Assessment of face area hangingwall stability in a hard rock bord and pillar mine

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ABSTRACT: The aim of this project was to assist Triggered Action Response Plan teams to issue rapid yet comprehensive support recommendations in a production environment. The research was conducted in a shallow tabular hard-rock environment in a bord and pillar mining configuration. The assessment included evaluations of bord hangingwall behaviour under various geotechnical conditions, bord spans, face advances per blast, and the influence of the last line of permanent support. The results showed that the effectiveness of the last line of support is influenced by keyblock dimensions, particularly the perimeter exposure of these blocks in the hangingwall. A reduction in span and advance per blast were found to be beneficial in reducing the height of the potential falls of ground. A set of common failure conditions has been assessed and discontinuity orientations description is provided. The description of the condition is accompanied by recommendations of support configuration or suitable spans.

Keywords: Face area, TARP, FOGs, Hangingwall, span.

1 INTRODUCTION

The Bushveld deposits, situated in the northern part of South Africa (Figure 1), are shallow-dipping stratiform tabular ore bodies which strike for many hundreds of kilometres. The platinum group metals are concentrated in two ore bodies known as the:

- UG2 Reef, chromitite seams; and
- Merensky Reef, a mineralised pegmatoidal pyroxenite.

The research described in this paper took place on the UG2 reef at a Platinum mine (Mine 1), which is located on the western side of the Bushveld Complex near the town of Rustenburg (Figure 1). The mine employs a bord and pillar mining configuration at a depth of less than 500 m below surface.

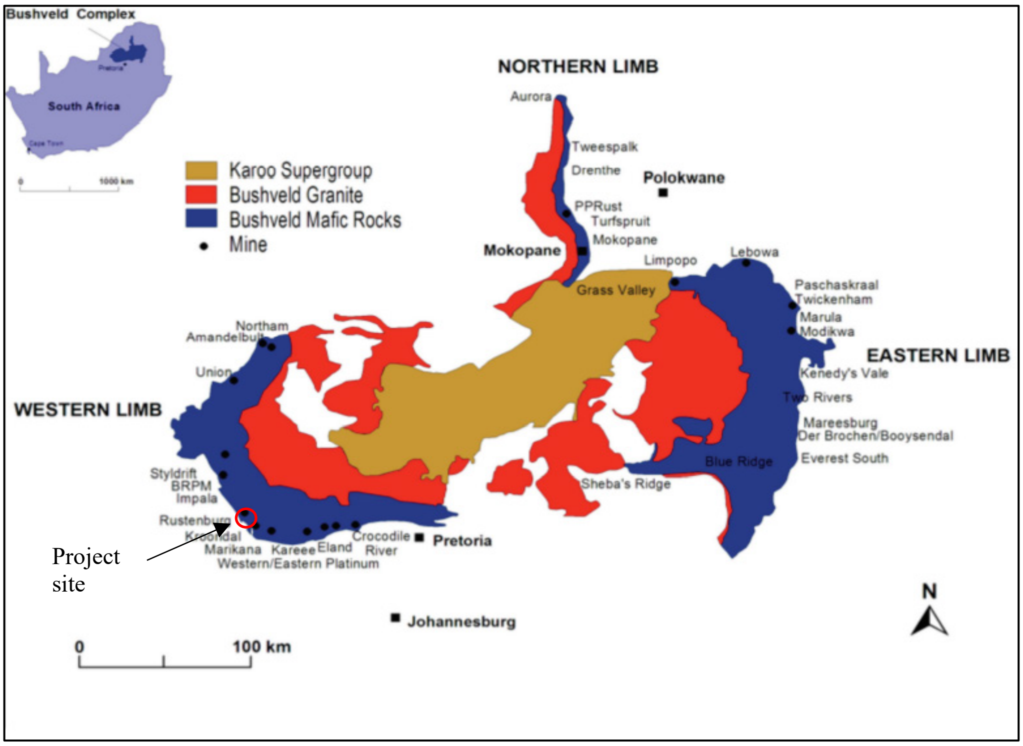

Figure 1. The extent of the Bushveld complex and the project site (Roberts & Clark-Mostert, 2010).

