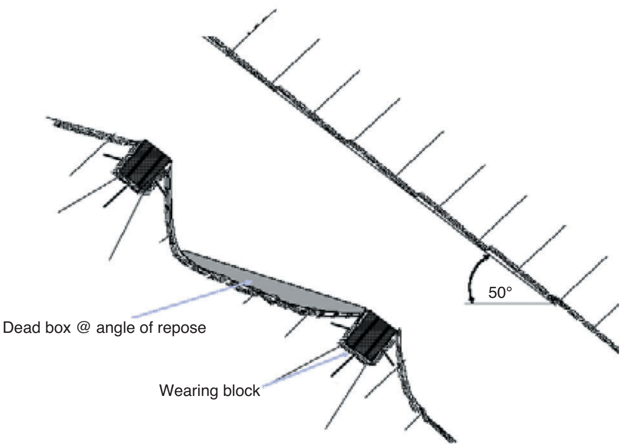

Figure 10—Functioning of weaving blocks

Figure 9, shows the layout prior to the commissioning of the ore pass, while Figure 10 below shows a sketch of how the wearing blocks should function. The dead box will be of the same material as the ore, and is the best natural wearing protection in an ore pass. Ore material does not become airborne due to impact with the sidewalls. Contact between the ore flow and the walls of the ore pass is minimized, as the accumulated rock acts as a natural skin on the footwall reducing the abrasive wear. Note that the mild steel tendons will wear away with the sidewalls without losing any integrity of the support. Depending on the dimensions and the inclination of the ore pass, wearing blocks were installed at various configurations, as indicated in Figure 11. The grizzly units are 380 mm x 380 mm cast manganese steel units, which then gives a combined unit dimension of 0.72 m x 1.44 m. These manganese steel units are pinned in place and reinforcing steel is installed. All the steel work is covered with andesite concrete, as shown in Figure 12. It was previously mentioned that impact damage to the sides and footwall of ore passes contributes to the extent of the damage; however, the intersection of one ore pass feeding into another ore pass, termed a 'dog leg' can contribute greatly to the impact and wear rate in an ore pass. (see Figure 13.) In order to lessen the intensity and extent of this potential damage area, Moab wearing blocks were placed on the sidewall of an ore pass directly opposite the dog leg, as shown in Figure 14. This serves to protect the intersection between the two ore passes by breaking the momentum of the ore flow.

Other considerations

Winder installation

In long and steep ore passes, a licensed winder is installed to facilitate transport of men and material to and from the working platforms. Channel tracks are installed to carry the conveyance, which transports material and equipment to the site. The safety and working platforms are also positioned by this conveyance. The channel tracks, as shown in Figure 15, are installed when the ore pass is longer than 40 metres vertical height and, or if the ore pass is steeply inclined. Equipping platforms can have several stages as shown in Figures 16 and 17. This will allow for separate work to be done simultaneously thus reducing the time without compromising on safety.

Conclusions

- With proper risk identification, planning and focus from all relevant employees, damaged ore passes can be repaired. On some ore passes at Moab Khotsong, it was noted that increased or unacceptable wear was taking place after the ore passes were commissioned. Use of the ore passes was suspended, and the 'wearing blocks' were installed and the ore passes recommissioned. The result is that several years later there have been no reports of damage in the ore passes, and the ore flows consistently and evenly.
- It is not always possible to place ore passes in the optimum site, and the installation of the 'wearing blocks' has helped to minimize the damage that would probably have occurred if the ore passes were supported by traditional means.
- Damage in 'dog legs' in ore passes can be minimized if the wearing blocks are positioned so as to cushion the impact of the rocks from the intersecting ore passes.

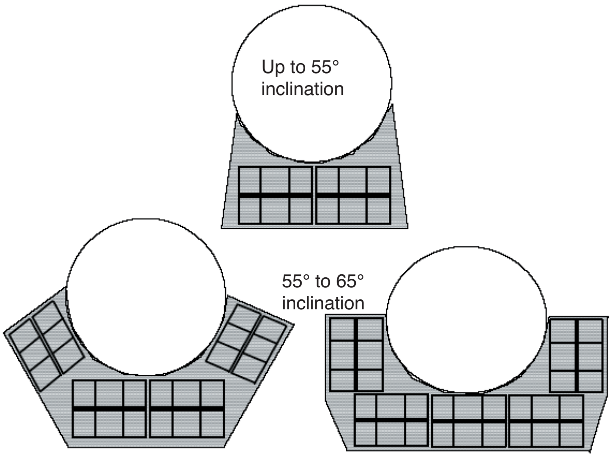

Figure 11—Wearing block configurations

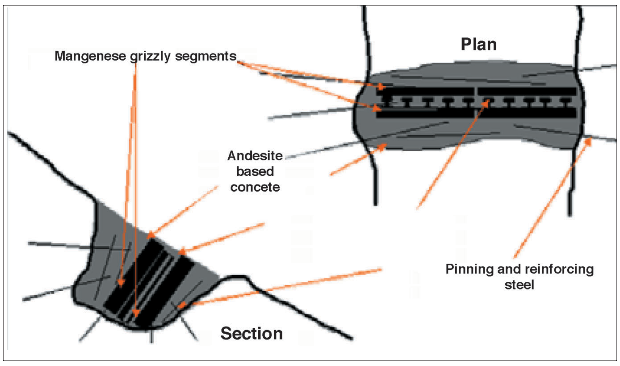

Figure 12—Grizzly segments

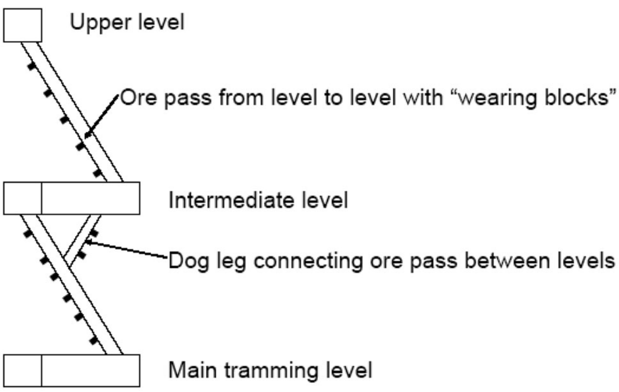

Figure 13—Layout of ore pass with dog leg

A well designed ore pass

- Dips at 55° to 65° above the horizontal
- Penetrates the strata as close to 90° as possible
- Is situated in de-stressed ground and in competent rock
- Takes cognizance of the direction and magnitude of principle stresses.

Prior to commissioning the rock pass should be inspected and re-supported if necessary. This is vital for ore passes at depth. The rate of flow of rock down the ore pass must be controlled and monitored. If possible the ore pass should be kept full and bleed of as required.

Figure 14—Wearing blocks in a sidewall

Figure 15—Channel tracks

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