Structural mechanisms contributing to large-scale hangingwall instabilities on the UG2 reef horizon

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ABSTRACT: The platinum mines in the Bushveld Complex of South Africa are characterized by a structurally complex rock mass. The mining activities in the narrow hard rock reefs are labour intensive with manual drilling, blasting, and cleaning methods. The underground personnel operate near the mining face where there is an increased risk of falls of ground. The presence of geologic structures in the stopes contributes towards hangingwall and pillar instabilities. The resulting falls of ground and large collapses may result in fatalities, significant ore reserve write-offs and even mine closure. Weak clay-like (alteration) zones contribute to these instabilities but are typically overlooked by mining personnel as it is not commonly encountered, and it is therefore not identified as a hazard. This paper summarizes the findings from case studies that investigated the impact of these structures, as well as suitable remedial strategies that may significantly reduce the risk of instabilities and improve mining safety at these operations.

Keywords: structural complexity, hangingwall instability, pillar instability, ground penetrating radar.

1 INTRODUCTION

The platinum mines in the Bushveld Complex of South Africa extract narrow, tabular ore bodies. The rock mass associated with these reefs is structurally complex. This study focused on the layered Critical Zone, specifically the Upper Group 2 Chromitite Reef (UG2 Reef) and the associated geologic structures. This ore body is approximately 1.2 m thick, with a small dip of 9 to 12°. The typical stope face conditions and mine layout are shown in Figure 1. On-reef development includes raises and stope panels with inter-pillar spans of approximately 30 m. With multiple pre-development locations, the option exists to change the mining direction or inter-pillar span if necessary. The mining activities are labor intensive with manual drilling, blasting, and cleaning methods. The underground personnel operate near the mining face where there is an increased risk of falls of ground. The presence of geologic structures in the stopes contributes towards hangingwall and pillar instabilities. These structures include regional large-scale structures, layer-parallel shears, ramp structures, joints, and weak clay-like layers (Hartzenberg & Du Plessis 2014). The weak clay layers are referred to as alteration zones in this paper. These structures are commonly associated with a deterioration in rock mass conditions and have contributed to unstable mining layouts on various mining operations. For example, Perritt & Roberts (2007) recognized the risk associated with shallow dipping structures that are difficult to identify in the underground environment. Couto & Malan (2023) described the collapse of the Everest Mine in the Bushveld Complex where an alteration zone is present in the vicinity of the ore body that impacts the hangingwall (HW) stability and pillar design.