Prior to the investigations, a total of 26 Falls of Ground (FOGs) were investigated at the mine over a five-year period (2017-2021). Most of these FOGs (67%) were recorded in the face area (MCOP, 2022), where high concentrations of workers are located. The mine uses a typical Triggered Action Response Plan (TARP) as described by the Mining Occupational Safety and Health (MOSH) leading practice in South Africa (MOSH, 2023). TARP relies on an Entry Examination and Making Safe (EEMS) team to identify unusual geological structure or ground conditions. Identification of such geotechnical conditions and remedial actions required by these conditions rely heavily on an individual's previous experience and are therefore subjective. This subjectivity was proven by the varied support recommendations issued by different people for similar ground conditions. In addition, FOGs continued to occur in the face area even with the support recommendations. The aim of this research was to provide documented guidelines based on analyses of previous FOG incidents, statistical evaluations, and analytically sound solutions. The drive to meet production targets demands that proper support instructions be provided quickly. The research described in this paper addresses this need.

2 TARP APPLICATION

Ground conditions may be classified as TARP 1, TARP 2 or TARP 3 depending on the trigger described during EEMS, with TARP 3 being the highest risk (MCOP, 2022). Response teams are graded according to condition severity, with the TARP 3 team comprising the most senior mining people (MCOP, 2022). The TARP response team are required to fully assess the hazard and issue appropriate support recommendations. The mining team must be able to carry out the support recommendations in a safe manner for the successful application of TARP. All these activities are primarily carried out in a newly exposed face area after a blast.

3 DATA COLLECTION AND PROCESSING AND MODEL SET-UP

The effective strength of the rock mass on the boundary of an excavation is dependent on the size of the excavation because the size influences the volume of exposed rock and number of discontinuities (Jager & Ryder, 1999). As a first step in establishing guidelines to address TARP triggers, hangingwall (HW) behaviour needed to be understood within the unsupported face area. To this end, FOGs that have occurred in the face area were analysed and failure mechanisms were established with the aid of numerical modelling. Appropriate methods to ameliorate such failure mechanisms were determined for various bord dimensions. The investigations included the effectiveness of the last line of support. Numerical assessments were validated against actual FOGs, and TARP guidelines established accordingly. The reef orientation in the area is 294/09.

Borehole cameras and Ground Penetrating Radar (GPR) were used to determine the position of reef parallel parting planes. A total length of 377.4 m of scanline mapping was done on dip and strike to determine joint orientations and properties. The collected data was processed using DIPS (Rocscience, 2023a). Various ground conditions that deviate from normal that call for TARP intervention were analysed and compared to normal ground conditions (NGC) using The Potvin (1988) Modified Stability Number (N'), Jblock (Esterhuizen, 2011) and Unwedge (Rocscience, 2023b) models. Sensitivity analyses were done on the bord span and unsupported face span using numerical models for the various ground conditions.

NGC comprise discontinuities with near vertical dip angles and weak chromitite stringers higher than 2.7 m above the HW. These conditions are adequately supported using the normal support standard: 18 mm diameter, resin bolts on a spacing of 1.5 m x 1.5 m.

The following ground conditions were analysed during the investigations, where Shallow Dipping Structures (SDS) refer to discontinuities with a dip ≤ 60°:

- NGC plus a chromitite layer at 1 m above the HW;
- shear zone (a zone of ≥ 0.5 m in which shearing has occurred on a large scale, so that the rock is crushed and brecciated (MCOP, 2022);
- SDS striking obliquely- (Dip Direction (DD) 199°, 0°, and 180°), near parallel- (24° and 204° DD) and perpendicular (294° and 114° DD) to mining direction;
- SDS dipping in the same direction as the orebody (0° and 24° DD);
- SDS dipping opposite to the orebody (204°, 199° and 180° DD); and
- Structures striking perpendicular to mining direction but dipping in the same direction as the mining direction (294° DD), and opposite direction to the mining direction (294° DD).

