

Investigating the different support methods for various geological structures encountered in hard rock mining within the Eastern Limb of the Bushveld Igneous Complex, South Africa.

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Declaration:

I, Wicus du Preez (the undersigned), declare that the thesis/ dissertation, **Investigating the different support methods for various geological structures encountered in hard rock mining within the Eastern Limb of the Bushveld Igneous Complex, South Africa**, which I hereby submit for the degree **MSc Engineering Geology** at the **University of Pretoria**, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

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ABSTRACT:

Mining operations throughout the Bushveld Igneous Complex faces challenges in regards to the safe support of geological structures. Falls of Ground pose a massive risk to safety and production of any underground mining operation and programmes to eliminate falls of ground must be effective and implementable. The investigation will focus on the geological structures found across hard rock mines in the Eastern Limb of the Bushveld Igneous Complex, South Africa. How these features are identified, recorded and supported. Geological structures such as dykes (magnetic and non-magnetic), faults, joints, reef rolls, thrust faults (domes) and potholes are all geological features found in underground workings within Eastern Limb mining operations. Each of these structures pose a risk to the safe working and productive mining of a mining operation if left under/un-supported. Geological structures occur in underground workings, some panels contain multiple structure's that call for complex support recommendations and procedures. Mining panels within the investigation and monitoring period are classified according to the geological features they contain and divided in Green, Yellow and Red panels, with the change in colour representing the ground conditions of that panel and the subsequent team that need to issue recommendations. Green panels are safe for work with no major geological structures that pose a risk to underground workings, normal mining with normal support according to the support standard and procedure can commence. Yellow panels have geological features that were identified and marked but are of such a nature that the Team Leader, Miner and Shift Supervisor can decide on support recommendations in addition to the standard support system. Red panels will be the focus of the investigation, these panels have been rated according to the complicating geological structures they contain. Recommendations for underground panels with complex geological features are made by a team of specialists comprising of a Geologist, Strata Control Officer, Mine Overseer and Shift Supervisor. The geological structures are mapped, recorded and studied where after recommendations are agreed upon. The investigation focusses on the recommendation issued to support various geological features and their continued monitoring throughout a 1 year period and whether the recommendations are adequate. Complex geological structures with support recommendations were monitored and failure or change in ground conditions were identified to determine whether recommendations were sufficient. From the monitoring it is clear that the majority of geological features are adequately supported and continued to be safe for underground work to take place throughout the monitoring period. In areas where failure, change or falls of ground occurred within the study period, it was investigated and found to be due to human factors or external factors and not due to the physical support of geological features. External factors include a change in ground conditions since the visit (water presence where there was no water present when recommendations were issued), incorrect or incomplete installation of support and the incorrect identification of a geological feature. The success of supporting geological features depend on the correct implementation of the support recommendations issued to support complex geological features within underground workings. The system was monitored during the investigation period and found to be efficient and accurate in identifying and supporting complex geological features. The success rate of supporting geological features by means of this system is effective and easily implementable from operation to operation. The complex geological features that were supported using the recommendations issued by the investigation team are safely supported and the system used to support these features is highly effective.

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1. Introduction

Structural geology within the mining industry, especially hard rock mining plays a pivotal role in the successful mining of the ore/reef body. Mines within the Bushveld Igneous Complex, South Africa (both the western and eastern limb) have to negotiate many challenging factors including worldwide economic slumps, labour unrest, violent protest action, political uncertainties and fluctuating exchange rates. Amidst these challenges the most daunting might possibly be creating a safe working environment. This boils down to safely support complex geological structures in a cost effective and timeous manner to ensure production targets are met within a safe, supported and healthy working environment.

The research within the dissertation gives insight on complex geological features that pose a risk to safe underground workings and the manner in which these features are identified, investigated and supported. Similar geological features can occur from operation to operation varying in extent, different geological features are supported in differed manners. The manner in which geological features are supported will depend on a variety of factors (geological feature, extent, orientation, influence) and will eventually influence the cost, safety and production of that specific panel, section or mine.

Each mining operation has a legal and moral responsibility to ensure all precautions are taken when it comes to the safety of its workers. Complex geological features pose a massive challenge to this responsibility for underground mining operations within the Eastern Limb of the Bushveld Igneous Complex and having a system where complex geological features are identified, investigated and adequately supported is important for the success of the operation. It is vital to ensure that the processes and procedures a mining operation has in the safe support of geological features are safe, effective and implementable.

1.1 Aims and objectives of the investigation in relation to the studying of support for various geological structures.

The main aim of this dissertation is to investigate the method on how different geological structures within underground workings are supported and whether these features show any failure within the investigation period. The systems being used to investigate and support these complex geological features will also be investigated as this forms an integral part within the safe support of complex geological features.

Main aims:

- Identify and understand complex geological features found within underground mining operations in the Eastern Limb of the Bushveld Igneous Complex, South Africa.
- Investigate the different support systems used to support these geological features and monitor supported features for failure during a specific timeframe.

- Monitor the system and the effectiveness to identify, investigate and issue support recommendations for complex geological features.

If the geological features are adequately supported we can deem the system implementation and the support recommendations in supporting these complex geological features successful. Important aspects in regards to the investigation includes whether geological features are over- or under supported. This plays a major role in the cost of keeping a mining operation profitable and the time delays taken from productions shifts in order to support complex geological features. Over-supporting areas will result in additional financial commitments along with loss of production times and targets.

Safety plays a large role within the mining industry and an injury on duty or fatal accident is an unfortunate event in itself, never mind the large financial losses a company can suffer. Under-supporting any geological feature will never be considered within the mining environment, there will always be a margin to the extent to which a geological feature will be over-supported, the phrase “better safe than sorry” is applicable here. The main aim is to investigate the support of complex geological features to ensure that these features are supported in the most effective manner in terms of safety and production.

1.2 Methodology

The investigation will be conducted at a hard rock mine (metalliferous) located in the Eastern Limb of the Bushveld Igneous Complex, South Africa. The Middle Group packages, more specifically the Middle Group 1 chromite layer is the layer of reef extracted from the investigation area. The investigation spanned from January 2016 to December 2016 where mining panels that experienced adverse geological conditions were identified. These panels experienced complex geological structures that were identified, investigated and support recommendations issued by qualified rock engineering personnel and relevant mining practitioners, subsequently these panels were monitored for the duration of the investigation period.

The recommendations issued for each panel containing complex geological features were recorded over the period of a year for dissertation purposes. The panels containing complex geological structure where support recommendations were issued were monitored to investigate whether the geological features are successfully supported over time and that no change or failure has occurred (within the duration of the investigation period). If a change or failure of a geological structure within a panel has occurred an in depth investigation visit was conducted to determine the cause of failure.

A database of selected underground panels containing complex geological structures was created and used to determine the effectiveness of the support recommendations. The database was also used to analyse whether there is a relationship between certain geological features and their associated support recommendations. Some sections within the dissertation needed certain methods to be applied, geological software to be used or skillsets developed to ensure that the correct data is collected and represented.

It is important to note that during the investigation, extensive underground mapping was conducted on geological features as part of monthly mapping visits, these mapping exercises excluded the mapping conducted on specific visits to underground panels that contain complex geological structures. In addition to the mapping, surface boreholes were used to gain information on the ore body within the investigation area, The surface exploration hole data was extracted from a database (geological database storage software) and used to conduct an in depth study on the ore body, reef contours and overall orebody structure. 3-dimesnional geological models were constructed and contours plotted in various geological software programs.

For the purpose of the investigation only applicable data sets, figures, plots and information is included, the bulk of the work cannot be included in the investigation due to the sheer size of the information gathered during the investigation. The thesis contains the necessary information to show all relevant processes and methods within the investigation to reach a conclusion in terms of the aims set out within the dissertation.

Once the investigation period was over the data was analysed with the aim to determine how complex geological features are supported and whether these features were adequately supported throughout the investigation period. The data also gives insight on the effectiveness of the system used to identity, investigate and issue support recommendations for the support of complex geological features.

1.3 Outline of dissertation

The dissertation is divided into 7 different sections including the introduction and the conclusion. The first five parts form the foundation and includes the rationale of the investigation as well as a literature review of both the Bushveld Igneous Complex and structural features. The sixth section introduces the actual research and application of the investigation. The bulk of the investigation data, research and work is covered in the sixth part of the dissertation. The last section comprise the discussion of the data and conclusions. A synopsis of the dissertation is given below:

1. Introduction – The introduction will touch on the subject matter that will be discussed within the thesis. It will also lay the foundation of the investigation giving insight on what can be expected and clearly defines the purpose of the dissertation.
2. The second part is a literature review focusing on the overall Bushveld Igneous Complex and its formation. This part will include short descriptions on the history of the Bushveld Igneous Complex, the stratigraphy and outline of economic important layers. The importance of the Bushveld Igneous Complex in an economic aspect will be touched on. From an overview on the Bushveld Igneous Complex, our focus will shift to a regional setting within the Eastern Limb of the Bushveld Igneous Complex.

3. Common Geological structures found within an underground environment in the Bushveld Igneous Complex, their formation, description and effect would form the basis of part three of the investigation. The focus will be on geological structures found throughout underground workings mining within the Upper Critical Zone (MG1 package). The Middle Group 1 chromite layer is extracted within the investigation area, the MG1 reef chromite layer will be discussed in regards to specific localized stratigraphic sequences.
4. The fourth part of the thesis will focus on explaining the support system used to identify, investigate and eventually issue support recommendations for the support of complex geological structures.
5. Standard support recommendations for supporting underground features were analysed in part five of the investigation. Normal support standard in underground workings along with the reason why the support is adequate will be the focus of this part. Support for different ground conditions caused by geological features along with the support of complex geological features will form the focus of this section.
6. The bulk of the data gathered within the investigation period will be discussed in the sixth section of the dissertation. A breakdown of the data gathered and used throughout this investigation will be discussed. Certain case studies will be chosen for further study based on the geological features they contain. The panels that have complex geological features that are relevant to the aims of the dissertation will be identified from the database and discussed in detail including their geological structures and associated recommended support and monitoring. The specific panels will be chosen based on the geological features present in each; this will be done in such a manner that all the geological features found throughout the Eastern Limb are highlighted within the issued reports. The success of supporting the geological features during the investigation period will form part of this section. If any geological features displayed failure during the investigation an investigation on each change or failure in term of geological features supported will be conducted.
7. Conclusion – The conclusion was derived after studying all the data that have been analysed. The success of the investigation will depend on the success rate in relation to the support of geological features. Data analysis will enable us to streamline the support of complex geological features within current systems. The conclusion will also discuss the aims and objectives with a focus on the investigation and whether the dissertation has successfully reached the main aim of supporting complex geological features.

2. Literature review of the Bushveld Igneous Complex

2.1 History and discovery of the Bushveld Igneous Complex

The Bushveld Igneous Complex in South Africa is most famous for its massive mineral deposits and contains the largest known ore reserves of platinum group elements, chromium and vanadium in the world (Eales and Cawthorn, 1996; Cawthorn *et al.*, 2006). Platinum Group Elements include palladium, osmium, rhodium, iridium, ruthenium and platinum and these elements paired with the occurrence of chromium in layered units and vanadium deposits makes the Bushveld Complex one of the most economically important deposits in the world (Cawthorn *et al.*, 2006). Chromium within Chromite seams were discovered before Andries Lombard discovered platinum deposits on his farm in 1924 (Grabe, 2002).

The first discovery of a chromite outcrop was discovered in the Rustenburg area within the Hex River outcrop by Carl Mauch in 1865 (Grabe, 2002). The Bushveld layered intrusion chromites were formally mentioned within an annual report by GAP Molengraaf in 1898 (Grabe, 2002). Geologists, Hall and Humprey later published a report focused solely on chromite deposits in 1908 (Grabe, 2002).

Platinum Group Elements were discovered much later in 1924 when the economic important reef known as the Merensky reef was discovered (Grabe, 2002). Lombaard discovered “a few specks of heavy white metals” while panning in a riverbed on the farm Maandasghoek and upon finding what he suspected might be platinum he contacted Hans Merensky who confirmed the suspicion that the “heavy white metal” was indeed platinum (Cawthorn, 1999).

The importance of these discoveries especially in economic terms was not fully comprehended at the time. As technology advanced the method to extract these minerals from the ore bodies and the subsequent demand for the material re-ignited interest in this deposit. Upon the discovery of the Merensky Reef, work pertaining to the gathering of geological data started in the form of various exploration operations (Grabe, 2002).

Upon exploring the Maandagshoek area other layers were discovered and Merensky started to understand the extent of the discovery (Cawthorn, 1999). Despite all the research at the time of the discovery of the Bushveld Igneous Complex it took another 100 years before mining of this layered intrusion became economically viable (Schürmann *et al.*, 1998).

Once mining houses officially started mining the Bushveld Igneous Complex it did not take long for this unique geological occurrence to become an internationally known phenomenon in terms of geological discoveries and economic importance. The Bushveld Igneous Complex along with the Witwatersrand Area might be the most scientifically studied geological features, in part due to their rarity and in part their economic importance.

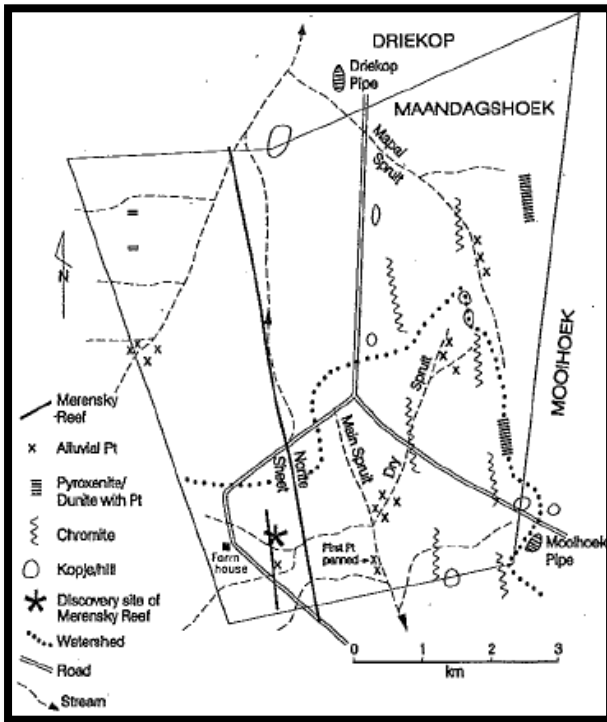


Figure 1: Plan of the farm Maandagshoek where Platinum was discovered in 1924 (unpublished report of Hans Merensky 1924).

The Bushveld Igneous Complex has been studied by many a scientist in great detail and a wealth of knowledge has been obtained. The understanding of the geology of the Bushveld Igneous Complex in terms of origin, formation, structure and stratigraphy has also improved as mining operations expanded, despite the improvement in the understanding of the Bushveld Igneous Complex the origin of this “one of a kind” geological feature is still hotly debated amongst scientists.

2.2 Geology of the Bushveld Igneous Complex

Layered intrusion are found around the world, the most economically important and largest layered intrusion to date is arguably the Bushveld Igneous Complex in South Africa (Eales and Cawthorn, 1996; Cawthorn *et al.*, 2006). The Bushveld Igneous Complex is 2056.3 Ma years old and spans over an area of 65 000km² from Lydenburg, Steelpoort and Burgersfort in the Eastern Limb all the way to Rustenburg in the Western Limb and then to Potgietersrus in the Northern Limb down to Bethal in the Southern Limb region. The bushveld intrusion covers most of the Transvaal Super Group region (Cawthorn *et al.*, 2006).

The Bushveld Igneous Complex is a complex layered intrusion with a vertical thickness of 7-9km with various lithological layers ranging from ultra-mafic to mafic rocks in the Rustenburg Layered Suite to the granites of the Felsic Suites (Eales and Cawthorn, 1996, Cawthorn *et al.*, 2006). It is within these layers that the economically important layers occur. The Bushveld Igneous complex contain a multitude of ore deposits of importance, these include; PGE’s, Chromium, Vanadium, Iron, Titanium within the Rustenburg Layered Suite and Tin, Fluorspar, and Andalusite within the Felsic Bushveld rocks (Cawthorn *et al.*, 2006 and Kottke-Levin, 2011).

Layered intrusions formed due to magma slowly cooling, the silicate rock forming minerals such as olivine, pyroxenes, amphiboles, feldspars, quartz, biotite mica and muscovite mica crystallised to form the igneous rocks within the Bushveld Igneous Complex (Schouwstra, Kinloch and Lee, 2000). As the magma cooled, fractionation occurred in cycles where hot magma of different compositions extruded and cooled down, this process was repeated and layered intrusions resulted (Schouwstra, Kinloch and Lee, 2000).

Chrome deposits within the layered intrusion of the Bushveld Igneous Complex are more common, as magma composition varied so did the extrusion of this magma causing layers to form due to varying compositions, it is within these varied composition extrusion that the PGE, chromium and vanadium deposits formed. As compositions varied different layers formed, an example of this will be the formation of layers rich in PGE Platinum group Elements and other minerals including iron, nickel and copper (Schouwstra, Kinloch and Lee, 2000).

The outcrop and world heritage site at the Dwarsriver River, Steelpoort shows the different layers that formed and that now contain the economic important PGE's and Chromium deposits.



Figure 2: Picture of the chrome outcrop found within the Dwarsriver River, Steelpoort (W. du Preez, 2013)

The Bushveld Igneous Complex formed as a “basin shaped” deposit with the formation centre (point of magma extrusion) forming the point that all the limbs dip to, this is due to the fact that upon cooling the centre of the complex weighed the most pulling all the limbs down. This means all the limbs dip towards the centre, the eastern limb dips towards the west, the western limb dips towards the east, northern limb dips towards the south and southern limb dips towards the north. The layers within the Bushveld Igneous Complex dips shallower than the layers within the Pretoria Group (Cawthorn, et al., 2006).