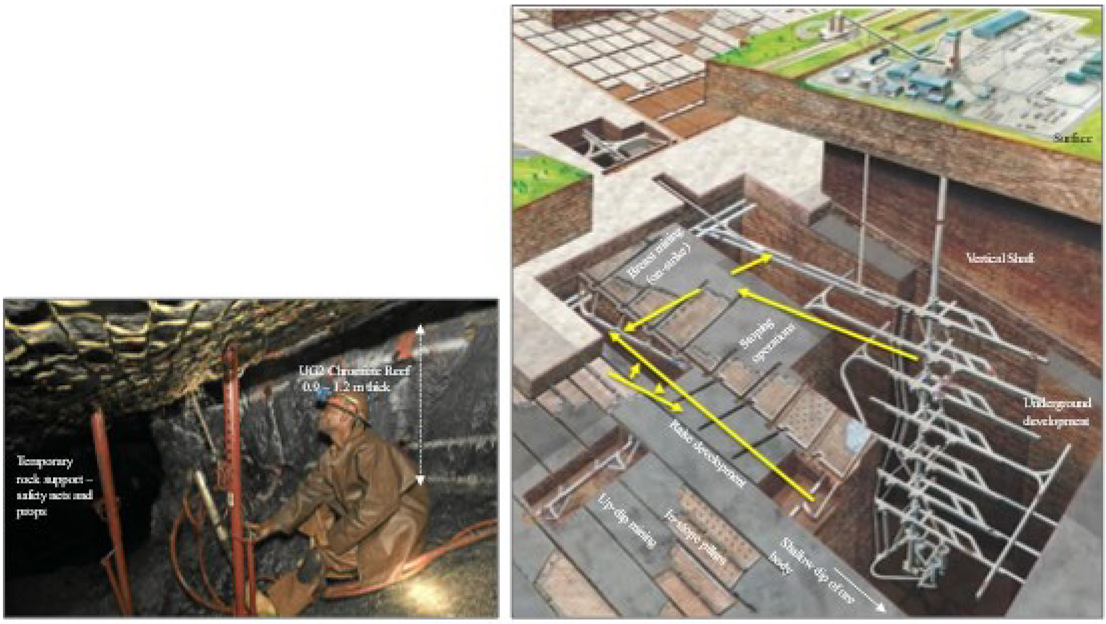

Figure 1. Left: Labour intensive mining operations: installation of temporary and permanent ground support. Right: Oblique view of an underground UG2 chromitite reef mining layout.

Geologists and Rock Engineers on the operating mines often function in isolation from one another, resulting in poor hazard identification and risk classification of the geologic structures. The alteration zones are often not recorded during exploration and underground drilling as the soft material gets washed out and are typically indicated simply as a core loss.

The geologic structures will affect the choice of mining method and layout (breast or dip mining in Figure 1), the support strategies and the available ore reserves. Information described in this paper provided an improved understanding of their interaction and potential instabilities when exposed by mining. The author applied new scanning technology (a sub-surface profiler), which allowed the presence and location of these structures to be verified in the hangingwall for the first time. This resulted in an improved spatial interpretation of the structures and emphasized the need to consider these for layout and support design and pro-active decision making in operating mines.

2 PROBLEM STATEMENT

The study by Hartzenberg (2019) was motivated by multiple large-scale mine instabilities that occurred in the Bushveld Complex. This includes, but is not limited to, the formerly known Lonmin Marikana Operations, Impala Platinum, Aquarius, and Everest Mine. Du Plessis *et al.* (2015) noted that similar large-scale instabilities have been reported in the mines of the Great Dyke in Zimbabwe (Zimplats) due to a major collapse along a main decline that was associated with alteration zones. These structurally related instabilities have resulted in serious mine injuries, multiple fatalities, production losses, significant ore reserve write-offs and even total mine closure. All these occurrences highlight the need for additional studies to improve the understanding of the rock mass behaviour.

The key objective of this study was to identify and understand the influence of prominent regional and secondary geologic structures (Figure 2), including alteration zones (Figure 3), on the UG2 Reef hangingwall stability and in-stope pillar behaviour.

To identify and confirm the occurrence and extent of the geologic structures, geotechnical mapping, and a sub-surface profiler (ground penetrating radar system) was used by the author to scan up to 10 m into the HW. This ground penetrating radar (GPR) system is designed specifically for the challenges faced by underground mining operations as the scanner is user friendly and can be used in narrow underground excavations with limited space. It is rolled along the HW, and the data collected is transmitted wirelessly and processed in real time (Figure 3). This gives instant feedback on the geologic structures present in the area (Figure 4). A decision can be made whether the structures can be adequately supported in a timely manner to ensure safety, or whether the area should be evacuated to determine an alternative strategy.

This paper focuses on summarizing the findings and the remedial strategies developed to negotiate these structures. The new knowledge was used to suggest improved support strategies and layout modifications in areas where the geologic structures are present.

Figure 2. Left: Unstable hangingwall conditions in an underground stope panel where a low-angle ramp structure is present. The only support on the edge of this brow was in-stope rock bolt support and cementitious grout packs. Right: Panel instability shown at the red ellipse. Large-scale movement along a regional large-scale WNW-ESE trending fault structure caused a panel collapse.