4 INVESTIGATION FINDINGS AND TARP GUIDELINES

4.1 Ground conditions with shallow dipping structures

Resin bolts of 1.6 m length are sufficient for normal conditions and for SDS with a trace length of less than 3 m. The height of the Vertical Tensile Zone (VTZ) is irrelevant in the presence of SDS, and the fallout height was shown to be controlled by the extent of the SDS in the HW. In the absence of support, the span controls the Fall of ground Thickness (FOT) or height (Watson & Gerber, 2018). The larger the span, the higher the FOT. Tendon support failure was due to the elements being too short. The strategy for addressing SDS should therefore be aimed at reduction in unsupported span, either by reducing the bord span or the advance per blast or increasing support length. Figures 2 and 3 show the recommended strategy for addressing SDS. These figures should be included in field books so that support instructions are issued underground.

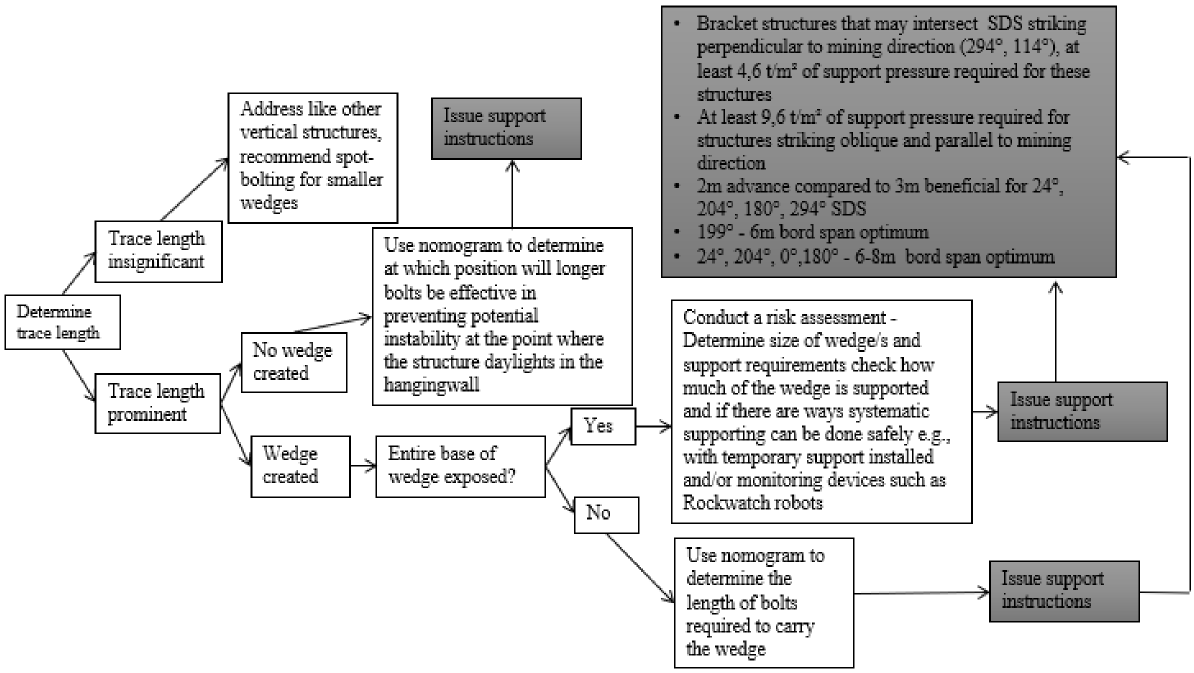

Figure 2. Flow diagram for addressing shallow dipping structures.