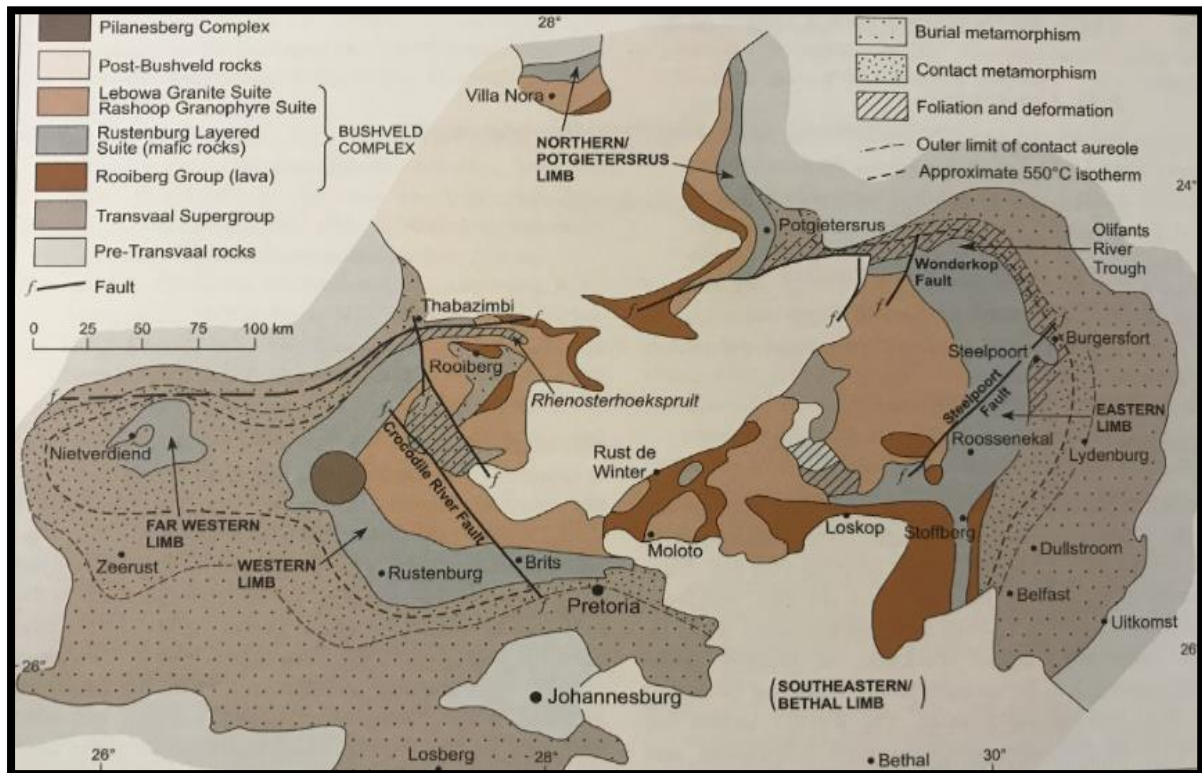


Figure 3: Geological map of the Bushveld Igneous Complex and associated limbs (The Geology of South Africa, 2006).

The layers within the Bushveld Igneous Complex are easily identifiable and the stratigraphy continuous from east to west, on formation these limbs were thought to be connected as a sub horizontal layers. Stratigraphy is often influenced by regional geological features such as the Steelpoort fault complicating the layered nature of the stratigraphy within the Bushveld Igneous Complex.

The thickness and location of layers beneath the surface vary due to the topography onto which the Bushveld Igneous Complex magmas were deposited, the topography that consisted out of mountains and areas differing in elevation means the thickness of the Bushveld Igneous Complex layered intrusion varies from area to area and is influenced by locality from eruption, level of erosion and topography of host rocks before eruption. Some areas within the Bushveld Igneous Complex also experience pockets/lenses of internal waste which distorts the stratigraphic sequence on a regional/local level, iron rich ultra-mafic (IRUP) intrusions also occur in some areas (Cawthorn et al, 2006).

The Bushveld Igneous Complex magmas were deposited upon the Transvaal Super Group and formed 4 distinct zones/limbs (Viljoen and Schürmann, 1998 and Cawthorn et al., 2006). The Northern, Southern, Eastern and Western limb all form part of the greater Bushveld Igneous Complex, all the limbs share similar major stratigraphy and geological features (Viljoen and Schürmann, 1998 and Cawthorn et al., 2006). The investigation focuses on mining operations within the Eastern Limb of the Bushveld Igneous Complex. The Eastern Limb has two major faults influencing operations, these geological fault structures are the Wonderkop and Steelpoort Faults (Viljoen and Schürmann, 1998 and Cawthorn et al., 2006).

The Bushveld Igneous Complex is large, an understanding of the sheer size of this layered intrusion showing its location within South Africa along with its size is necessary to emphasize the importance of this deposit and in turn the investigation. The extent to which the Bushveld Igneous Complex is found on surface in the form of various outcrops makes it easily accessible from many locations and areas, this creates a favourable situation for many mining operations to mine the same deposit without interference.

The Bushveld Igneous Complex is host to a multitude of mines, results from studies in one area of the Bushveld Igneous Complex can often times be extended and implemented in other areas due to the similarities they share (mining the same ore body at different points). The competition for mining these deposits are fierce with big mining companies fighting for rights to mine “ideal” areas, this also creates solutions that can be implemented on a large scale from one company to another. If a process or procedure works in one mining operations chances are that it can be implemented in other operations as successfully.

2.3 Stratigraphy of the Bushveld Igneous Complex

The Bushveld Igneous Complex contains various units/limbs/ suites and zones. The layers found in the western limb are similar to that of the eastern limb when viewed as a cross section. The stratigraphic sequence is mostly uniform across such a cross sectional unit and is only influenced by regional geological aspects (Cawthorn, 2011).

The Pretoria Group forms the base of the section with the overlying Rustenburg Layered Suite. The Lebowa Granite Suite and Rashedoop Granophyre cover the Rustenburg Layer Suite with the Rooiberg Group above them. It stays vital to have a clear understanding on the Bushveld Igneous Complex as a whole, be it elementary before focusing on the economically important layers (Cawthorn et al., 2006). The size of the Bushveld Igneous Complex is astonishing covering a massive surface area of 65 000 km². It is also the largest mafic layered intrusion in the world with some zones within the stratigraphic sequence measuring up to 9 km thick (Schouwstra et al, 2000).

The Rustenburg Layer Suite is the focus of this investigation due to its location (investigation area falls within the Rustenburg layered Suite) and the economic important layers contained within this suite. The Rustenburg Layered Suite consist out of the Upper, Main, Critical, Lower and Marginal Zone (Cawthorn et al, 2006). The different zones within the Rustenburg Layered Suite contain different rock types, each rock type (group of rocks) is associated with a specific zone. A good indication of moving from one zone to another is often the change in major rock type.

The outcrops of the Rustenburg Layered Suites within the Eastern Limb of the Bushveld Igneous Complex are influenced by 2 major fault systems. The Wonderkop and Steelpoort faults both influence the positions of reef outcrops. The effect of these faults has an impact on mining operations in terms of what reef outcrop can be economically extracted. The research area is marked with a red star on Figure 5 and falls within the Upper Critical Zone, of the Rustenburg Layered Suite within the Bushveld Igneous Complex.

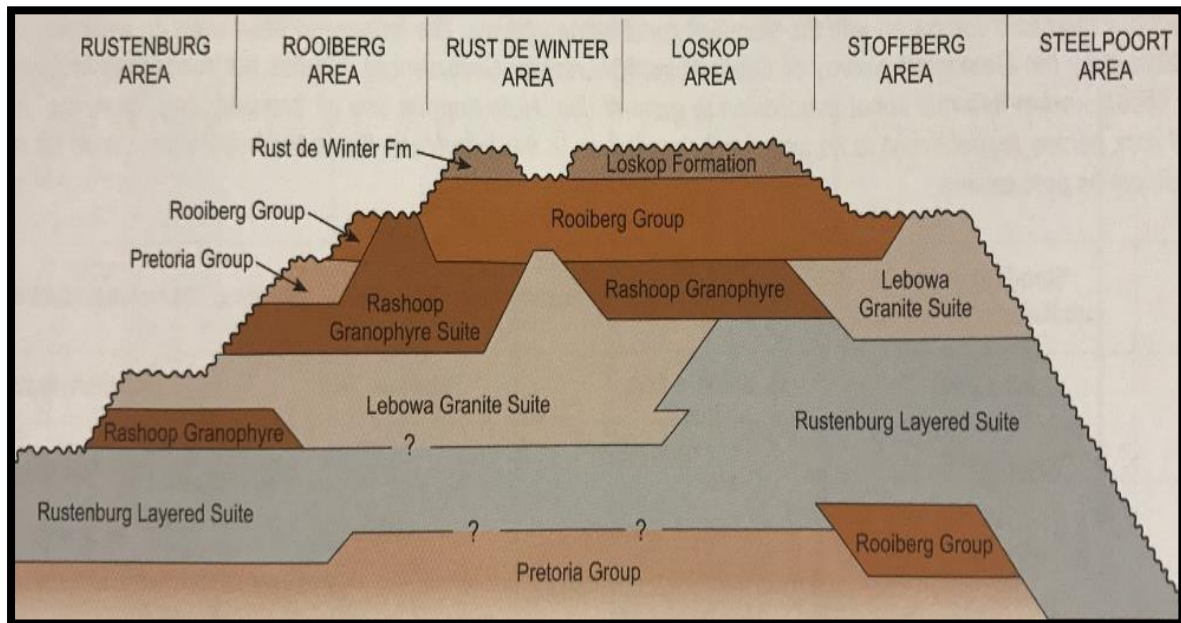


Figure 4: Schematic geological cross section through the Bushveld Igneous Complex (The Geology of South Africa, 2006).

The Middle Group within the critical zone, more specifically the Middle Group 1 chromite layer will form the focus of this investigation, it is important to specify where within the larger stratigraphic sequence the focus will be due to the different formational compositions of the rocks as one move through the stratigraphic sequence.

The Merensky Reef (upper groups) and Middle groups are located within the Upper Critical Zone. The Upper Critical Zone mainly consists out of Norite, Anorthosite, Pyroxenite and Chromite (Lee, 1996). These rocks are important because they form the footwall and hanging wall in the Middle Group 1 chromite layer mining operations and thus the rocks that need to be supported for safe workings to take place.

Regional Geology within the Eastern Limb influence the ore body that will be mined, south of the Steelpoort fault the Middle Group packages are mined (predominantly Middle Group 1 chromite layer due to its thickness and chromium concentration). North of the Steelpoort Fault the focus moves to the Lower Critical Zones – Lower Group with mining operations extracting ore from the Lower Group 6 chromite layer. The Steelpoort and Wonderkop Fault influence the regional geology within the Eastern Limb of the Bushveld Igneous Complex (Cawthorn et al., 2006).

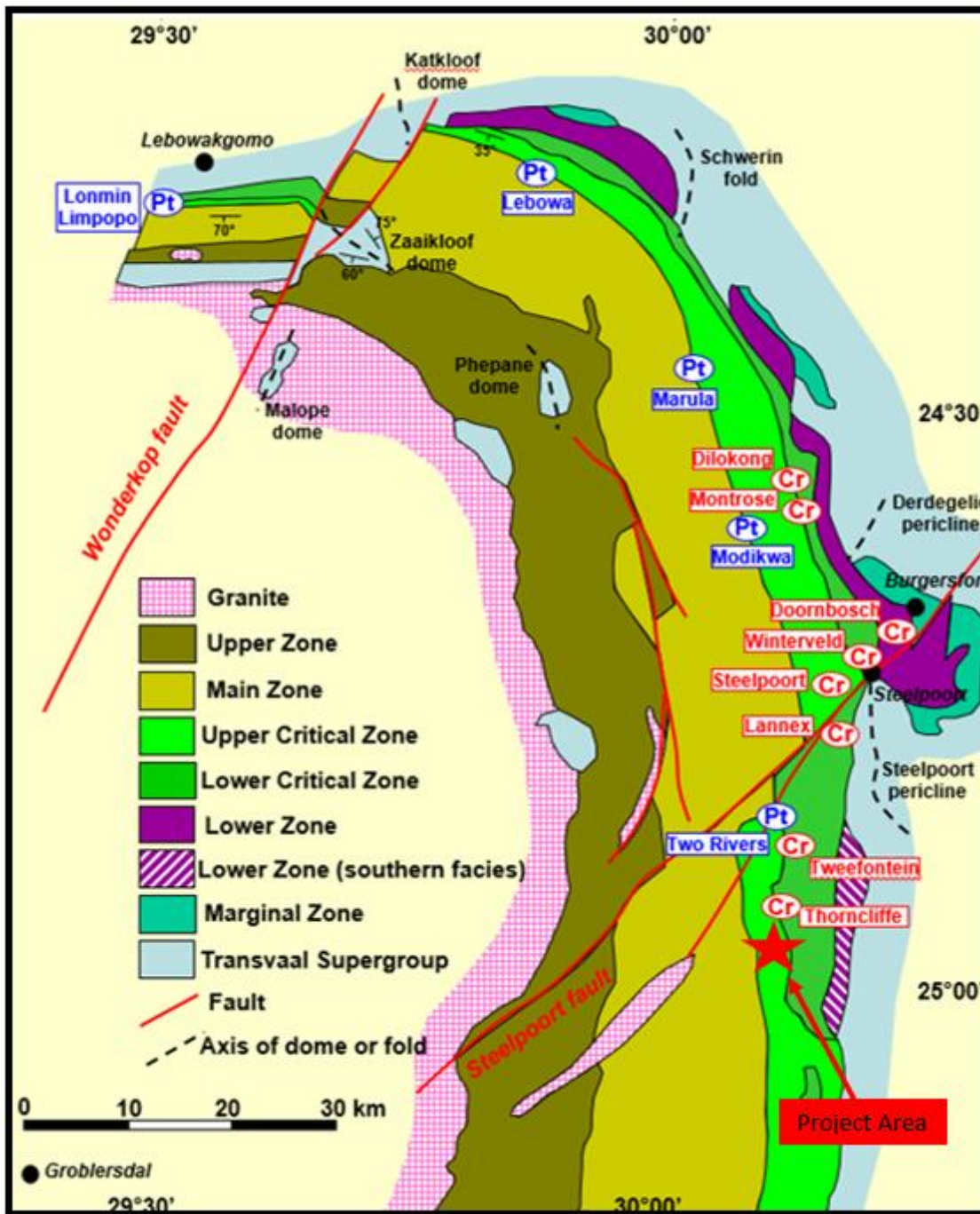


Figure 5: Outcrop of economically important layers of the Rustenburg Layered Suite within the Eastern Limb of the Bushveld Igneous Complex. (Edited by W. du Preez from Internal Glencore presentation).

Chromium from the Middle Group 1 chromite layer is extracted within the investigation area. The Middle Group 1 chromite layer was identified as the chromite layer that will be mined, both surface and underground operations took place with reef dips of 14-16° within surface operations and a regional dip of between 10–12° within underground operations. The Middle Group 1 chromite layer within the investigation area is 1,65m thick on average with internal pyroxenite lenses in some areas. Chromitite markers (chromite stringers) directly below the Middle Group 1 makes the layer identifiable with a 75cm thick Middle Group 0 chromite layer occurring roughly 3m below the Middle Group 1 chromite layer (Geological Summary Report -Helena MG1 Investigation Internal Report, 2005).

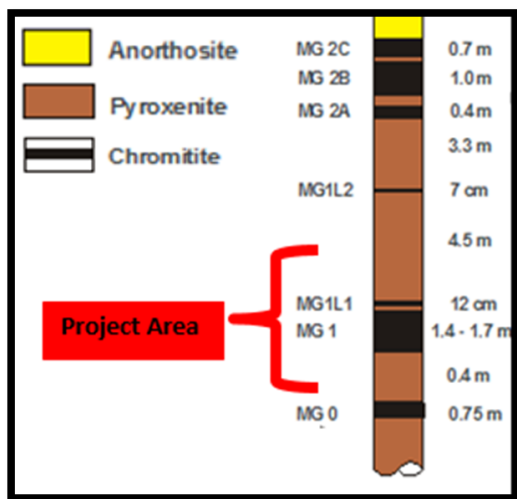


Figure 6 – Stratigraphy of Middle Group 1 chromite layer (MG1) within the investigation area (edited by W. du Preez, 2017).

Stratigraphically the Middle Group chromite layer (MG1 – MG4) within the investigation area shows good correlations with Middle Group layering occurring in the Western Bushveld (Viljoen and Schürmann, 1998 and Cawthorn et al., 2006). Local stratigraphic variations do however occur, these variations can be further studied by looking at exploration results and underground mapping and will be specific to each individual operation.

The Middle Group 1 chromite layer within the investigation area consist out of a solid chromite layer with internal waste pyroxenite lenses present in some areas. The internal pyroxenite waste lenses occur as localized lenses within the reef package, the effect of internal waste on support recommendations and complex geological features should be minimal if the waste lenses are small. Some areas experience thicker internal waste lenses, these internal waste lenses should be considered when making recommendation on how to support complex geological features (Geological Summary Report -Helena MG1 Investigation Internal Report, 2005).

The hanging wall layering and a disseminated chromite leader also forms part of the mining cut causing mining heights of 1, 80 – 2.20m. The Middle Group 1 leader 1 chromite stringer varies in thickness from 2cm-20cm depending on the region within the investigation area. If the mining cut does not included the Chromitite leader within normal mining sufficient support should be recommended to ensure that the parting between the stringer and underlying pyroxenite slab does not fail but stays intact (Geological Summary Report -Helena MG1 Investigation Internal Report, 2005).

After the reef has been extracted a pyroxenite hanging wall is left exposed to be supported. The pyroxenite hanging wall has an average thickness of 4.5m until another leader (Middle Group 1 leader 2) of roughly 7cm is intersected and then a pyroxenite hanging wall all the way to the Middle Group 2 bottom contact. The contact between Middle Group 1 top reef contact and Middle Group 2 bottom reef contact will in effect be the hanging wall of Middle Group 1 to which recommendations will pertain (Glencore Geological Department (Internal reports), 2017).