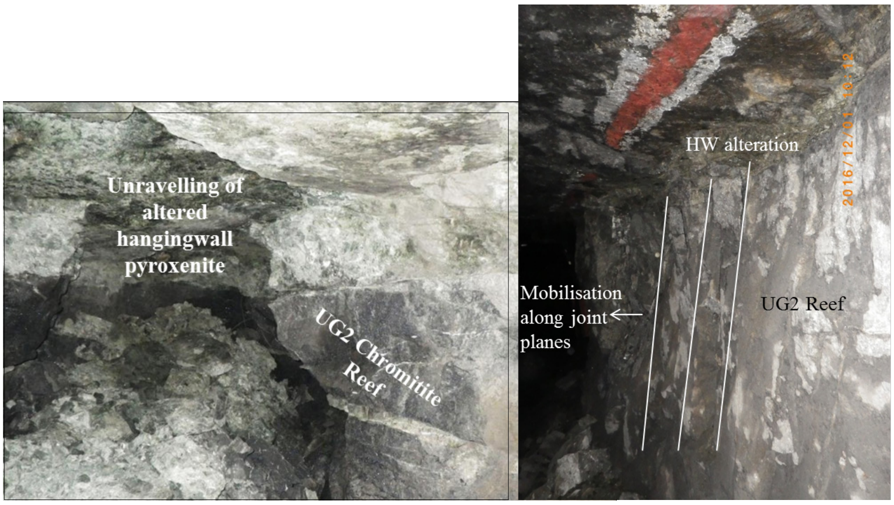

Figure 3. Left: Weak clay-like layer (alteration) zone exposed directly above the UG2 Reef, causing unravelling between installed support units. Right: Alteration along the top UG2 Reef contact causing mobilization along the joint planes. This led to pillar collapse.

Figure 4. Left: Illustration of the physical use of the GPR, rolling it along the hangingwall. Right: Illustration of how to operate the GPR in an underground environment to detect the geologic structures in the hangingwall, shown in real time on the tablet. It is used to gain a better understanding of the presence of structures that may lead to instabilities.

3 THE IMPACT OF GEOLOGIC STRUCTURES AND ALTERATION ZONES ON MINE STABILITY

On many operations, mining layouts and support designs are inherited from best practices in industry or to accommodate a specific extraction method. Adverse rock mass conditions are frequently not identified by mining personnel and the consequence of mining in these conditions is only realized once significant instabilities have occurred (Figure 2 and Figure 3).

The regional structures are continuous along multiple lithological units that cut deep into the HW of excavations, beyond the local support capacity. The strike, dip and continuation length of these structures should be considered in the mining layout. The low-angle ramp structures are usually difficult to identify and only visible once wedge failure had occurred along these structures (Figure 2). Therefore, the mining direction, approaching structures from the stable side, should be taken into consideration during production planning, based on the findings from underground geotechnical mapping and using the GPR.

The alteration zones are typically not detected by the exploration and underground drilling. After the exposure of these zones in an active section of an underground mine, it was noted that these zones can be present in the footwall (FW), HW (directly above the UG2 Reef) or higher up in the hangingwall (based on falls of ground that occurred). It also varies in thickness from a few centimeters to up to 1 m and undulates on strike and dip. Spatial variation along the dip and strike of the ore body and location in the HW should be considered. It was only during the underground development of excavations that exposed significant alteration zones, that the potential severity and risk of falls of ground in these zones were understood. As shown in Figure 4, it is extremely difficult to support these zones as it unravels around support units. If it occurs higher up in the HW, it can cause significant instability. Thick zones directly above the UG2 Reef also contributes to significant dilution that can cause certain blocks of ore to be uneconomical to mine.

Multiple site investigations were conducted at underground operations and the studies included geologic mapping and the use of the GPR. Figure 5 illustrates the scanned image along a mined-out stope panel for 19 m. The interpretation from this GPR scan is also shown in Hartzenberg (2019). Notice how the ramp structures 'ramp up' to potential weakness planes. These are also possible sources/locations of alteration zones. The red zone from the scanned image confirms that a significant alteration zone is present along the UG2A markers (thin chromitite layers that act as natural parting planes). The presence of alteration zones was also confirmed by drilling into the HW, with careful consideration of the clay-like layers that are present.