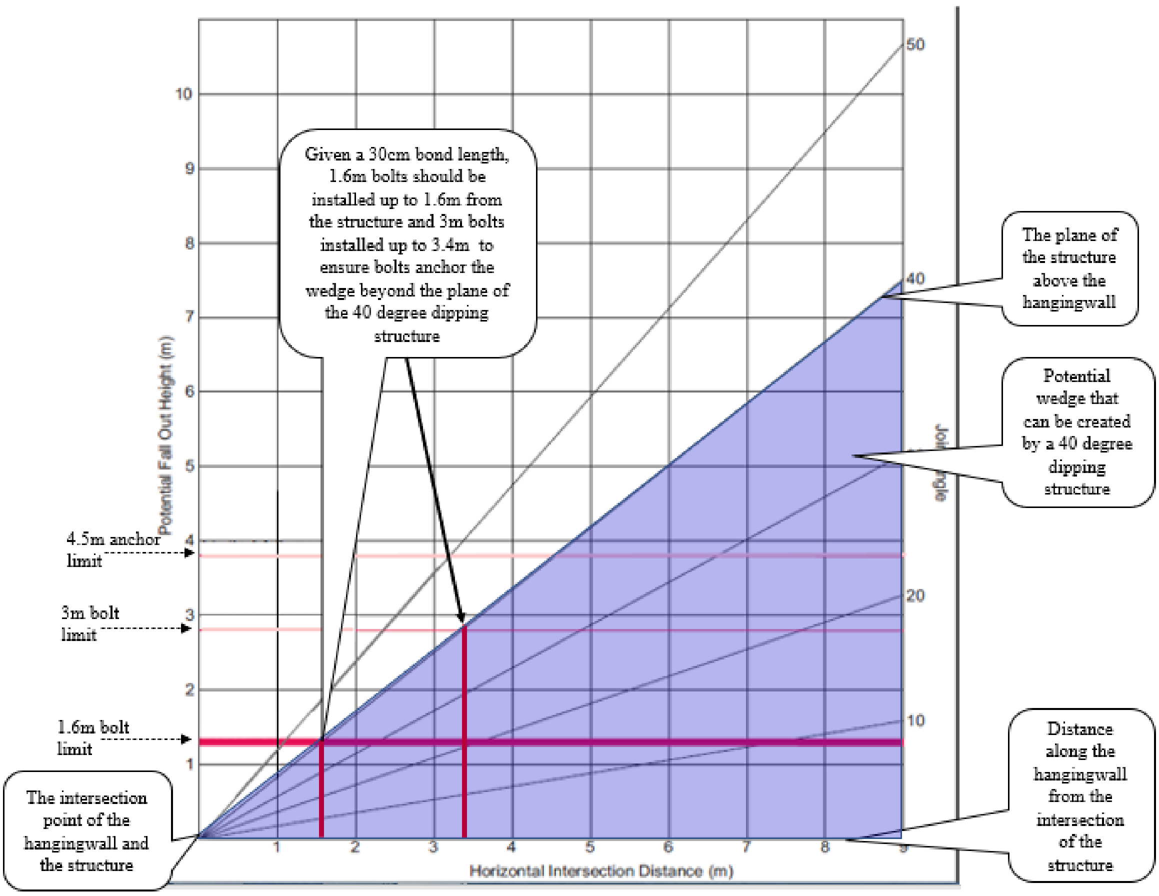

Figure 3. Nomogram for determining effective length of bolts and determining the point at which the bolts become ineffective (After Carstens, 2013).

The strategy in Figure 2 and 3 is for conditions where the entire bord was on the weaker side of the SDS. The trace position of prominent structures in the HW should be considered when issuing support instructions. The last line of support provides no support if there is a discontinuity between the support and possible wedges in the face area.

4.2 Ground conditions with a parting plane "near" the hangingwall

The problem of reef parallel parting planes usually occurs near the edge of potholes (Figure 4). The overall strategy in such situations is to determine the height of the parting planes above the HW. Borehole camera surveys or GPR can be used for this purpose. Specific lithological markers indicate when such conditions are present, as demonstrated in Figure 4. All the FOG investigations where HW stratification was involved (18 cases), had a FOT of less than 1 m, irrespective of bord span, (FOG register, 2022). Vertically inclined pegmatite and serpentinite veins prove to be unfavourable features in these conditions and therefore the strategy under these conditions should be aimed at leaving pillars to bracket the veins.

JBlock parting plane assessments showed that 99% of all keyblocks failed in between support units and out of the 1% of the support failures, 87% were due to insufficient support strength. The models were run with partings at 1 m in the hangingwall with 0.2 m standard deviation. The support failures were because of the potential formation of large blocks. Such ground conditions require sufficient back area support to allow for safe access to the face area. Large blocks may increase demand on the last line of support due to cantilever effects. It is therefore recommended that the maximum surface area that can be supported by bolts be calculated for a given FOT. The TARP team can use this as a guide in concluding on support requirements in the back area, and whether it is safe to proceed with face area support installation. A reduction in advance per blast will also minimize the exposed surface area of blocks.