Figure 7 – MG1 reef chromite layer outcrop within the Upper Critical Zone (photo from internal geological report).

2.4 Economic Importance of the Bushveld Igneous Complex

Mining practises in conjunction with agricultural activities form part of the backbone of the South-African economy. Mining operations occur throughout South-Africa where vast quantities and a variety of commodities are extracted for exportation or used as materials within the industrial operations, chromium and PGE's form part of the commodities that South Africa extracts and export (Merafe Resources Presentation – Maximising South Africa's chrome ore endowment to create jobs and drive sustainable growth).

Chromium and PGE extraction within South Africa contributes greatly to the national economy and local mining economies alike. The mining of these commodities within the Bushveld Igneous Complex has greatly improved the standard of living and future prospects of local communities and small mining towns alike. As the population of the world is growing exponentially the demand for raw materials taken from the earth will increase, as demand increase so does the value of the material and subsequently the process that is used to extract the ore.

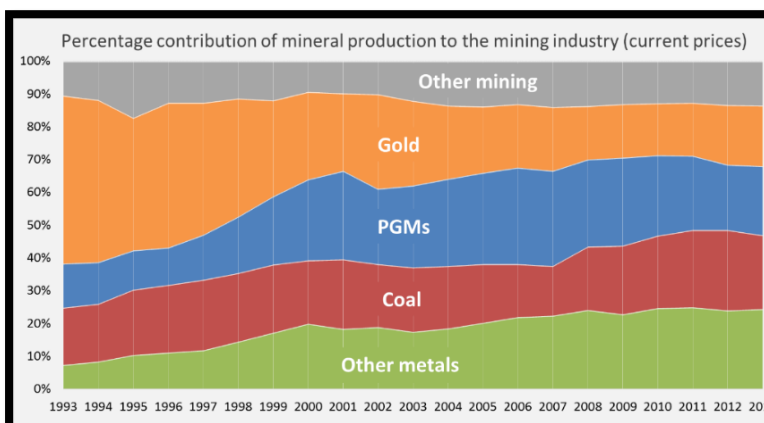


Figure 8 – Mineral production within the mining industry. (Gross Domestic product (PO441), 3rd quarter 2014).

Chromium is an element found within the chromite ore that is mainly used in steel to produce stainless and alloyed steel (Hobart King, 2017). PGE's vary in importance and use with some elements more desired than others. The resistance to corrosion, melting points, oxidation properties, electrical conductivity, electrical properties and use within the glass and motor vehicle industry makes the PGE's important. Due to the increase in global emission, platinum became an important element to help curb the emission released through motor vehicles (Mining Weekly, Creamer Media, 2006).

South Africa within the Bushveld Igneous Complex contain the largest known deposits of Chromium and PGE's in the world. Approximately 50% of the world's chromium is mined within the Bushveld Igneous Complex (Cawthorn et al., 2006). According to Cawthorn the Platinum and Palladium within the Bushveld Igneous Complex represents more than 75% and 50% of the world reserves (Cawthorn et al., 2006).

3. Common Geological structures found within mining operation in the Eastern Limb of the Bushveld Igneous Complex Bushveld Igneous Complex.

Mining within the Bushveld Igneous Complex is complicated by geological structures. Geological structures are features within a rock or rock mass where the shape, size, form distribution and location can be identified and described (Earth Structures, Pluijm and Marshak, 2004). Geological structures are expected throughout the Bushveld Igneous Complex. As geological structures are identified certain characteristics are associated with certain features and environments, geological structures can be broadly classified according to different classification schemes (dependant on the goal of an investigation). Different classifications within the broad classification schemes can be used for different purposes to identify or compare geological structures (Earth Structures, Pluijm and Marshak, 2004).

A general classification of geological structures as explained from the Earth Structures textbook is used to form a foundation for understanding geological features within the Bushveld Igneous Complex and how to classify them. Classification of geological structures is based upon this system with a focus on the geological structures that occur within underground workings in the Eastern Limb of the Bushveld Igneous Complex (Earth Structures, Pluijm and Marshak, 2004).

The Bushveld Igneous Complex formation created a setting where complex structural geological features occur on surface as well as in underground workings. The structural geology has an impact on both the safety and productivity of extracting the ore body. Geological structures that affect mining within the Eastern Limb of the Bushveld Igneous Complex are well understood and have been negotiated since the early 1990's, an example of a major geological structure is the Steelpoort Fault. The Steelpoort Fault is well known and successfully negotiated to ensure profitable mining operations (Cawthorn, 2011).

Table 1 - Classification of Geological structures adapted from Earth Structures textbook. (Earth Structures, Pluijm and Marshak, 2004).

Classification Classes	Class Sub-divisions	Class Description				
I - Geometry –Shape and form of structure.	<ul style="list-style-type: none"> • <i>Planar surface</i> • <i>Curvi-planar surface</i> • <i>Linear feature.</i> 	<i>Most basic classification – Joints, Veins, Faults, Fold, Shear Zone, Foliation, Lineation etc.</i>				
II – Geological Significance.	<ul style="list-style-type: none"> • <i>Primary</i> • <i>Local gravity driven</i> • <i>Local Density Inversion Driven</i> • <i>Fluid Pressure Driven</i> • <i>Tectonic</i> 					
III – Timing of formation.	<ul style="list-style-type: none"> • <i>Syn-formational</i> • <i>Penecontemporaneous</i> • <i>Post-formational.</i> 					
IV – Process of formation.	<ul style="list-style-type: none"> • <i>Fracturing</i> • <i>Plasticity</i> • <i>Diffusion.</i> • <i>Frictional Sliding</i> 					
V – Mesoscopic Cohesiveness during deformation.	<ul style="list-style-type: none"> • <i>Brittle</i> • <i>Ductile</i> • <i>Brittle/ductile</i> 					
VI – Strain significance.	<ul style="list-style-type: none"> • <i>Contractional</i> • <i>Extensional</i> • <i>Strike-slip</i> 					
VII – Distribution of deformation.	<table style="width: 100%; border: none;"> <tr> <td style="width: 50%;"><i>Continuous</i></td> <td style="width: 50%;"><i>Penetrative</i></td> </tr> <tr> <td><i>Localized</i></td> <td><i>Discrete</i></td> </tr> </table>	<i>Continuous</i>	<i>Penetrative</i>	<i>Localized</i>	<i>Discrete</i>	
<i>Continuous</i>	<i>Penetrative</i>					
<i>Localized</i>	<i>Discrete</i>					

The geological structures that form the focus of this investigation are those that are found throughout the (metalliferous) hard rock mines extracting chromium in the Eastern Limb of the Bushveld Igneous Complex. Each geological structure that has an effect on the underground mining operations within the Eastern Limb of the Bushveld Igneous Complex are discussed briefly in terms of their origin, nomenclature, geometry and continuity in the hanging wall/footwall and hazards they pose to underground workings.

The main geological features that are of concern relating to the safety within underground workings are thrust faults (domes), potholes, reef rolls, joints (near vertical and low angle), dykes, faults and IRUPS. These features are often simplified to fit within a mining environment and many colloquial terms are used and developed. The study of these features within this investigation will focus on the scientific terms with reference to the mining terms.

Geological structures found within mining operation in the Eastern Limb of the Bushveld Igneous Complex are tabled below. These structures are further divided within the investigation based on colloquial mining terms but scientifically the majority of the structures fall within the classes depicted in the table below.

Table 2 – Geological features with colloquial mining terms.

Geological structure	Colloquial mining terms
Joints	Low angle joints, near vertical joints, joint zones, joint sets, cross cutting joints.
Faults	Up throw fault (U/T fault), Down throw fault (D/T fault), thrust faults, fault zone, shear zone, and fault set.
Pothole and Reef Roll	Steeply dipping reef packages, intersection of different stratigraphic layers or sequences.
Dyke	Dolerite dyke, Dyke with displacement, Dyke with associated area of influence.

3.1 Joints

Joints can be described as “fractures that occur naturally within a rock along where no shear displacement has taken place” (Earth Structures, Pluijm and Marshak, 2004). Joints are planar or curvi-planar features that are exposed on surface within outcrops or when underground excavations like mining operations mine through these features. Joints most commonly form parallel to the principal stress directions (sigma one and two) and perpendicular to sigma three, throughout a regional geological aspects these stress regimes vary as stress fields are influenced by a variety of factors (Earth Structures, Pluijm and Marshak, 2004).

Joints are important geological features to identify, support and safely negotiate throughout underground operations. The basic identification and classification of joints must be conducted from a standard that is relevant and accurate.

Joints are geological discontinuities, these discontinues breaks larger rock masses into separate blocks along the joints (weakness within the rock mass). Joints have no vertical or horizontal displacement within the rock mass, once a joint is exposed in underground workings loose blocks and wedges created by multiple joint system may fail and fall from the hanging wall if the gravitational force exceeds the tensile strength keeping it positioned within the hanging wall. Joints and joint’s surface may be weathered, not weathered or altered (chemically/physically) (Barton and Choubey, 1976).

Joints affect different features within the hanging wall such as rock strength and the ability to transfer water (hydrous solutions) along joint fractures. Both the rock strength and permeability of the rock are vital factors one need to consider when making support recommendations on geological features (Fensham, 2017, personnel communication, Steelpoort, unreferenced). Joints in itself are seldom a threat to mining operations but when coupled with multiple cross cutting joint sets or low angle joint features mining challenges do arise, these are further complicated if a joint or joint set occurs within a same panel where other more complex geological structures are present which is often the case within underground mining operations.

Table 3 – Description of Joint feature terminology used within underground mining operations (Earth Structures, Pluijm and Marshak, 2004).

Terminology	Description
Conjugate system	Two sets of joints oriented such that the dihedral angle between the sets is approximately 60°.
Continuous joints	Thoroughgoing joints that can be traced across an outcrop, and perhaps across the countryside.
Cross joints	Discontinuous joints that cut across the rock between two systematic joints, and are oriented at a high angle to the systematic joints.
Cross-strike joints	Joints that cut across the general trend of fold hinges in a region of folded rocks (i.e., the joints cut across regional bedding strike).
Discontinuous joints	Short joints that terminate within an outcrop, generally at the intersection with another joint.
Joint	A natural, unfilled, planar or curvi-planar fracture which forms by tensile loading (i.e., the walls of a joint move apart very slightly as the joint develops). Joint formation does not involve shear displacement.
Joint array	Any group of joints (systematic or non- systematic).
Joint density	The surface area of joints per unit volume of rock (also referred to as <i>joint intensity</i>).
Joint origin	The point on the joint (usually a flaw or inclusion) at which the fracture began to propagate; it is commonly marked by a dimple.
Joint set	A group of systematic joints.
Joint stress	The region around a joint surface where joint-normal tensile stress is insufficient to cause new joints to form.
Joint system	Two or more geometrically related sets of joints in a region.
Non- systematic joints	A joint that is not necessarily planar, and is not parallel to nearby joints.
Orthogonal system	Two sets of joints that are at right angles to one another.
Strike-parallel joints	Joints that parallel the general trend of fold-hinges in a region of folded strata (i.e., the joints parallel regional bedding strike).
Systematic joints	Roughly planar joints which occur as part of a set in which the joints parallel one another, and which are relatively evenly spaced from one another.

Joints features throughout the Bushveld Igneous Complex vary in orientation, extent, dimensions and frequency of occurrence. Joints occur in systematic and non-systematic arrays, with some areas displaying systematics joints with a general trend over a large area. (Barton and Choubey, 1976). Systematic joints are planar joint features were a parallel/sub-parallel family of joints spaced evenly apart occurs. Non-systematic joints occur randomly (Earth Structures, Pluijm and Marshak, 2004). Joint features also form an environment where additional geological structures may arise depending on conditions. Shear fractures/shear zones, faults (fault zones) and veins all commonly form in conjunction with multiple joint features. It is important to identify and classify these features as a separate entity as faults could be classified as joints but joints cannot be classified as faults (Earth Structures, Pluijm and Marshak, 2004).



Figure 9 – Joint set within underground excavation.

Joint features commonly form a blocky hanging wall environment containing loose rocks (key blocks) within the hanging wall. Once wedges/loose blocks are barred from the hanging wall the joint plane is exposed. The exposed joint plane gives evidence of the point of origin of the joint based on the plumose structure. The plumose structures and overall stress regime can be determined by the roughness/softness of the exposed joint plane. The roughness/softness of the exposed joint plane will be dependent on the grain size of the rock, this will differ from area to area as not all rocks have similar properties or environments (different stress regimes).

Joints within the Bushveld Igneous Complex often have veins that formed within the joint fracture (between the 2 blocks of rocks). Veins are formed when fractures (openings/planes) where pre-existing weaknesses exists are filled with a hydrous solutions which precipitates and forms a mineral. (Earth Structures, Pluijm and Marshak, 2004). The most common vein fill found in mining operations within the Bushveld Igneous Complex is Calcite, Quartz and Chlorite.

Systematic joints are planar joint features were a parallel/sub-parallel family of joints spaced evenly apart occurs (Earth Structures, Pluijm and Marshak, 2004). There is only one area within the investigation area that the general trend of the joints can be determined. From figure 10 below the joints are the lines in pink, it is clear that the majority of the joints occur within a general trend, orientation and direction, the joints also dip in the same direction within this area. These systematic joints are trending NW-SE, the trend direction is parallel to a large fault zone (Borwa fault zone) found within the mining complex. Non-systematic joints are joints features that occur with no defined orientation, trend or spacing. Non-systematic joints occur randomly.

The reason for similarities in the orientation and dip of this amount of joint features across a relatively large are in mining terms are due to the stress regime. The stress regimes differ slightly from mining operation based on regional geological aspects. Systematic jointing within the investigation period is commonly accompanied by faulting. Systematic jointing paired with faulting creates a challenging mining environment to negotiate.

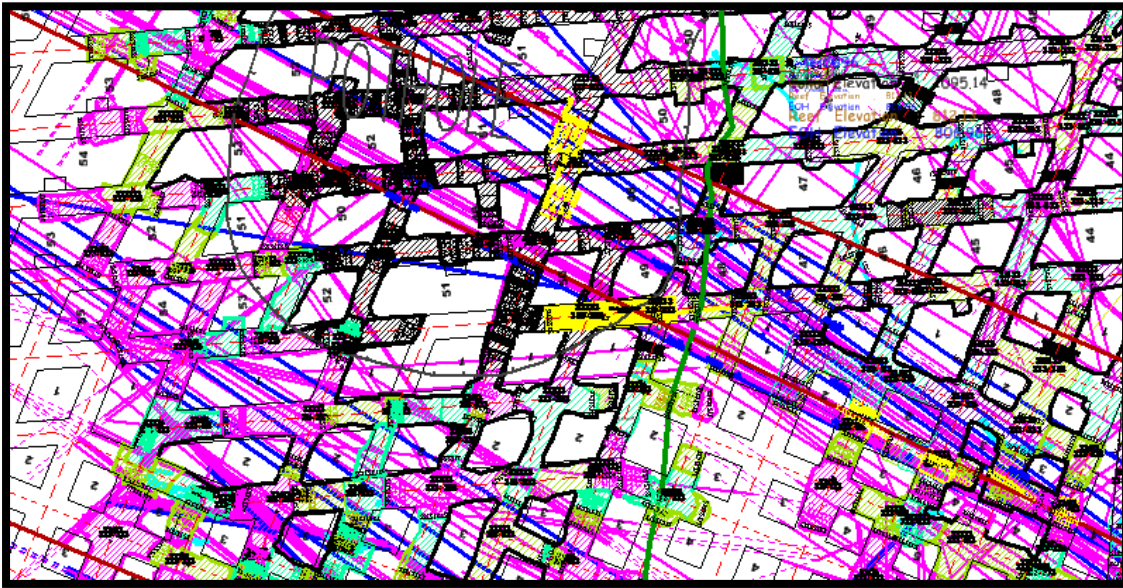


Figure 10 – Plan view of area within investigation area depicting general trend and orientation of systematic joint features (W. du Preez, 2016)

Joints are the most common geological feature throughout the investigation area, joint features and associated ground conditions occur within the bulk of the panels investigated during the investigation. The joints within the investigation area vary in orientation, extent, dimensions and frequency of occurrence throughout the investigation area. Joint features occur in systematic and non-systematic arrays within the investigation area with some areas displaying systematic joints with a general trend over a large area.

Ground conditions and geological features associated with Joints and Joint sets.

3.1.1 Blocky ground

Areas where multiple joints occur are often cross cut by other joints features to form blocky ground areas where loose wedges are present throughout the hanging wall. The size of the loose blocks depend on the spacing between the joints as well as the cross cutting joints, the smaller the spacing the larger the amount of joints and the smaller the blocks or fragments within the hanging wall. If the joints are spaced far apart and are cross cut by joints that are also spaced far apart the blocks within the hanging wall will be considerable in size and classified as wedges between joints. It is also important to note the features within cross cutting joints to determine the age of the joints, are the younger ones the prominent joint vs older joints and so forth, what formed these joints and what effect does it have on the geological features within the investigation area.

3.1.2 Shear Zones

Joints occur due to the stresses that are applied to a rock mass, these pressures increase until a release of pressure in the form of a joint is created. For joints to form the bulk of the pressure must be exerted within one plane direction, this is also how multiple joints spaced closely apart are formed. If the pressure that is being applied becomes more the joints spacing

will increase eventually causing a joint to experience the bulk of the pressure, these areas within joint sets deform due to the change in pressure, original rock properties are changed due to the pressure, and shear zones (areas of weakness where the pressure exerted had the maximum effect) are formed. Shear zones are areas within the joint set where the planes within the set experienced the most pressure forming a shear zone. Shear zones from part of important structural features to look out for within joints and joints sets, these zones indicate areas of weaknesses within the hanging wall.