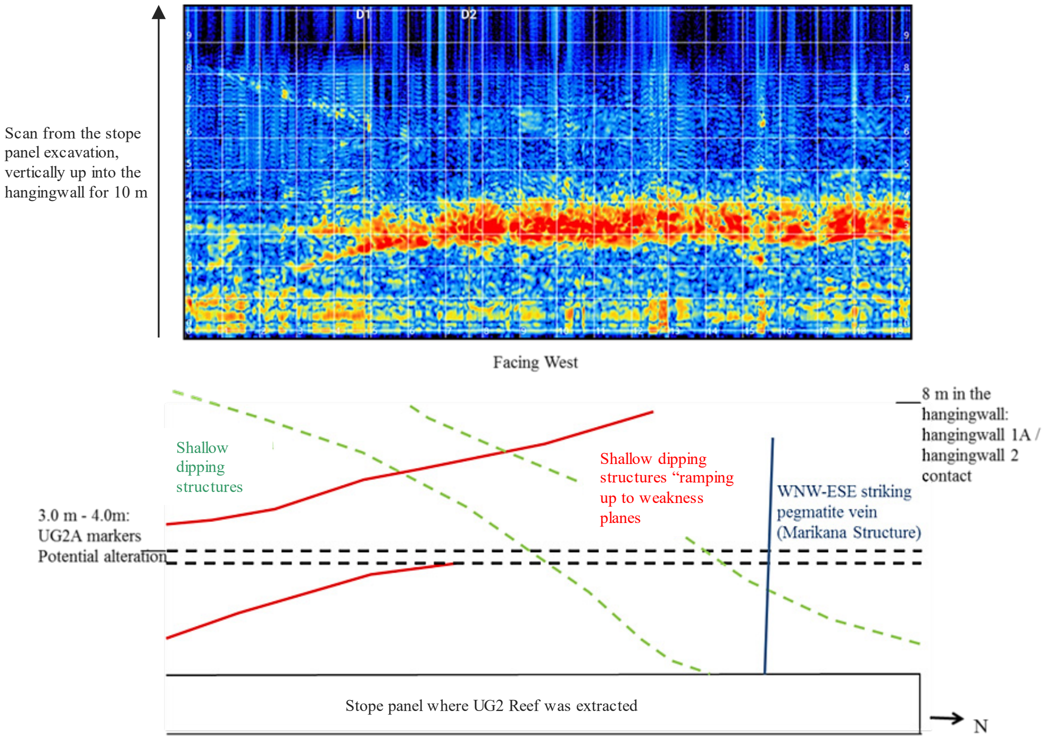

Figure 5. Top: Sub-surface scan of a section into the hangingwall. Bottom: Interpretation of the hangingwall section, showing the stope panel, potential parting planes, geologic structures as well as an alteration zone along the UG2A markers. The WNW-ESE striking Marikana Structures cause significant instabilities and should be considered when the direction of mining is determined.

From the multiple site investigations and learnings, remedial strategies have been proposed to reduce the occurrence of instabilities. The remedial strategies proposed by Hartzenberg (2019) in the areas where regional and secondary geologic structures are present, are summarized in Figure 6. The remedial strategies proposed for areas where the alteration zones are exposed along the top UG2 Reef contact, or within the hangingwall, are summarized in Figure 7.