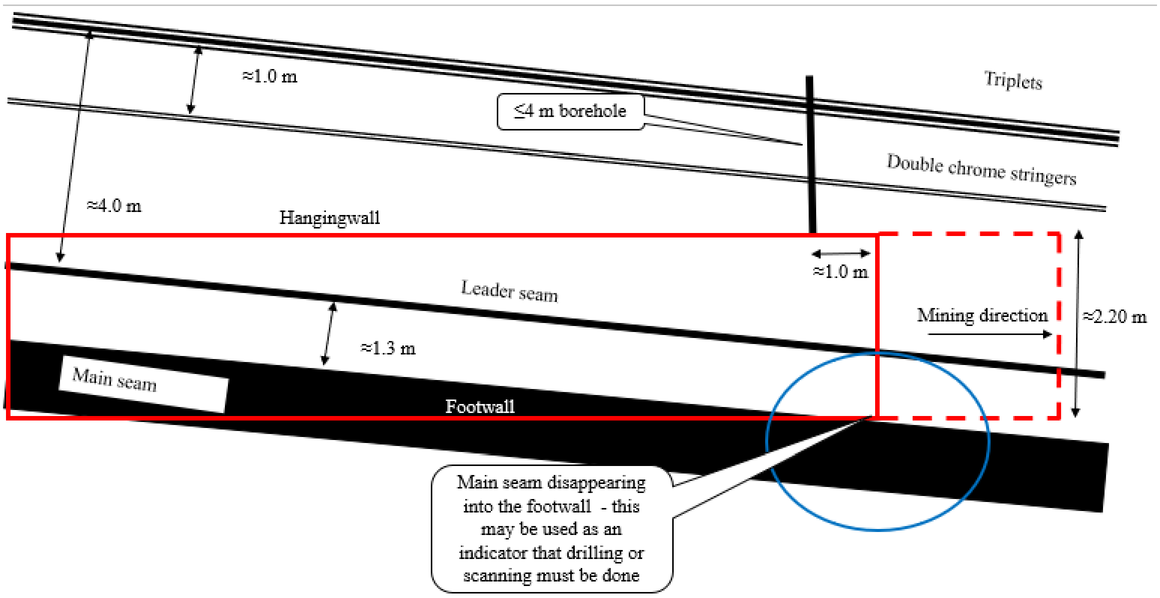

Figure 4. Position of chromitite layers with respect to the main seam for a typical reef roll.

4.3 Shear zones

Shear zones have a low N' rating (Potvin, 1988). The FOG database shows that shear zones unravel at a span of as little as 4.5 m. Therefore, a minimum practicable span of 4 m and advance per blast of 1 m is recommended for shear zones in cases where bords cannot be abandoned. The bord span is restricted by size of the mining equipment and the advance per blast is restricted by the area that can be made safe after blast from a supported area. A smaller advance means that support such as shotcrete can be applied up to the face whilst the person is under a supported area. Tendon support installed on either side of the shear zones does not offer support to the sheared zone. The shear zone unravels unless the zone is supported with good areal coverage support that is anchored with tendon support reaching to more competent ground. Cable anchors, trusses, radial barrels, mesh, and shotcrete is generally required to stabilize shear zones. Immediate support installation is required for such ground conditions as these structures tend to self-mine. Areal coverage requirements can be determined through Rock Mass Rating (RMR) charts provided by Stacey (2001).

5 CONCLUSIONS

Recommendations have been provided to reduce the risk of FOGs in the unsupported face area for a variety of common geotechnical conditions. The aim of the research was to provide TARP members with information that will allow quick yet well investigated decisions in a production environment. Investigations involved the use of JBlock and Unwedge software packages as well as Potvin's (1988) stability graph ratings, which were compared to FOG reports, borehole camera observations and GPR surveys. A set of useful guidelines has been produced, which are provided in the paper.

For ground conditions with parting planes the demand is dependent on the block sizes. Identifying potential keyblocks is priority when presented with these triggers. The best method for addressing shear zones is small spans and immediate support installation. The mining span and bolt length have the greatest influence on stability where there are shallow dipping structures.

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