3.1.3 Veins

Joints form planes of weaknesses within a rock mass. If there is water present within the investigation area joints, dykes, shear zones and faults will also be the preferred travelling route for the water, it is easier to travel through small spaces than solid spaces. If the fractures fill with water, precipitation eventual occurs forming a mineral within the once open spaced joint fracture. Veins are common within joint sets and the effect on the support measures are similar to supporting normal joint features, this is solely dependent on the thickness of the vein. Within the investigation area, the vein formations are limited to calcite or pegmatite veins with a thickness of between 10cm-25cm.

3.1.3 Infill

Serpentine is a clay (mica) mineral that occurs within the investigation area and forms on the planes between rocks and within joints, shear zones and faults. The serpentine infill creates a slippery layer between the planes of the rock masses be it horizontally or vertically. The infill cause the cohesion properties between the planes to decrease and failure occurs much earlier. Serpentine is a clay based mineral and easily dissolved upon continued interception with water effectively decreasing the cohesion properties between rock planes to zero with failure eminent.

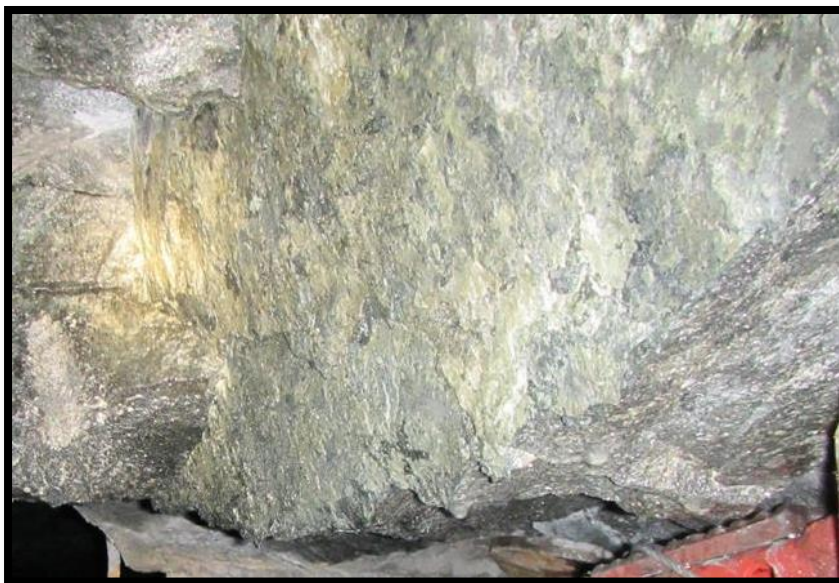


Figure 11 – Serpentinite infill forming a layer on rock plane *note the greenish colour (W. du Preez, 2016).

3.2 Faults

Faults pose a risk to both the safety and production of a mining operation. Faults are classified as geological features where measurable slip has occurred. Slip refers to the movement (shear displacement) that occurs within a rock body (in relation to another rock body). The displacement can occur within local and regional areas in a variety of scales and across small- or vast distances. The “geological discontinuity” that divides two blocks of rocks is known as a fracture (joint) once these blocks move in relation to one another a fault feature is formed (Earth Structures, Pluijm and Marshak, 2004 and Perrit and Roberts, 2007).

Faults are similar to joints in almost all aspects except that faults display a sense of movement, displacement of one rock mass in relation to another, and joints do not. If there is a break within or along a plane of a rock and movement is noted a fault is present, if there are multiple faults with the same properties and features evenly spaced we refer to these areas as fault zones (Earth Structures, Pluijm and Marshak, 2004). Fault zones are similar to shear zones, they only differ in terms of deformation, a shear zone forms when brittle deformation took place with no measurable slip evident from within the affected zone, hence no movement between the broken rock planes. A fault zone is a brittle structure displaying multiple breaks within a rock mass with movement evident from one break to another (Earth Structures, Pluijm and Marshak, 2004).

The challenge with faults within the mining environment comes when faults are classified. Identifying faults and fault zones are simple and fast due to the effect it has on the mining operations. Faults are easily identified within the Bushveld Igneous Complex due to the uniformly stratigraphic sequence of the layered intrusion, the layers can be accurately traced from outcrop in the East towards the center and eventually the outcrop in the West with no major differences. Once a reef band is displaced the face of a mining panel is influenced (no reef/limited exposure) and production delays are imminent. These delays need to be minimized to ensure monthly production targets are met.

Due to the importance of production within a mining environment faults are classified in terms of their effect on the extracted reef/ore body. Faults are simplified within mining environments in terms of their influence and only classified according to the amount and direction of slip. The movement in terms of direction is limited to U/T faults and D/T faults referring to the movement that occurred from the original reef package. Scientifically faults are much harder to correctly classify and complex to explain.

Mining geologists have to record all the scientific details on how to name a fault and must record it as such, he can then explain the impact of the fault in “mining” terms to “mining personnel”. As discussed earlier, the definitions in terms of a fault is well understood within a mining environment but naming and classifying a fault system is not. The sole focus of mining is to ensure that as much of the ore body is extracted in the shortest amount of time in the safest manner. When a fault is encountered the only concerns are, where the reef positions/location is (when reef is completely lost), what the impact on safely mining this area will be and when will mining intersected and resume normal mining on the reef package/ore body.

Faults are generally classified according to the direction of relative displacement and offset. The Slip of a fault refers to the actual displacement the rock body has made from its position prior to the influence of the fault. Separation within a fault refers to the apparent displacement the body of rock experienced with relation to its original positions. Slip is defined by the direction of movement, sense of movement and the magnitude of displacement (Perrit and Roberts, 2007).

Throughout the Bushveld Igneous Complex, different faults are encountered each with its own characteristics and influence. It is important to be able to identify a fault and differentiate between the different types of faults an underground, mining operation within the Eastern Limb of the Bushveld Igneous Complex will experience. Faults will be further explained with reference to the main types of faults, these faults occur on a regular basis within the investigation area.

Main type of faults:

- 3.2.1 Thrust Faults
- 3.2.2 Normal Faults
- 3.2.3 Strike Slip Faults

3.2.1 Thrust Faults (Domes/Curved Joints)

Thrust faults occur within underground workings in the Eastern Limb of the Bushveld Igneous Complex. Thrust faults are commonly referred to as “domes” within the mining environment. “Domes” or “curved joints” are colloquial terms used to describe thrust faults. Thrust faults are extremely dangerous in underground workings and are responsible for a large amount of falls of ground throughout the Bushveld Igneous Complex.

An analysis conducted by the Department of Mineral Resources (DMR) found that “inadequate and/or failure to conduct proper Early Entry Examination contributed significantly to such fall of ground incidents. And this inadequacy is a result of lack of knowledge and appropriate skills by competent “A” persons (which refer to Team Supervisors and Miners) on how to deal with geological features associated with their respective working places.” (Glencore Internal falls of ground presentation)).

Thrust faults can be described as low angle faults (similar to low angle joints), and forms within area where convergence occurred, pressure acts in on area and affects large areas of rock mass due to the thrusting of the pressure (Perrit and Roberts, 2007). The thrust faults within the Bushveld Igneous Complex can be more accurately described as stepped thrusts and form a ramp-flat geometry (Perrit and Roberts, 2007).

The intersection of the thrust fault area of concern will then solely depend on where the mining cut intersected the thrust fault feature, what part of the feature is exposed the “ramp” part or the “flat” part. Thrust faults occur when the footwall moves up towards the hanging wall, in mining this is termed as an up-throw fault where the reef chromite layers displaced into the hanging wall. Thrust faults are when the older strata from the bottom are brought into contact with the younger strata on top due to the displacement of the fault feature (Perrit and Roberts, 2007).

These features are often found in sets or layers called piggy back/onion peel doming, when multiple ramp-flat geometry features occur on top of one another. From the figure below the different layers and undulating/curved nature of the thrust fault feature can clearly be seen within section view. The orientation of the mining panel will intersect this feature at different locations, if the face is for example the advancing face as shown in the figure below the feature will be classified as “dome” that needs to be supported (Perrit and Roberts, 2007).

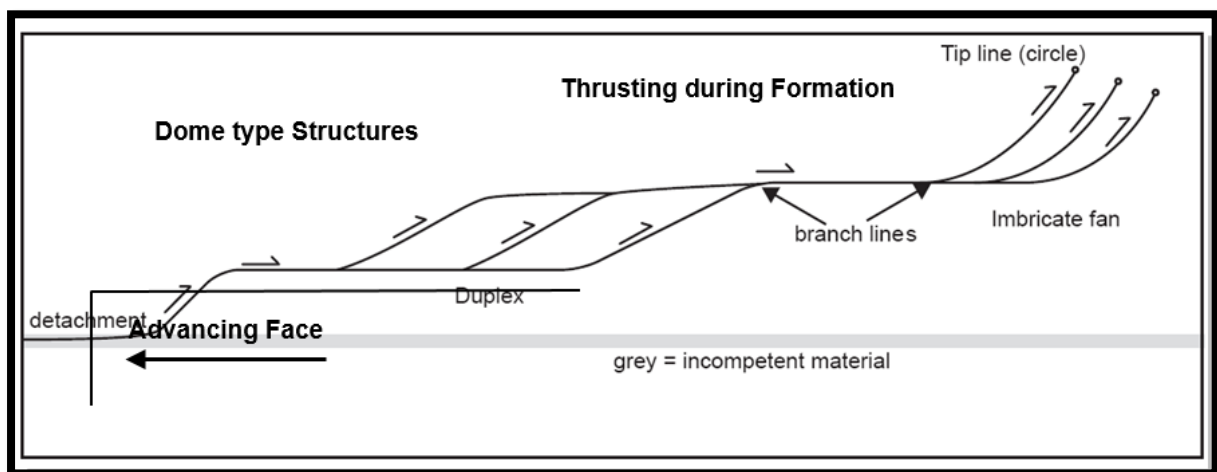


Figure 12 – Thrust fault geological features with a reference to “dome” structure and thrusting during formation. (Glencore Internal Presentation).

The weak side of the domes pose a risk for falls of ground to occur, where large loose blocks/wedges can form part of the dome plane (curved joint) and fall towards the footwall. Thrust faults are often further complicated by additional geological features such as intersecting joints and serpentinite infill. Many underground workings where domes occur contain large amounts of serpentinite type infill especially on the dome plane (curved joint). This infill creates a plane of little to no cohesion made worse when water is present and failure on the weak side of the dome is as good as guaranteed if not correctly identified and supported.

Where the mining face intersected the thrust fault feature largely determine the effect the feature will have on mining practices. Thrust fault intersection only has three possible outcomes: a flat footwall-hanging wall scenario, flat footwall-hanging wall ramp scenario and footwall-hanging wall ramp scenario.

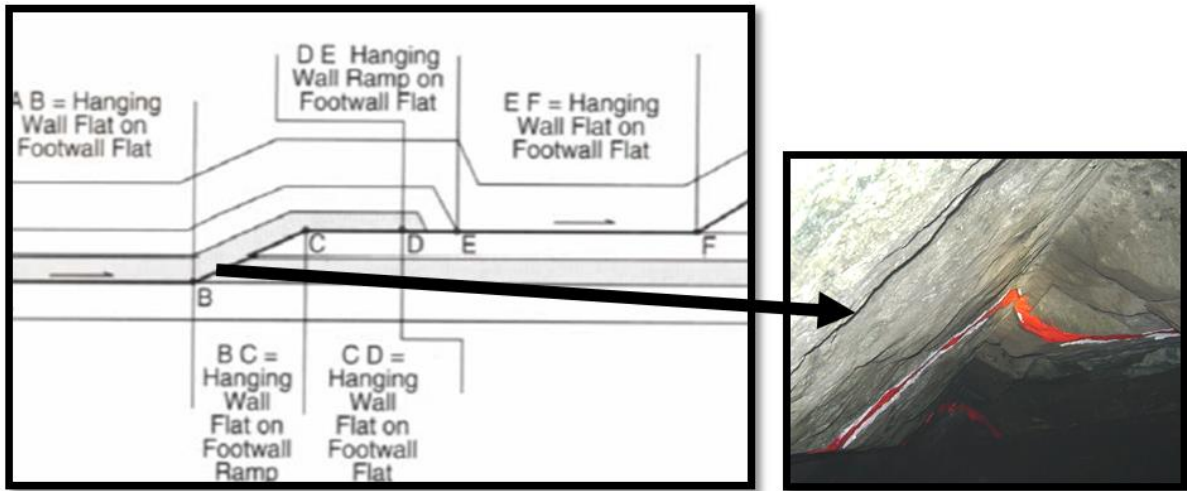


Figure 13 – Flat and ramp geometry with reference to thrust fault geological features. (Glencore Internal Presentation and Earth Structures, Pluijm and Marshak, 2004).

Thrust fault feature can vary in extent and almost never occur as a singular feature within an area, areas where thrust faults are had large pressure forces forming these features. The thrust faults within a general area that was formed from the same process will display similar orientations, directions and dips, these features will also display similar sense of movement.

“Domes” are sometimes difficult to identify and mining takes place into a dome plane before it is fully exposed, this places mining personnel under the weak side of the dome. Supporting the weak side of the dome is the focus in regards to safe working. Mining designs and layouts are often changed so that the weak side of the “dome” structures rest on pillars instead of holing’s between panels. Serpentinite infill forms on the surface of planes on the contact between different planes or features. Geological features containing serpentinite are of great concern especially where water presence is evident due to the lack of cohesion within serpentinite layers when contact with water occurs. Figure 14 shows the area of concern in regards to the intersection of a thrust fault feature, the wedge fallout is typical to what will be experienced in a mining environment where this feature is under supported.

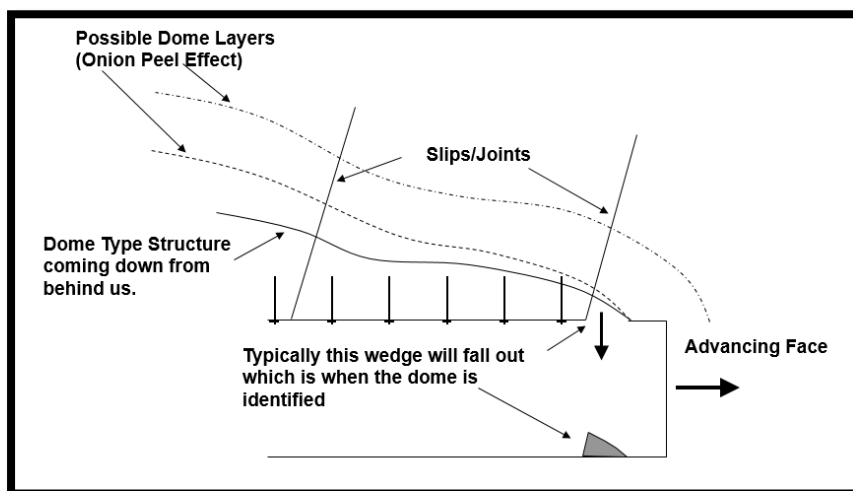


Figure 14 – Advancing mining panel and effect of overlying thrust fault features. (Glencore Alloys Internal presentation- Rock Engineering Department).

Fallout of large wedges along the weak side of the low angle faults(thrust faults) pose a risk to mining practises, fallout along these feature are a major concern within the Bushveld Igneous Complex (Perrit and Roberts, 2007).



Figure 15 – Failure of “dome” thrust fault feature within underground workings (edited from (Perrit and Roberts, 2007 and Internal presentation-Glencore Alloys).

3.2.2 Normal faults

Normal faults when there is a downward movement of the hanging wall in regards to the footwall, in other words the younger strata at the top (hanging wall) is brought into contact with the older strata (footwall) at the bottom (Earth Structures, Pluijm and Marshak, 2004).

In mining terms a normal fault is referred to as a down throw fault, this is derived from the sense that the reef chromite layers are “thrown” down into the footwall due to the fault. Normal faults are the easiest to manage in term of support measures within a mining environment (investigation area) as there is no risk of reef that will be present within the immediate hanging wall area.

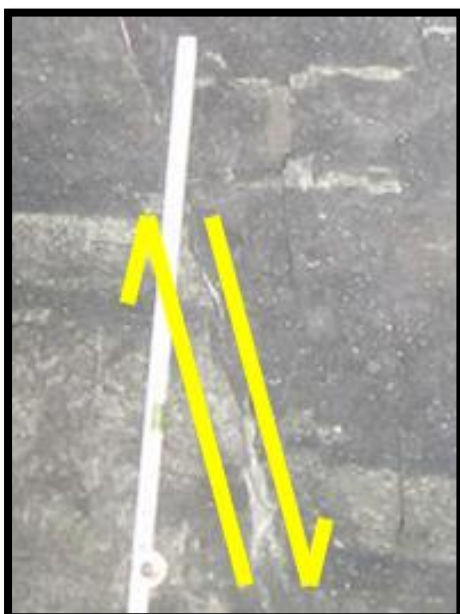


Figure 16 – Normal fault encountered within the investigation area (Wicus du Preez, 2016).

3.2.3 Strike slip faults

Strike slip faults occur when the movement of one rock mass in relation to another occurs on strike. Strike slip faults are similar to transform movement along tectonic plates. Strike slip faults within the investigation area are quite rare and the effect on mining will be in term the reef position instead of supporting concerns as the hanging wall and footwall conditions will stay the same. Strike slip faults refer to the horizontal movement of one plane in regards to another with no or little vertical displacement (earth structures), the investigation area had not experience any major tectonic activity since its formation and the for strike slip geological features to affect a mining operation within the Bushveld Igneous Complex a large tectonic event had to occur (Earth Structures, Pluijm and Marshak, 2004).

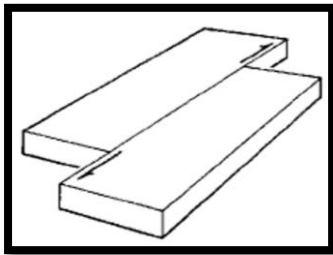


Figure 17 – Typical displacement of blocks within a strike slip fault environment. ((Earth Structures, Pluijm and Marshak, 2004).