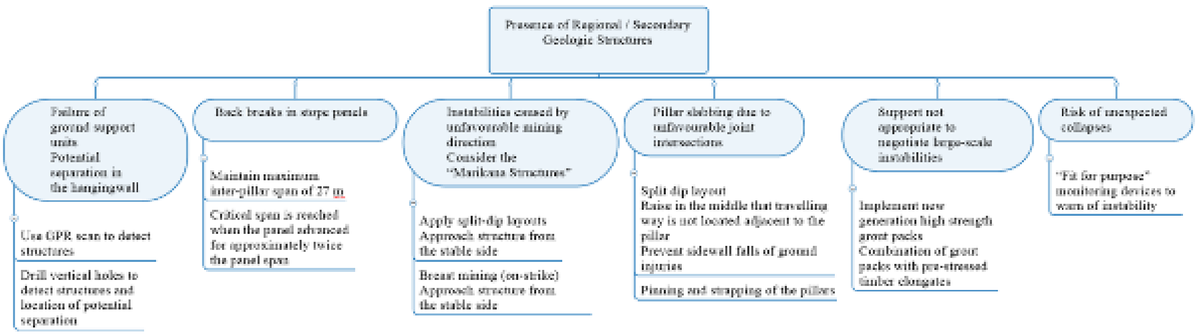

Figure 6. Remedial strategies where regional and secondary geologic structures are present.

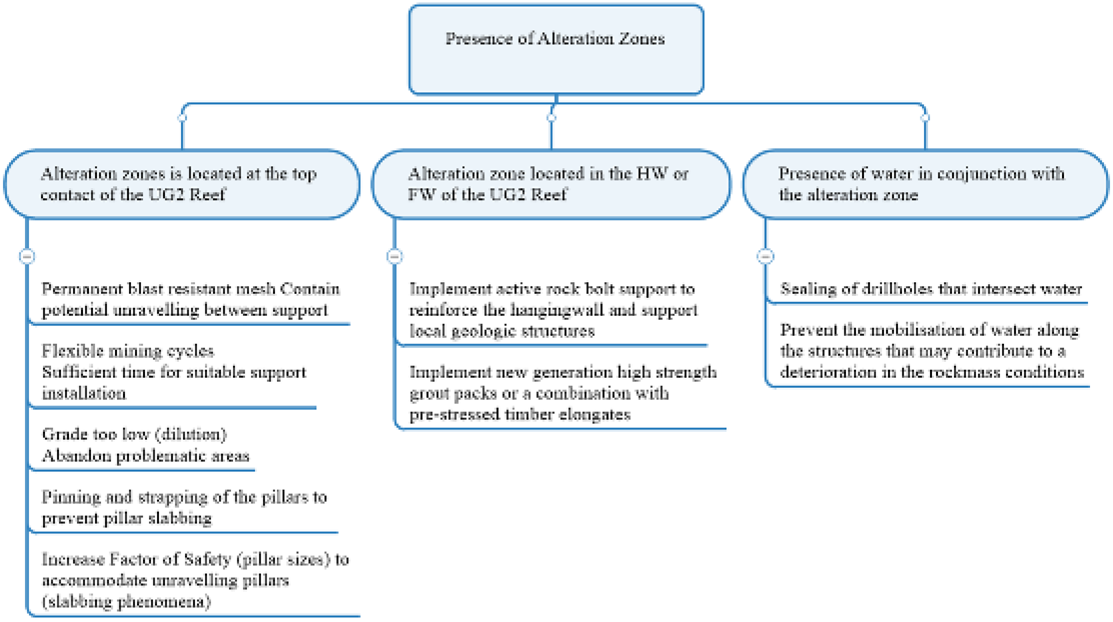

Figure 7. Remedial strategies where weak, clay-like (alteration) zones are present.

4 CONCLUSIONS

This study was a first attempt to integrate a detailed knowledge of geologic structures with practical rock engineering solutions in platinum mines. These two subjects are typically treated in isolation, but it is clear from this study that it needs to be more closely integrated for addressing rock mass stability problems and the design of stable mining excavations in the platinum industry. Pro-active identification of these structures during drilling, development geotechnical mapping and GPR scans should be used to ensure proper support recommendations are implemented and effectively communicated to the underground mining personnel.

Suitable remedial strategies were developed, and these are summarised in the paper. Use of appropriate mining layouts and mining directions, optimum panel spans and support strategies are required where these structures are present. This work may significantly reduce the risk of large-scale instabilities and it is therefore considered an important contribution towards improving safety for the mines in the Bushveld Complex.

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