An accurate and easy to understand theory to use when trying to understand different faults and the different forces of stress within a specific fault will be to apply Anderson’s theory of faulting. The image below is an extract from a structural geology textbook, Earth Structures depicting Andersons fault theory.

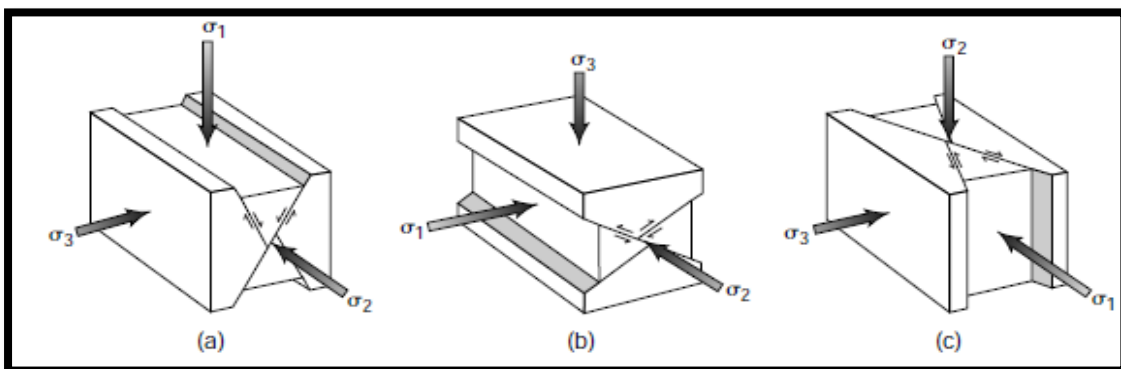


Figure 18 – Anderson’s theory of faulting. (Earth Structures, Pluijm and Marshak, 2004).

(a) Refers to a normal fault with high angles as can be seen from the image. A thrust fault or reverse fault is shown in (b), this feature has low angles. The last image is of a strike slip fault. The main difference between the classification and understanding of faults is in terms of the stresses/forces that from the fault, made it the way it is. Each fault within the image above has different direction in which the stresses interact with the rock ensuring that the “end-product” will have different characteristics and properties (Earth Structures, Pluijm and Marshak, 2004).

The scientific formation and understanding of fault systems are more complicated than the colloquial terms and mining understanding due to the difference in focus, mining focuses on production where geologists who are scientists in nature focuses on the “how” and “why”.

Brow Features are commonly associated with Fault structures- A brow is classified as an abrupt step in the hanging wall extending for more than 2m's. Brows are classified according to their size and influence on a mining panel. If an Up throw fault of 2m is intersected within a mining panel a brow feature will form due to the difference in elevation of the reef layers (movement due to the fault feature). Brow features are also present where large underground excavations take place, areas such as tips and head section negotiate brow features.

3.3 Potholes and Reef Rolls

Potholes and Reef Rolls will be discussed together due to the similarities between these features. Both occur where reef packages dips steeply into the footwall, the size and extent of the dipping of the reef chromite layer into the footwall indicates whether a pothole or reef roll is the featured encountered (Lomberg et al., 1999).

Reef rolls and potholes are formed when the reef chromite layer transgresses the footwall with a change in dip and strike. Upon formation the ore bodies were formed due to hot magma extruding (surface, within other stratigraphic sequences), cooling off forming layers and eventual forming the ore body. The reef layers formed in uniformity across an extremely large area and within this large area there are instances where a change in dip and strike in relation to the reef chromite layer occurred. The area where undulating reef or changes within the reef chromite layer occurred are areas where irregularities in terms of the dip of the reef chromite layers are experienced (Lomberg et al., 1999).

Reef rolls occur where there is a local change in the strike and dip within mining panels, reef rolls often occur as a linear feature that runs/cuts across many panels within a section. Reef rolls are thought to be linear features where the dipping of reef into the footwall occurs along a linear line or area where potholes occur as a circular or elongated feature (personal communication, PJ Grabe 2016).

Potholes occur when there is a change in strike and dip but the characteristics are more severe than in the case of a reef roll and the reef transgresses the footwall within a short distance. The orientation, occurrence and shapes of potholes differ from area to area, the area under investigation intersects potholes of roundish basin shape depression. Studies have found that potholes have certain features such as the size of the pothole is dependent on the thickness of the reef (Lomberg, 1999). The initial dip of the chromite layer also indicated whether or not the pothole will be large in extent or not. Some evidence suggest that the amount of dip of the reef chromite layer indicates the size of the pothole with steeply dipping reef chromite layer indicating a small pothole and shallow dipping reef indicates a larger pothole feature (Lomberg et al., 1999).

Potholes are challenging to negotiate due to the fact that the panel is no longer mining on reef and that the stratigraphy of the chromite layer has been altered due to the slumping that occurred. The fracturing of the ground within potholes can cause instabilities and dangerous working areas. Geological drilling to locate the reef position along with the position of various other reef bands is important for both safety and production.

Generally the differences between potholes and reef rolls are subtle, mining personnel often struggle to differentiate between a pothole feature and a reef roll feature. Differences between these two features exists in the extent of the dip of the reef layer and the size of the feature (Lomberg et al., 1999).

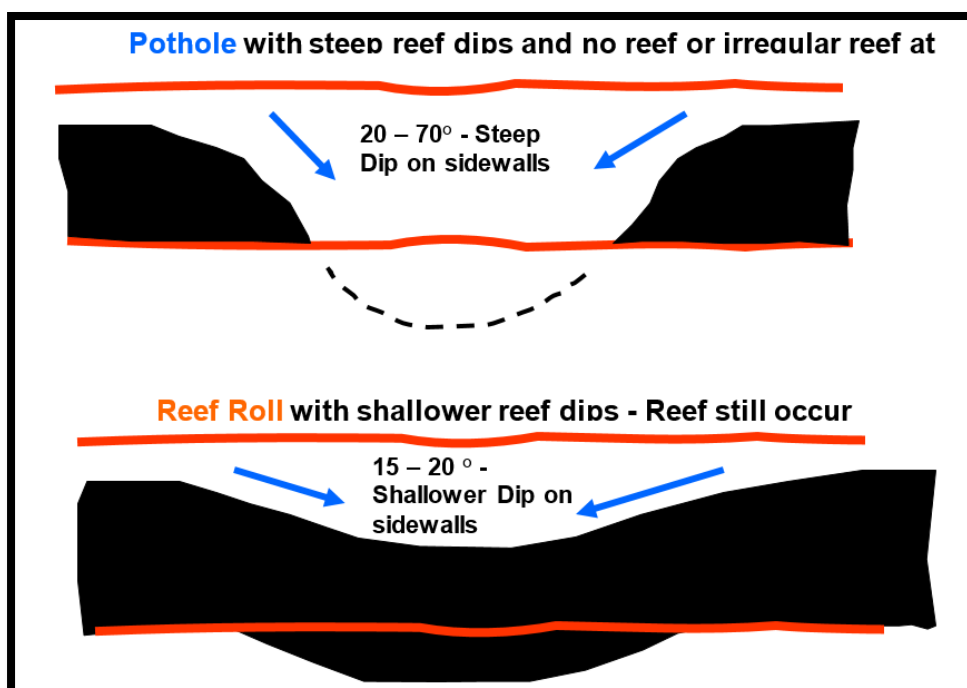


Figure 19 – Section view of differences between a pothole and reef roll feature. (Internal Presentation)

Pothole features encountered within the investigation area varied in dip, strike and extent from one pothole feature to another. A pothole feature within the investigation area was identified on an underground mapping visit.

From figure 20 below the top contact of the Middle Group 1 chromite layer and the Middle Group 1 Leader 1 is exposed just above the package, another small leader (Middle Group 1 Leader 2) is exposed just above this leader and then a thicker reef chromite layer towards the top part of the picture. The reef chromite layer towards the top is that of Middle Group 2A chromite layer the bottom contact, the entire chromite layer between Middle Group 1 top contact and Middle Group 2A bottom contact is exposed in a couple of meters clearly displaying the forces of drag a pothole feature has on the chromite layers. The image on the right in figure 20 was taken a couple of meters towards the d/dip side of the image on the left, the top contact of Middle Group 2C and the Anorthosite hanging wall is exposed further indicating that this an extremely steeply dipping pothole feature.

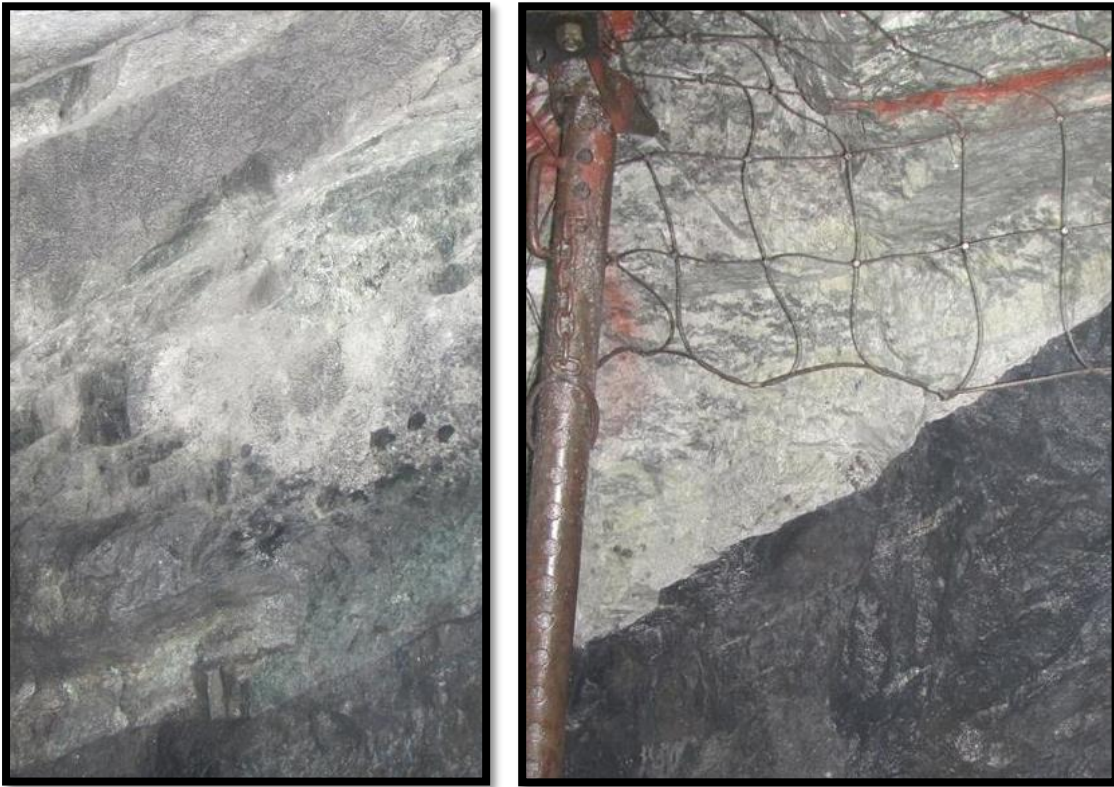


Figure 20 – Pothole intersection- note the steep dip of the reef packages (W. du Preez, 2016).

3.4 Dykes

Dykes form within pre-existing's planes of weaknesses/ areas within rock bodies. The size of the dyke is dependant in the magmatic intrusion and the space (weaknesses) within the rock body. Dyke features can occur over extremely large areas and have a major impact on mining in terms of safety and production (Earth Structures, Pluijm and Marshak, 2004 and Roberts and Clark-Mostert, 2010).

The dykes within the Eastern Limb of the Bushveld Igneous Complex occurred due to magmatic intrusions and are not sedimentary in nature. Dolerite dyke features within the Bushveld Igneous Complex vary in thickness from centimetres to tens of meters. The ground conditions within and adjacent to a dyke feature is unfavourable. The dyke feature experiences blocky and friable ground but due to limited planes of weaknesses within investigation area rock masses are usually tightly constrained between the bodies of rock. The areas adjacent to dyke features are the main areas for concern in terms of safety due to sympathetic jointing/faulting (Roberts and Clark-Mostert, 2010).

Dykes are theoretically viewed as a vertical intrusion where sills are thought to be horizontally intruded into the rock mass (dependant on pre-existing planes of weakness). Within the Bushveld Complex Dykes are often sub-vertical or “angled” and did not intrude at 90°, dykes often have dips of 60-80°. Despite these characteristics these features are still classified as dykes.

Aeromagnetic studies were conducted within the investigation area to determine the influence and extent of the dyke features. It is important to remember that smaller parallel running dykes are shadowed by major dykes and not always picked up on aeromagnetic seismic surveys, these feature must be mapped by surface and underground mapping if possible (Internal Report).

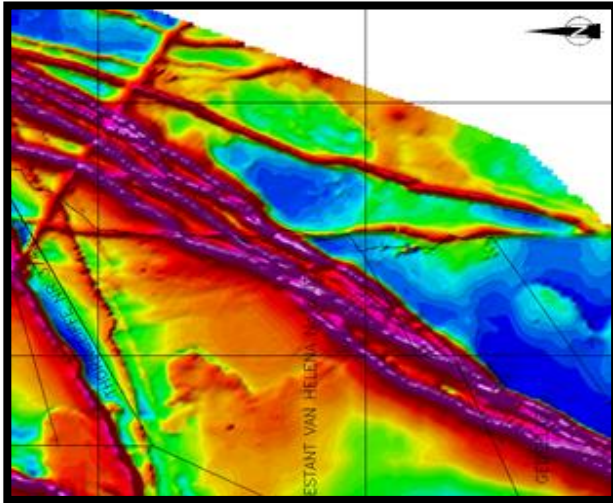


Figure 21 – Magnetic total field airborne image for the investigation area (Internal Geological Report).

The intrusion of dolerite dykes within the pre-existing planes of weakness in rock masses often displaces the reef chromite layer within the local area similar to that of a fault, the reef position before and after the dyke are not similar (Fensham, 2017, personal communication, Steelpoort, unreferenced). Some Dolerite Dyke features within the investigation displaces the Middle Group 1 chromite layer up to 7m. When there is a displacement on a dyke feature be it horizontal or vertical additional measure in terms of support and mining should be considered due to the changes from normal mining conditions.

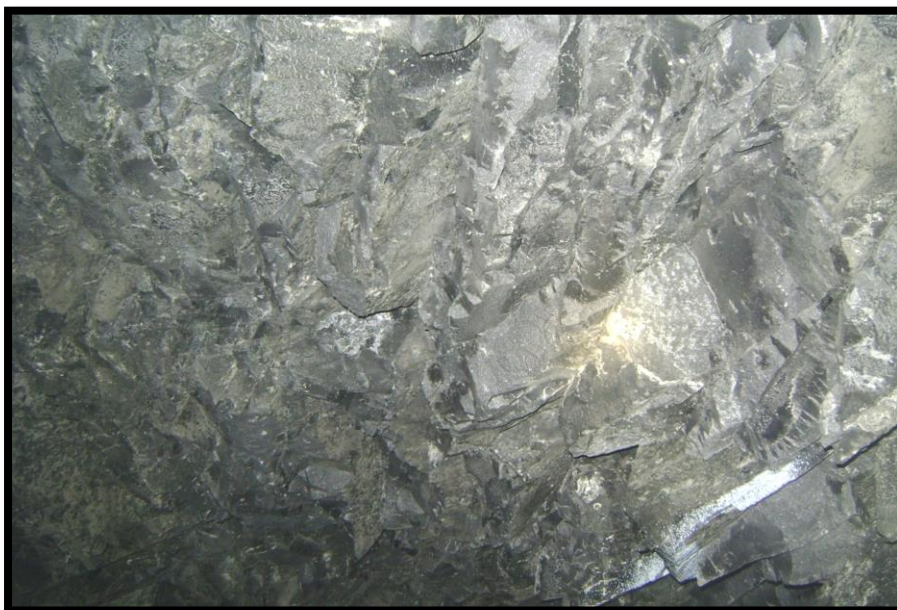


Figure 22 – Exposed dolerite dyke feature within investigation are – Note the blocky hanging wall conditions (W. du Preez, 2016).

4. System to support complex geological features.

The focus of this dissertation is on how geological features in a typical metalliferous mine is supported using support mediums. Each mining operation has a different approach on how to tackle, handle and eventually solve the problem of supporting geological features safely. As each operation will have a different approach the fall of ground preventive system will have the same goal across the board, to safely extract economically viable ore from the ore body in a safe and cost effective manner.

The system within the investigation area has the same purpose. The complex geological features within an underground panel are identified from where support recommendations are issued. These panels and their associated geological features are identified, recorded and monitored for any change or failure in regards to the support of geological features over time. A relationship can be derived from the underground panels where geological features are successfully supported using the system and the issued support recommendations supported versus panels where failure occurred whilst support recommendations were issued. From this success vs failure ration we should be able to determine how effectively the geological features are supported by following support recommendations detailing specific support instructions and mediums.

If there is a failure in terms of supporting geological features within a panel where recommendations are issued within the monitoring timeframe, an investigation will be conducted. The cause of the failure will be determined by the investigation and an alternative approach will be suggested, this will only be done on incident specific panels. We will assume if no failure has occurred within the monitoring period that the recommendations to support the geological features were sound, in most cases mining has long since advanced past these areas within the one year timeframe.

This system is implemented to combat falls of ground hazards due to complicating geological features. The most effective manner in which to combat any fall of ground is either to remove dangerous hang from underground workings or to support these features adequately so that they will not fail after time.

Any system being implemented is dependent on decision making and the classification of risk by the people involved.

Underground personnel are responsible to safeguard their working environments and follow certain procedures for each mining panel to subsequently identify high risk areas. Areas that are classified as “at risk areas” are declared according to the complexities they contain. Underground personnel have a small booklet that outlines the exact criteria for classification of panels based on varying factors including geological features. Red panels and recommendations are issued by qualified role players. The qualified role players forms the investigation team, this team visits all red panels and issue support and mining recommendations.

By continuously implementing a system where complex geological features are identified, visited and support recommendations issued throughout underground workings we can gather related information to create a database. This database will show how geological features are supported, from the support recommendations we will be able to see if different geological features/ ground conditions are supported differently and how effective certain support measure are compared to other ones for specific geological features or ground conditions. The database can be used for analysing and improving the current system for support and subsequent recommendation and to identify possible pitfalls or shortcomings.

The fall of ground procedure in underground workings and the daily implementation and knowhow of the system implemented within the investigation area classifies underground working panels into three categories. Panels are either declared Green, Yellow or Red.

Green panels – Contain no major geological features (dykes, domes, faults etc.) or human induce errors (over breaking, substandard support and poor blasting). Green rating indicated (Panel and Declaration Book). Normal mining can take place with no or very little additional support recommendations. The Miner and Team Leader are comfortable to allow people to enter and work.

Yellow panels – Panels are declared yellow when a panel has exposed poor/unfavourable ground conditions due to intersection of geological features. These features are classified according to a scale (based on geological complexity/features) and then rated (in this case it will be a yellow rating). The Team Leader and Miner are not comfortable with the exposed ground conditions. Panel is declared yellow on the sidewall and barricaded off. It is then reported to the Shift Supervisor. A decision must be jointly made by the Shift Supervisor, Miner and Team Leader on how to negotiate the geological feature. The decision will be communicated to the workforce, indicated in the safe declaration book and overseen by the Team Leader, Miner and Shift Supervisor.

Red panels – Panels are declared red according to classifications (based on geological complexity/features), red panels normally intersected complex geological features. The Team Leader, Miner and Shift Supervisor have agreed that additional support and expert recommendations will be needed in the safe support and future mining of this panel. The Panel has been marked RED, barricaded off and communicated to the workforce. The safe declaration and communication book has been updated. The red panel is then reported to the Mine Overseer of that specific section and a visit is arranged. No work or people may enter that panel until it has been visited by the investigation team and relevant support recommendations issued and completed. Only crews doing the support related work may enter the panel if valid recommendations by the investigation team have been issued. The Shift Supervisor stays responsible for the compliance to the support recommendations and should ensure that all support is installed according to procedure and in compliance with recommendations issued. If the support within the red panel has been completed and signed off by the shift supervisor normal mining can commence.

4.1 System procedure and rating.

A booklet which serves as a complete summary for Falls of Ground is issued to all relevant underground personnel to help in identifying complex geological features and outlining the steps that need to be followed once such features have been identified. This booklet is issued to key underground personnel; this includes Safety Representatives, Team Leaders, Miners, Shift Supervisors, Mine Overseers and Mine Managers. All personnel within the shared services department has such a booklet these include, Surveyors, Strata Control Officers, Samplers, Geologists, Rock Engineers and relevant assistants.

The booklet acts as an aid that can be used to identify geological structures and follow the correct procedures to combat falls of ground. The following section will focus on the identification of geological features and their subsequent rating by referencing and explaining the booklet. The booklet has a detailed discussion outlining the Falls of Ground process, this is important as an understanding of this process gives a sense of the geological features encountered within underground workings and what the effect and reaction will be within the framework of the system.

All mining operations have their own standard of procedure, before any work can take place it is important to apply the relevant standards and procedures. The colour codes on the figure below outlines the steps that need to be taken when green, yellow and red panels are encountered.

Various triggers are classified according to different geological features that can be found within underground workings. The table gives the underground personnel a quick reference to check the specific rating of a panel in accordance with geological features intersected. If the panel has any of these geological features present the panel should be classified according to this rating and the date and rating must be painted on the sidewall.

Triggers are vital within the booklet and forms the foundation of this investigation. Geological features are identified and rated according to their influence and danger towards safe mining. If geological features are misidentified or incorrectly identified the feature will not be supported with support recommendations running the risk of being under-over supported and may incur safety, production and cost implications. This can contribute to falls of ground occurring without any recommendations, the identification of geological features are vital to combat falls of ground.

Classification of geological features occur differently with some features classified on a sliding scale from green to red (safe to dangerous) where other geological features are immediate classified as red (dangerous). Each classification has a defined route of action to be taken.

<ol style="list-style-type: none"> 1. Conduct pre-shift and mid-shift examination, bar and make safe. 2. Install all support required by the mine standard.
<ol style="list-style-type: none"> 1. Barricade off and call the Shift Supervisor. 2. Carry out joint examination with the Shift Supervisor, Miner and Team Leader. 3. Communicate the actions in the safe declaration book/form. 4. Comply with recommendations given by the examining team. 5. Once the panel has been examined by the examination team, it can be declared safe to work under the conditions given. 6. If un-sure, the Shift Supervisor shall declare the panel red.
<ol style="list-style-type: none"> 1. Barricade off and report to the Mine Overseer/Site Champion. 2. Request and take part in a TARP visit with the TARP team. 3. Communicate the actions in the safe declaration book. 4. The TARP team will give support recommendations. 5. Only on completion of the recommendations made by the TARP team, signed off by the Shift Supervisor, will normal work commence. 6. A panel will remain Red until all TARP recommendations have been completed and signed off by the Shift Supervisor.

Figure 23: Guidelines pertaining to different rated panels.

A brow is an abrupt step in the hanging wall extending for more than 2m's. Brows are classified according to their size which determines their respective rating. Domes are immediately classified as red panels due to their risks of FOG's when inadequately supported. Mining operations often mine into the weak sides of "domes" without any exposure of the dome until failure occurs, thus making this geological feature extremely dangerous.

Dykes (magnetic and non-magnetic) are found within underground workings. Dykes are classified according to their thickness within the hanging wall, this thickness is used to give panels where dykes occur a rating. Dykes are found with associating geological features that are often more dangerous than the dyke feature itself.

Shear zones formed within dyke, highly jointed and faulted areas. Dyke features intruded into the planes of weakness of the layered rock and deformed the surrounding rocks due to extreme pressures. These shear zones are found along most dolerite dykes within the area of study (Eastern Limb of the Bushveld Igneous Complex). Multiple jointing often occurs which contains shear zones due to the blocky and brittle nature (amount of jointing in a small area). Serpentine coatings also occur in highly jointed/sheared/faulted areas where the mafic minerals in the rocks have been deformed. These areas are particularly dangerous when water is present.

Faulting within the mining industry is generally classified according to its throw (up or down) seeing as this is the only important aspects in relation to production and safety. Faults with throws of more than 80cm up or down is classified red, this is due to the amount of the chromite layer that may be contained within the hanging wall or the panel running the risk of mining off reef. The correct identification of faults and their respective throws are vital seeing as reef within the hanging wall is only classified as yellow, if a fault is miss-identified and reef in hang is discovered, panel runs the risk failure within the reef chromite layer contained in the hanging wall due to inefficient support.

Low angle joints within underground workings are given a rating based on the dip of the joint features. Dipping joint features form wedges within the hanging wall that needs to be supported, furthermore these structures are complicated by any intersecting geological feature. Potholes are declared red. Pothole features are dangerous due to the fact that the reef is dipping and the reef packages are found within the hanging wall in the underground workings, special support recommendations need to be issued when portholes are intersected.

Pillar failure is a red feature and normally occur where off-line mining occurs. Off line mining refers to areas where the drilling and blasting was conducted into an area where a pillar was planned within underground workings. Steeply dipping reef of more than 12° is classified as a red rating. Steeply dipping reef often occurs where reef rolls or intersection of major geological features such as dykes are intersected. The risk to underground workings with steeply dipping reef is more focused towards the mobile machinery than actual fall of ground risks

Shear zones occur in areas where multiple jointing, faulting and dykes occur and are classified according to their size. Shear zones are areas where serpentine coatings occur, these areas must be closely monitored by mining personnel for any presence of water. Water within mining operations can cause erosion of rocks/features found within the hanging wall and should be immediately upon inspection be classified red. Water poses a huge risk in areas where serpentine coatings are present, the interaction of the serpentine with water causes lack of cohesion between planes subsequently causing failure. Wedges occur in highly jointed areas and can increase in size as barring of the hanging wall takes place. Wedges are classified according to their fallout thickness.

Reef in hanging wall			
Blocky / friable ground			
Dome			
Multiple faulting			
Hanging wall Blasting / TMM Hanging wall damage			
Pillar failure			
Pothole			
Uncontrolled fall of ground			
Water dripping			
Brow	Less than 30cm thick	30cm to 80cm thick	Thicker than 80cm
Dyke	Less than 30cm thick	30cm to 80cm thick	Thicker than 80cm
Fault	Throw less than 30cm	Throw between 30cm to 80cm	Throw more than 80cm
Idle panel	Less than 14 days	Between 14 and 30 days	More than 30 days
Low-angle joint	Less than 25°	Between 25° and 60°	25° to 60° with intersecting geological feature
Reef dip	Less than 12°	Undulating reef	More than 12°
Shear zone	Less than 30cm thick	30cm to 80cm thick	Thicker than 80cm
Stoping width	Less than 2.5m	Less than 1.8m or between 2.5m and 3.0m	Higher than 3.0m
Wedges	Fallout less than 30cm high	Between 30cm and 80cm	Fallout more than 80cm high

Figure 24: Panel ratings for specific geological features and ground conditions.

4.2 The importance of the classification system.

The sole reason for the implementation of a system to classify complex geological features within underground working panels is to combat falls of ground and ensure a safe working environment. The aim of such a system is to act as a fail-safe to ensure all personnel within underground workings work in a safe and supported panel without risk of injury. The importance lies in the ability to identify dangerous/unfavourable hanging wall conditions and adequately supporting them in such a manner that work can continue safely, production targets can be met and fatal injuries due to falls of ground are eliminated.

The system to classify geological features based on their characteristics forms the connection between identifying the geological features and subsequently supporting them. If the geological complex features are not identified, a team consisting of suitably qualified and experienced rock engineering and other relevant mining practitioners will not be able to issue support recommendations. Without support recommendations the crews installing the support will not be able to support the complex geological structure effectively.

5. Standard support mediums used to support complex geological features and adverse ground conditions within metalliferous mines.

The support used in underground workings differ from commodity mined, area and mining method, the aim of the support throughout all environments is to “safely support geological features”. Support within underground excavations including mining is the methods and materials used to maintain/increase the load bearing capacity of the rocks (Hoek and Wood, 1987). This includes the support of complex geological features where specific blocks of rocks or areas are supported to ensure that the rock mass stays self-supporting after support has been added (Hoek and Wood, 1987).

Within the study area the support of complex geological features and the subsequent effectiveness is investigated. Support systems will be specific to geological features identified and supported within the study area. The support measures within the study does not constitute support systems for mining operations as a whole but rather for geological features encountered within mining operations. Fundamental aspects in successfully supporting a underground operation include the understanding and characterization of the ore body to determine geotechnical and rock mass behaviours, the regional effect of stresses and the mining method (“size, geometry and relative orientation of excavations with regard to rock mass and stress field”)(Watson,2004).

To effectively mine an ore body, adequate rock support design need to be in place which include an array of processes and steps; exploration and preliminary design, mine design and support design to name a few (Hoek, Kaiser and Bawden, 1993). These factors are not discussed within the study as the focus is on the support of complex geological features within the current system implemented within the study area.

Underground workings have different standard support systems in place depending on local ground conditions pertaining to a specific investigation area. The support systems are also influenced by the mining cut, mining width and height along with the mining method. Mechanized Mines within the Eastern Bushveld Complex mining bord and pillar have similar standards that they need to comply with to ensure safe conditions for workers. Support systems are generally tailor made for each specific mining operation and signed off by the Rock Engineer.

The focus of the investigation is on how to effectively support complex geological features within red panels (support recommendations issued by experienced rock engineering and other relevant mining practitioners) and whether these features are adequately supported. The discussion below will highlight the different forms of support commonly used within the investigation area along with support commonly used in less complex to complex geological settings.

Standard working procedure within the investigation area dictates that before any support can be installed within a mining panel, temporary support with safety nets need to be installed to ensure that the installation of the permanent support is completed under the protection of the temporary support (safety net and camlock jacks). This enables the workers to always work under supported hanging wall conditions albeit temporary until permanent support is in place, hereafter the face will be drilled, charged and blasted. It is important to remember that whenever a panel encounters adverse geological features it should be classified according to the geological features it contain. Normally a panel is declared via the classification system after which barring and the installation of temporary support takes place if the panel has been declared green and upon barring and installation of temporary support geological structure caused the panel to be red it should be re-declared red and an investigation visit should be scheduled.

This section will broadly discuss the different types of methods and/or recommendations used when supporting complex geological features. The methods and support materials used will be discussed in both their use and importance within underground workings. If a support medium/measure has any shortfalls they will also be discussed, it is important to remember that all support measures will have shortfalls when implemented incorrectly or to support a feature it was not made to support. The support of the geological features within the hard rock environment will be in line with support measures used in different hard rock operations, the basis of supporting features in hard rock mines will stay the same if the same stratigraphic chromite layers are mined and/or similar geological features are encountered.

Temporary support used within underground workings consist out of mechanical (camlock) jacks and safety nets. Temporary support is installed to act as a support measure while installing permanent support. This measure has deemed to be highly successful and have saved countless lives. This procedure is a standard within the investigation area, the installation of temporary support has no connection with specific ground conditions or geological features.



Figure 25: Temporary support with safety nets to act as support for the installation of permanent support.

5.1 Support Material

5.1.1 Resin Anchored roof (rock) bolts

Resin anchored roof (rock) bolts are the most common type of support used within the investigation area. Generally the rock is solid, hard and intact despite local geological features, these roof bolts have no problem to “grip” within the hanging wall rock mass (Hoek and Wood, 1987). The strength of the surrounding rock mass improves with the installation of a roof bolt (Van Heerden, 2007).

Some areas where geological features occur such as highly sheared fault zones where the cohesion between rocks have been altered by high pressure environments cannot be successfully supported with mechanised roof bolts alone. On installation of the bolts they spin within the hanging wall without offering any “grip” and in turn load bearing capacity (Hoek and Wood, 1987).

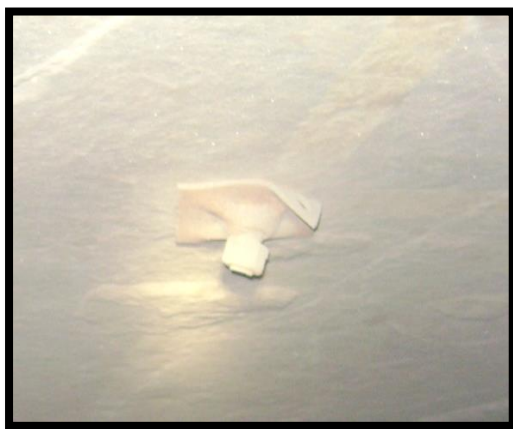


Figure 26: Roof bolt used as a minimum support measure within mining panels (W. du Preez, 2017).

Normal support procedure within underground workings in the study area dictate that the hanging wall should be supported by roof bolts spaced not more than 1.5m apart starting no less than 0.5m from the side wall. These bolts are highly effective in the support of loose rocks, blocks and wedges seeing as they only penetrate 1.2-1.4m into the hanging wall. Tensioned roof bolts are effective as a support measure within underground workings and are easy to install when compared against other support mediums.

Roof bolts within the investigation area are 1.5m in length. Roof bolt support is used in all underground workings and more often than not support recommendations are made in addition to the roof bolts. Roof bolts serve a great purpose in the sense that it keeps the immediate hanging wall stable and can easily support geological features that do not have a major impact on mining, features such as wedges in jointed areas and brows smaller than 80cm are easily supported by rock bolts. Roof bolts can broadly be viewed as the minimum support a mining panel will have within the investigation area.

Despite the effective use of resin anchored roof/rock bolts there are some drawback in the use of this support measure for some geological features. Fault zone areas have proved these rock bolts unsuccessful as a support measure (dependant on amount of altered rock within faulted area). The rock bolts also lose effectiveness within time due to concussion caused by blasting, the continued blasting caused the tension with the rock bolt to decrease losing its effectiveness.

If the bolt breaks or “slip” occurs during concussion the rock bolt is void with no support strength. The effect of concussion on rock bolts is only applicable after long periods of time, normal mining advances have taken mining crews far past areas decreasing the impact of this drawback. The rock bolts are often installed in areas where water is present. These bolts form a perfect conduit for water to travel along towards the excavation, when these bolts are in contact with water normal chemical reactions dictates that the bolts will start to rust. The amount of water and oxygen present will determine the rate of rust on the bolt but some bolts may be rusted to ineffectiveness in terms of support (Hoek, Kaiser and Bawden, 1993).

5.1.2 Grouted Cable Anchors

Cable anchors vary in length from 3.5m -6m within the study area. Cable anchors are similar in purpose to that of a roof bolt but can support larger geological features and add to the load bearing capacity of the immediate hanging wall (Hoek and Wood, 1987). Grouted cable anchors are used to support large geological structures, structures a roof bolt would not be able to support both due to the length of the anchor and the load bearing capacity.

Mechanical end anchors are steel cables varying in length. The anchors used within the study area has a washer, breather, sealing sponge and filler tubes and shell anchor (expansion shell) (M and J Mining – Cable Anchors). The grouted cable anchors are pre-tensioned until a specific load has been reached, (mechanically – until a pin indicates the desired tension load/load indicator) where after the hole is then cement grouted. (Hoek and Wood, 1987).

Cable anchors are commonly used in red panels to support the weak sides of domes (wedges) and large brow features. Cable anchors penetrate deeper into the solid hanging wall (rock), this creates a more stable and solid hanging wall area. Cable anchors are also very effective within hard rock mines due to their flexible nature, roof bolts cannot bend and consists out of a rigid piece of cylindrical steel. Cable anchors are formed by multiple thin cylindrical strands of steel that are flexible, in other words a 4m cable anchor can be used in a mining panel with a stoping width of 1.8m at 90° to the hanging wall (Hoek and Wood, 1987).

Grouted cable anchors are also used in pre-planned hanging wall excavations; these are areas such as tips and head sections to support the immediate and surrounding hanging wall. When supporting complex geological features or poor ground conditions in general, grouted cable anchors are very efficient support mediums.

In cases where the incorrect tension is applied the grouted cable anchor will not achieve adequate load upon installation, the effectiveness of the grouted cable anchor depends on the installation thereof (Van Heerden 2007). The correct hole diameter is also vital in the installation of cable grouted anchors depending on the cable grouted anchor used within the study area (Hoek, Kaiser and Bawden, 1993).



Figure 27: Grouted cable anchor support within underground workings (J, Bezuidenhout, 2017).

5.1.3 Aerial Coverage

Applications such as Shotcrete, Thin Skin Liner (TSL) or Tunnelguard constitutes aerial coverage, these applications are applied via high pressured machines to the hanging wall area. If applied correctly aerial coverage acts as a “cement” blanket that covers the hanging wall and all previously installed material. The support strength of the applications vary in product and the thickness to which it is applied but it is generally viewed as secondary support measures. Aerial coverage plays a vital role in stopping the oxidation and eventual degradation of the rock face/hanging wall area, this in itself goes a long way in supporting geological features (Van Heerden, 2007).

5.1.3.1 Shotcrete

Shotcrete is a term used to describe a mixture of cement, fine aggregate and sand that is applied to the hanging wall area and have been used in tunnel support since the 1930's. Technological advancement within underground support has seen silica fume used in cementitious mixture as well as steel fibre re-enforcement (Hoek, Kaiser and Bawden, 1993).

Shotcrete is used as aerial coverage to ensure that features within the hanging wall don't deteriorate. Shotcrete cannot be deemed as a primary support measure in the sense to prevent a fall of ground but rather a secondary support measure as aerial coverage to cover areas where bad ground conditions occur, despite this studies have shown that shotcrete can provide "effective support in mild rockburst conditions" (McCreath and Kaiser 1992, Langille and Burtney, 1992). Shotcrete is applied in different thickness depending on the desired outcome and geological conditions within a mining panel.

Shotcrete is applied in areas where blocky ground conditions occur within the study area, this includes areas where multiple cross cutting joints occur, dyke areas and areas where shearing within joint sets occur. The strength and application to which shotcrete can be used is often underestimated with current shotcrete mixes consisting out of re-enforced steel particles with effective and easy to apply applications throughout the mining environment. The only drawback with shotcrete is that a specialized crew needs to apply the correctly mixed shotcrete. If there is too much water with the mixture it loses some of its effectiveness, not enough water has a thick heavy sludge mixture as a result that is unable to be applied to the hanging wall.

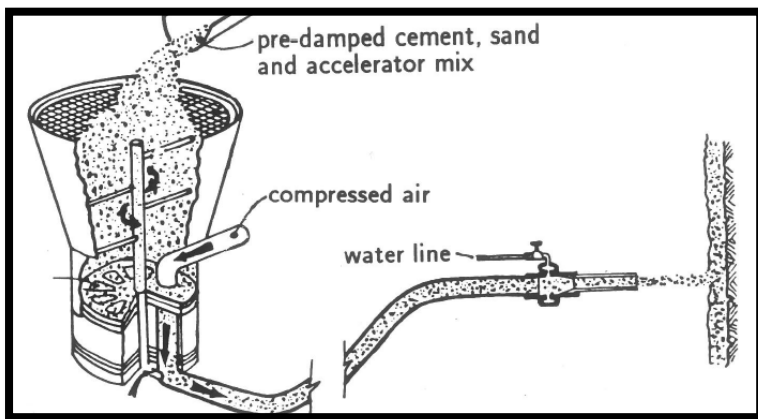


Figure 28: Process of shotcrete application (Hoek and Wood, 1987).

5.1.3.2 TSL (Thin Skin Liner)

Thin skin liner is similar to shotcrete in the sense that it is used as aerial coverage to ensure that features within the hanging wall don't deteriorate and oxidation does not take place. TSL has a higher viscosity than shotcrete and is applied in thin layers rather than the thick layers of shotcrete, TSL penetrates the cracks and joints within the rock mass, which locks the key blocks (Van Heerden, 2007).On the mine where the investigation was carried out TSL was not used as a support medium, but rather to ensure that deterioration and oxidation of the hanging wall does not take place and hence to reduce the likelihood of a Fall of Ground (FOG) to occur over time (Van Heerden, 2007).

5.1.3.3 Tunnelguard

Tunnelguard is a product that can be viewed as a combination of shotcrete and TSL. Tunnelguard only needs to be applied in thin layers on the hanging wall but has similar strength properties to that of shotcrete. Tunnelguard has the same drawbacks as the other aerial coverage applications in regard to the mixing of the product and eventual application.

5.1.4 Timber Elongates (Sticks)

Sticks comprise out of treated building sticks as used in the construction industry. These sticks aren't commonly used as permanent support in tunnels of board and pillar mining due to their nature of eroding and losing strength when water is present. Sticks are often bumped by underground vehicles moving them and causing the support void. Sticks as a support measure will always be used in combination with other support measures.

5.1.5 Straps/Mesh

Straps and mesh are similar measures that are in place to support the recommendations issued for areas where multiple loose wedges, loose blocks, brow faces and blocky ground conditions occur. Osro straps, steel straps and mesh netting acts as hanging wall surface support measures (Van Heerden, 2007). These support features are almost always accompanied by additional measure such as long anchors, bolts etc. (Van Heerden, 2007). Osro straps and mesh differ only in the sense of the geological feature/bad ground area that needs to be supported, if it is an entire area mesh will be used due to the additional coverage it offers when compared to osro straps.

Straps mentioned above are used in the form of osro straps within the project area. Generally osro straps have a higher load bearing capacity than mesh, both measures are always installed in combination with other support measure within the investigation area.

If mesh is installed the area is generally covered with aerial coverage mechanisms such as TSL, Tunnelguard or Shotcrete to ensure that the erosion and oxidation on the rock face (hanging wall) is minimized, this will also ensure that no small loose rocks will dislodged from the hanging wall. The correct application of aerial coverage on areas where mesh and or osro straps are installed is vital, the entire hanging wall as well as the mesh installed should be adequately covered. The installation of mesh may sometimes pose a challenge due to the difficulty in handling the mesh material and effectively pinning it to the hanging wall, often times it is not pinned tightly to the hanging wall and creates pockets where small loose rock fragment accumulate and will eventually need to be removed due to the risk of the mesh area failing.

The installed mesh should be firmly attached to the hanging wall by washers/face plates on the rock bolts/cable anchors (Hoek, Kaiser and Bawden, 1993). In some cases within the study area increase face plates (area) are used to increase the influence of the face plate.

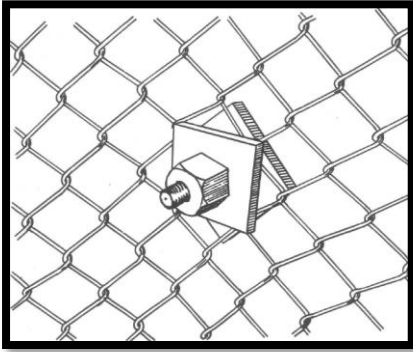


Figure 29: Mesh support within underground workings (Hoek and Wood, 1987).

Osro straps are used in underground workings within the area under study where specific features or smaller areas need to be supported (Hoek and Wood, 1987). Osro straps are used where multiple joint sets all occurring in one orientation are intersected. These joint zones form wedges within the jointed area and are perfect examples of where osro straps will be used. Straps will be installed perpendicular to the orientation of the joint sets to ensure that the wedges within the joint sets are supported (Van Heerden, 2007).



Figure 30: Osro Strap support used within underground workings (L. Meyer, 2017).

5.1.6 Sets

Sets are pre-designed structures made predominantly out of steel. Sets are recommended when very poor hanging wall conditions are experienced often in association with a major geological feature, such as a major fault zone with highly friable hanging wall conditions due to the deformation of the hanging wall rock. Sets are very effective within poor ground conditions but are expensive and only used as a last resort within the project area. Sets are installed in areas where permanent movement of people and machinery will take place. Sets are used so that if hanging wall failure occurs the strength of the set will keep the failed hanging wall “up” and in this effectively be the new hanging wall (Hoek and Wood, 1987).

Supporting the hanging wall takes place in two major forms, supporting the hang with measure that will prevent it to fail and secondly supporting the hang with measures so that when it fails it will still be safe (active vs passive support) (Hoek and Wood, 1987).

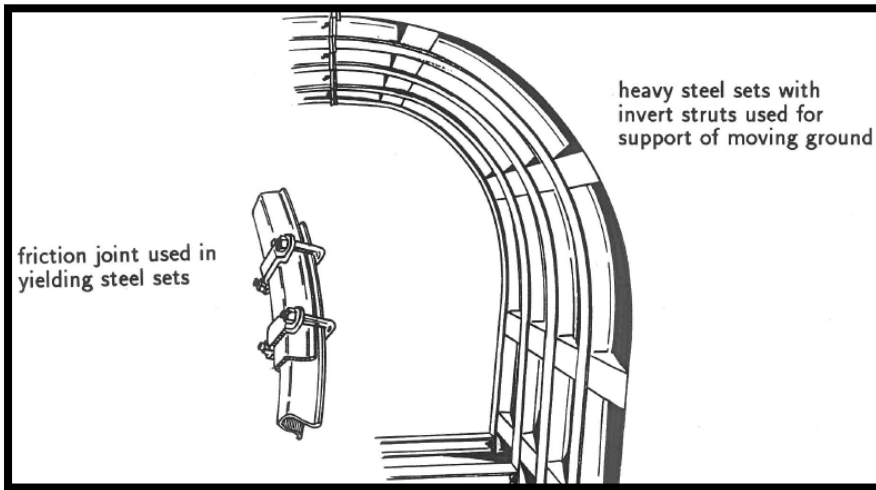


Figure 31: Pre-designed sets as a support measure within underground workings (Hoek and Wood, 1987).

Sets are used in areas where the hang will most likely fail in time and if so there will be no effect on mining practises or the safe work of personnel within this area. The installation of sets need to be done by a specialized and trained crew to ensure that there are no weaknesses within the structure. Once the hanging wall has failed the pressure of the hanging wall will rest solely on the installed sets. The weight of the overlying rock may be immense and any weakness within the sets will cause failure of the sets and eventual failure within the mining panel.

Sets are normally regarded as a last resort when it comes to supporting complex geological features and most often used in areas where permanent structures are going to be installed (main declines, belt development and travelling ways). If ground conditions constitutes the installation of sets alternative areas/measure are often sought due to the cost and safety implications, despite this sets are highly effective in supporting complex geological features across large areas.

5.2 Support and Mining Recommendations

5.2.1 Increase Roof Bolt Density

The density distribution of roof bolts are increased in areas where adverse ground conditions occur. Highly jointed areas with multiple wedges within the hanging wall are supported by installing additional roof bolts in loose wedges. Roof bolts are also increased in areas where major geological features occur, these bolts are drilled into the hanging wall adjacent to a feature from all sides.

5.2.3 Stop/Barricade Mining Panel

When a panel is visited and adverse ground conditions are experienced to such an extent where mining cannot be conducted in a safe and productive manner panels are normally stopped and barricaded. These panels can be temporarily barricaded or permanently barricaded depending on the recommendations issued.

5.2.4 Reduce Mining Span

The span of underground mining panels are reduced in cases where waste mining will occur or when mining through a major geological feature such as a pothole or a dolerite dyke. Panels are currently spaced at 8m, when spans are reduced they are normally decreased to 5m, 6m or 7m.

5.2.5 Re-establish Mining Panel

When a panel is visited and adverse ground conditions are experienced to such an extent where mining cannot be done in a safe and productive manner panels are normally stopped and barricaded. If these panels are necessary to mining operation and the adjacent panels have good ground conditions they will be used to re-establish into the temporarily barricade panel.

5.2.6 Specified Face/Hanging wall Blasting

Specific blasting is used in panels where specific features or areas need to be changed or modified to ensure safe mining can take place. Specified blasting is also used in areas where off line mining or off grade mining has occurred.

6. Investigation on geological structures supported using support recommendations.

Different case studies were analysed during the investigation to give a broad sense of what geological features were supported using support recommendations by the experienced rock engineering and relevant mining practitioners. All the information obtained from the reports were analysed and used to determine a relationship between the geological features and the support measures used. The success rate of supporting geological features was also investigated by comparing the successfully supported geological features to the failed geological features within the investigation period.

During the investigation period multiple underground visits were conducted to 445 underground panels where complicating geological features were identified. Some of the 445 underground panels were visited on multiple occasions as the panel was progressing through the complex geological feature. Each underground panel was issued with support recommendations. These panels were supported according to the issued recommendations and monitored for the entire investigation period (January 2016-December 2016) to determine whether the geological features were successfully supported.


Within the dissertation one case study will be explained from start to finish, the chosen report will include a detailed explanation from both a geological and support point of view. 10 additional reports will be included in the appendices of the dissertation for further analysis. The manner in which the case study is presented is the same manner in which all the other investigations were conducted and reports compiled.

Due to the size of the database and the amount of visits conducted it is impractical to discuss each report individually. Results, analysis and information obtained from the entire database will be used to reach a conclusion on whether the aims and objectives have been achieved. The statistics regarding the database will also be discussed briefly as to give comprehension on the amount of information processed during the investigation.

Table 4: Relationship between amounts of visits conducted per month.

	Red panel visits conducted
January 2016	21
February 2016	35
March 2016	54
April 2016	46
May 2016	42
June 2016	35
July 2016	35
August 2016	59
September 2016	65
October 2016	19
November 2016	8
December 2016	26
Total	445

6.1. January case study.

Complex Ground Features	Dome	Dyke	Pothole	Blocky Ground	Wedges	Water	Low Angle Joints	Faults	Shear Zones	Brow	Blast Damage	Over break	Substandard Support
REACTION	Anchors	Shotcrete	Tunnel guard	Increase Bolt Density	STOP/ Barricade	Reduce Span	Re-Establish	Sticks	Specified Blasting	Straps/Mesh	Additional support	Other	
OBSERVATIONS AND RECOMMENDATIONS													
Idle Panel that was not mined for more than 30days.													
Blocky hanging wall conditions present due to multiple cross cutting joint features intersected by a shaer zone along mining direction.													
Recommendations:													
Clean the area of all muck before support work commence.													
Barr all wedges, partings and the entire shear zone area within the hanging and side wall to solid.													
Install Osro straps prepindicular to shear zone, space the osro straps 1m apart along the shear zone.													
Reduce bolt spacing/increase bolt density, ensure that 1m bolt spacing pattern is not exceeded.													
Replace all damaged support and potruding roofbolts.													
Apply 50mm thick shotcrete aerial application as follow: Start 3m in front of Shear Zone feature intersection and apply shotcrete up untill the face of the panel.													
Take one blast and recall the investigation team to re-asses the panel.													
													

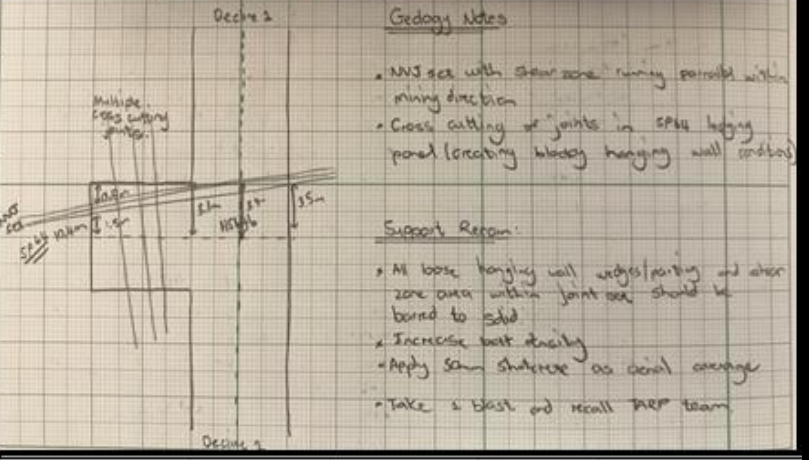
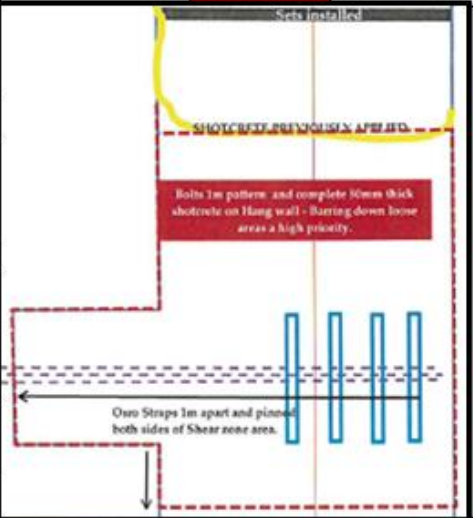


Figure 32: Case study January 2016.

- Geological features:**
- Near Vertical Joints (70°-90°).
 - Shear zone within NVJ set.
 - Cross cutting joint set.
 - Blocky hanging wall conditions.

- Support recommended:**
- Specified blasting (blast/barr down all reef in hang)
 - Reduce bolt spacing / Increase bolt density.
 - Install steel straps.
 - Apply shotcrete as aerial coverage.

The case study chosen for discussion within the dissertation pertains to a mining panel that was declared red due to the fact that no mining has taken place in the panel for the previous 30+ days. Before mining in this panel could commence a visit needed to be conducted to ensure that once mining commences it will be in a safe and supported panel.

Upon inspection of the underground panel by the investigation team, multiple cross cutting joint features were observed. The near vertical joint set had a shear zone (10cm-40cm) within the jointed planes, this near vertical joint set was cross cut by multiple prominent joints. The highly jointed area caused blocky hanging wall area to form.

The mapped geological structures were updated on the mine plans from the geologist's underground mapping notebook. Near vertical joints (70° - 90°) present within panel were recorded and duplicated on the mining plans. Shear zones evident within NVJ sets were also recorded and plotted on relevant plans along with the shear zone and jointing running parallel with mining direction. The cross cutting of near vertical joint set by other joint sets created blocky hanging wall conditions, relevant information was updated as shown on the figure below.

The support recommendation for the underground panel included the blasting/barring down of all loose hanging wall material. The barring of the hanging wall is essential to ensure that whatever the recommendations are that follow that they occur within a safe area where all the loose rocks have been barred down. The panel has no major geological features other than multiple joint sets, an increase bolt density (normal + additional) will ensure that all blocks and wedges formed by the joints are safely supported.

Lastly it was recommended that steel (osro) straps be installed across all the major joint features to ensure that the wedges in-between the joints are adequately held by the support measures. All of these recommendations need to be completed and then followed by the application of shotcrete as aerial coverage to enhance all the recommended support and ensure that no loose rocks or fragments thereof run the risk of falling from the hanging wall.

As this discussion was only based on one visited out of the 445 conducted it is important to look at a breakdown explaining the amount geological features that were identified, inspected and support recommendations issued for. It is just as important to investigate the different support mediums used throughout the investigation period. By analysing the amount of geological features and the specific amount of support mediums used with reference to all 445 underground case study reports a relationship can be derived. This relationship will give an indication on how certain geological features are supported for instance as the amount of "dome" features increase so will the amount of grouted cable anchors support.

6.2 Breakdown of complex geological features supported during the investigation period.

A breakdown of all the visit conducted on a monthly basis and the associated geological features gives an indication on the amount of geological features that were investigated and monitored during the investigation period. From the table below it is evident that 445 underground panels were visited during the investigation period. More than one visit can be conducted within a day and for the purpose of simplification, a visit is defined as a visit by the investigation team (consisting out of a Geologist, Strata Control Officer, Shift Supervisor and Mine Overseer) to a specific mining panel. If more than one panel is visited, it will be noted as multiple visits (more than one underground panel visited).

Table 5: Breakdown of geological features encountered during the investigation period.

TARP Report Number	Amount of Panels Visited	Geological Features - Red Triggers														
		Dome	Dyke	Pothole	Blocky Ground	Wedges	Water	Low Angle Joints	Faults	Shear Zones	Brows	12° + dip	Reef Roll	Idle ≥30 days	Height	Other
Jan-16	21	2	3	6	9	17	0	3	2	4	3	1	0	1	2	9
Feb-16	35	6	8	1	11	13	0	11	1	4	17	0	1	2	3	4
Mar-16	54	11	1	0	11	25	0	10	2	4	9	0	2	10	4	13
Apr-16	46	10	4	1	10	31	1	7	2	2	20	1	3	7	7	20
May-16	42	12	3	1	10	28	0	9	3	5	9	0	0	5	0	12
Jun-16	35	13	2	2	10	25	0	2	3	3	22	1	0	0	2	4
Jul-16	35	13	6	1	11	29	1	7	5	5	18	1	1	0	0	1
Aug-16	59	17	5	2	24	34	1	9	23	4	23	0	0	3	4	17
Sep-16	65	19	11	3	25	35	0	8	14	5	15	0	2	2	0	9
Oct-16	19	6	2	0	6	18	0	5	8	2	14	1	0	1	2	4
Nov-16	8	1	0	0	3	0	0	1	0	2	1	0	0	0	0	0
Dec-16	26	9	2	0	8	18	4	8	5	3	8	0	0	1	0	3
	445	119	47	17	138	273	7	80	68	43	159	5	9	32	24	96

Another table depicting the support materials used throughout the investigation period is included below. An interesting aspect to note is that the amount of grouted anchors are directly linked to the amount of thrust fault features and U/T faults encountered. A relationship between the amounts of support materials used during certain months where specific geological structures have been encountered can be determined upon further analysis of the data but for the purpose of the research the focus will remain on the geological features.

Table 6: Breakdown of recommended support response during the investigation period.

TARP Report Number	Amount of Panels Visited	Recommended Support - Response										
		Anchors	Shotcrete/ Fibre Crete	TSL	Reduce Bolts Spacing	Additional Support	Stop/ Barricade	Reduce Panel length	Straps	Sticks	Specified Blasting	Re-establish Face
Jan-16	21	5	7	0	17	8	1	2	1	0	6	0
Feb-16	35	14	7	3	20	8	4	5	8	0	6	0
Mar-16	54	14	3	8	19	12	6	10	4	0	15	0
Apr-16	46	27	4	4	19	21	1	6	7	0	21	0
May-16	42	15	10	5	21	16	6	7	7	1	13	0
Jun-16	35	18	8	5	21	21	4	10	2	0	8	0
Jul-16	35	22	7	7	14	24	5	7	3	0	10	0
Aug-16	59	33	17	6	34	23	5	11	4	0	20	0
Sep-16	65	32	11	9	38	21	9	12	3	0	24	0
Oct-16	19	12	4	1	13	13	5	10	4	0	11	0
Nov-16	8	5	1	3	0	0	1	1	0	0	0	0
Dec-16	26	16	0	5	13	8	6	6	5	0	11	0
	445	213	79	56	229	175	53	87	48	1	145	0

From the tables above we can easily determine the amount of geological features throughout the investigation period and different support measure issued in general per month. The visit remain the focus point of all recommendations and the tables are for statistical purposes alone, the discussion on how the geological features were supported within the investigation remains the main aim.

If a relationship between the geological feature encountered and support measure issued can be derived from the tables above it will be included in the general founding in term of supporting complex geological features that will be discussed later within this section.

When the geological features that caused the red triggers are broken down as displayed in the table above it is clear that the majority of all geological features found in the Eastern Limb of the Bushveld Igneous Complex are encountered within the investigation area. For all of these geological features there are site-specific recommendations to ensure that they are adequately supported. This database will then form the basis on a general approach on how geological features were supported throughout the investigation area. When the success rate and the general approach to support these features are analysed together we will clearly see how effective the complex geological features are supported.

6.3 Success rate of supporting geological features.

During the investigation period where the geological structures within red panels were visited, recorded and supported 445 mining panels were visited. Each of these panels were classified red according to the rating system and a visit by the investigation team was conducted. Upon the visit, the team issued recommendations, which was subsequently completed and signed off by the Shift Supervisor.

The success of the supporting of complex geological features over the period of one year can be measured against any failure/lack of supporting geological features. During the investigation period, only one mining panel experienced a situation where the system failed causing the geological features within that mining panel to fail. This panel will be analysed in the next section of the investigation.

When comparing the adequately supported geological features to places where failure occurred, it is clear that the geological features are adequately supported. From 445 visits conducted during the investigation period only one panel experienced less than desired results. This gives the support of complex geological features within the investigation area a success rate of more than 99% during the investigation period.

6.4 Failure of supported geological feature case study

If failure occurs within an underground panel containing complex geological structures where support recommendations have been issued a follow up/fall of ground visit was conducted to determine the cause of the failure.

The support of complex geological features throughout the investigation were successful but not without challenges, one underground panel containing complex geological structures experienced failure. The geological feature along which hanging wall failure occurred was the only unsuccessfully supported geological feature within the database and investigation period over the duration of a one year period.

The underground panel in which hanging wall failure occurred was due to a wedge shaped rock that dislodged along the contact plane of a dolerite dyke feature that runs oblique to the mining direction. Failure occurred as a result of water seepage along this particular area of the dyke. The fall-out included part of the dolerite dyke and part host pyroxenite rock.



Figure 33: Photo indicating the extent of the dislodged rock and water within hanging wall rocks- Note the serpentinite coating along exposed planes.

Water seepage has made its way from the water table down into the rock mass using the dolerite dyke and adjacent area of weakness as a travelling way due to heavy summer rains. Water was dripping from the hanging wall into the excavated mining panel. On the original visit no water was present within the hanging wall, recommendations on how to support the dolerite dyke area were issued and mining commenced. The wedge feature was still within unmined ground, mining progressed into this ground after the visit was conducted. Heavy rains occurred after the original visits and water seepage occurred deteriorating the conditions of the rocks and the planes between the dyke and associated area of influence to such an extent that failure occurred.



Figure 34: Photo indicating the extent of the dislodged rock and water within hanging wall rocks- Note the serpentinite coating along exposed planes.

Previous visits to this area identified the hazard and poor hanging wall areas where the dolerite dyke was intersceted were barricaded. The water was not identified early enough coupled with a highly jointed area, especially with the joint sets running parrallel with the dolerite dyke and being cross cut by another joint set running obliquely across the panel failure occurred. Exposed joint planes were covered by fairly thick serpentinite coating and the water seepage did reduce cohesion along contact planes. The most improtant lesson to learn form this is that the effective identification of geological features and continued monitoring thereof plays a vital role to ensure no failure of complex geological features occur.

6.5 General support recommendation issued per geological feature.

The majority of the red panels encountered during the investigation share similar properties and conditions if similar geological features are encountered. From the 445 underground visits conducted to complex geological structures to issue support recommendations, similar support recommendations were issued for similar geological features or ground conditions. From an analysis of the databases of visits, the geological features intersected and the support material used to support these geological features we can establish a relationship between the geological features and support mediums for the investigation area.

For example, if a panel has multiple jointing be it in different sections chances are the amount of joints will influence the immediate hanging wall to such an extent that large amount of loose wedges and blocks will be present within the hanging wall, these features will create a blocky ground environment. Upon barring the jointed features, loose rocks will be dislodged from the hanging wall forming brow features. These conditions will be encountered by the majority of the panels where cross cutting joints occur, the same applies for panels where faults, potholes, thrust faults, reef rolls and dolerite dykes occur in terms of general support recommendations.

The approach to different ground conditions and the general support measures that will be used within those ground conditions will be displayed by the use of a table, these approaches will then be connected with the geological features that will form in those conditions. The relationship between general geological conditions and the support measure for the resultant ground conditions can then be determined.

Despite the relationship between complex geological structures and methods to support them it remain important to conduct site specific investigations for each geological structure. Similarities exist between methods of support for certain features, these similarities were all based on individual visits to each feature, from this we can determine that the standard of implementing recommendations are sound. There will still be certain cases where geological feature will not fall within the broad support system for a certain structure due to varying factors from panel to panel.

The investigation revealed that general geological features and ground conditions are supported in a certain manner based on characteristics. Panel's displaying similar characteristics are supported in a similar fashion. The similar support recommendations proofs that all features are supported adequately but it remains of utmost importance to continually visit each individual geological feature and issue site specific recommendation. From these recommendations the database can be updated and analyzed for future improvements.

Table 7: Relationship between ground conditions, general support recommendations and geological features.

Ground/Rock (hanging wall) conditions	General support recommendations	Geological features present within such areas.
Solid, intact hanging wall conditions with little to no geological features. Defined mining cut maintained by accurate blasting and well defined sidewall at right angles to the hang- and footwall.	Normal roof bolt support spaced 1.5m apart.	No/little geological features. If joints are present they are not prominent and have no effect on mining.
Irregular hanging wall conditions due to the presence of minor geological features (these panels will be green or Yellow).	Normal and additional roof bolt support.	Geological features such as joints, minor faults and shear zones. Features occur independently from one another.
Irregular hanging wall conditions with multiple geological features, creating blocky ground conditions with wedges.	Normal and additional roof bolt support. Additional Mesh/steel straps if necessary. Aerial coverage application.	Multiple cross cutting geological features such as joints, minor faults and shear zones.
Poor hanging wall conditions with parting planes separating. Displacement or loss of reef and specific recommendations in terms of support is required. If support measures are installed within the hanging wall they still grip and act as support measures.	Normal and additional roof bolt support. Grouted cable anchors as primary support measure. Additional Mesh/steel straps if necessary. Aerial coverage application.	Potholes. Reef Rolls Major Faults Dolerite Dykes with displacement,
Multiple complicating geological features within slid hanging wall conditions. The hanging wall is solid in the sense that support measures can be effectively installed but is complicated due to amount of geological features.	Normal and additional roof bolt support. Grouted cable anchors as primary support measure. Additional Mesh/steel straps if necessary. Aerial coverage application.	Multiple cross cutting features such as joints, low angle joints, thrust faults, shear zones, faults and dykes.
Extremely poor and friable ground conditions were the host rock has been altered due to high pressure/temperature environments. Little to no cohesion between rock mass. No support measure grips within the hanging wall.	Installation of pre-designed sets. Additional Mesh/steel straps if necessary. Aerial coverage application.	Major fault zones. Major shear zones. Major dolerite dyke areas

Despite the relationship between geological features and the support recommendations issued it remains vital that all support recommendations of complex geological features be based on underground visits by experienced rock engineering and relevant mining practitioners. The database proves that certain complex geological features are supported in a similar manner when considering all 445 visits. Despite this, the database was constructed using information obtained from underground panels where complex geological features occur. The mining operation adhere to the normal support procedures and the rating of underground panels. The rating of the panel (green, yellow or red) will determine the actions to be taken as well as who will be responsible for the issuing of recommendations (escalation of responsibility). Complex geological features within underground panels rated Red are supported by issued support recommendations by experienced rock engineering and relevant mining practitioners.

7. Conclusion

Mining throughout the Bushveld Igneous Complex faces challenges in regards to the safe support of geological structures. Falls of Ground poses a massive risk to safety and production of any mining operation and programmes to eliminate fall of ground must be effective and implementable. The investigation focused on geological features encountered at Helena Chrome Mine in the Eastern Limb of the Bushveld Igneous Complex (Bushveld Igneous Complex). It is probable for the findings within the investigation to be applicable to neighbouring mines in the Eastern Limb of the Bushveld Igneous Complex with a specific focus on hard rock mines mining on a Bord and Pillar method.

From the monitoring it is clear that the majority of complex geological features where support recommendations were issued are safe and continued to be safe for underground work to take place throughout the monitoring period. During the investigation period failure within the hanging wall of an underground working panel occurred only once.

This incident occurred due to the sudden presence of water within the underground working panel along a major dolerite dyke intrusion with parallel running joint features. The water coupled with the presence of serpentine infill between the dyke contact and joint planes caused a decrease in cohesion between the joint planes along which failure occurred. A visit to the area was conducted and subsequent to the visit water appeared where after hanging wall failure occurred. The recommendations were issued before the water was present in the hanging wall area. The implementation of the support system in terms of identifying the water seeping from the hanging wall did not take place, this was the root cause of the failure seeing as if the water was identified and procedure followed another visit to the area would have been conducted.

Safety within the workplace forms an integral part in the success of a mining operation. The sole purpose is to ensure that all work being done in underground workings are done in a safe manner with no or minimal exposure to risk. Throughout the research, the focus was on the supporting complex geological features. The results clearly show the effectiveness of the support recommendation issued for complex geological structures. Despite the high success rate of the supporting geological structures accidents still occur and failure of the hanging wall still takes place (varying in degree).

The conclusions are based on all available data used within the investigation period taking into account the types of geological features supported, the amount of support recommendations issued as well as the success rate in terms of supporting complex geological features within the study area.

The conclusions can be summarized in alignment to the aims as set out in the beginning of the investigation:

- Different geological features are supported using different support structures/mediums. The most effective manner in which to support complex geological structures is to identify, investigate and eventual issue support recommendations pertaining to each specific complex geological structure.
- The support recommendations will vary both from geological feature to geological feature as well support recommended for the same feature in different areas (due to difference in extent, orientation and influence) between the same type of geological feature. There is no “one size fits all” solution to supporting complex geological features.
- Failure of support within geological features and underground workings can still occur despite all precautions and procedure due to human error/lack of judgement or misidentification of complex geological features. The focus should be on how to eliminate all possibilities of failure of supported geological features.

This dissertation proves that complex geological structure can be supported safely within underground workings if the geological features are identified and flagged according to their triggers and correct support recommendations are issued and implemented. Therefore, it can be reasoned that the geological structures found throughout the Bushveld Igneous Complex, South Africa can safely and adequately be supported to ensure a safe, profitable mining operation. The safe support of such complex structures also depend on the support system being used, if there are shortfalls in the support system and its implementation there will be shortfalls in the support of the complex geological structure. With all processes, human factors and errors should be considered.

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Appendix

Appendix 1: February 2016 Red case study.

TARP TRIGGERS		Dome	Dyke	Pothole	Blocky Ground	Wedges	Water	Low Angle Joints	Faults	Shear Zones	Brow	Blast Damage	Over break	Substandard Support	>12° dip	Other	
REACTION	Anchors	Shotcrete	TSL	Increase Bolt Density	STOP/ Barricade	Reduce Span	Re-Establish	Sticks	Specified Blasting	Straps/Mesh	Additional support	Other					
RIG Panel No.	OBSERVATIONS AND RECOMMENDATIONS										S/Supervisor Sign offs	ADDITIONAL INFORMATION/PLAN/SKETCH/PHOTOS NB NOT TO SCALE ILLUSTRATION ONLY					
	<p>Multiple panels in one M/O Section can be captured on one report</p> <p>The face of the Roadway 2 is at Survey Peg 7090 + 10.5m(H7031 + 34.7m) Roadway 2 has intersected 2 x Fault zones resulting in the Reef being present within the hang wall Where the Panel intersected the Fault, a shear zone have been created Recomm: At face minus 6.2m install 1 x line of anchors along dip and spaced max 1.8m apart Start just beyond these anchors and take reef from hang wall The brow that will created by above needs to be supported with mesh and resin anchored bolts spaced 1m apart Continue to take reef from Hang wall until out of the Fault zone Where stoping width exceeds 2.5m install additional bolts in the Sidewalls All Hang wall support in the fault zone (resin anchored bolts) to not exceed 1m spacing and ensure that all support is to standard prior to any blast being effected// Barring and Making Safe remains high Priority</p>																

- Geological features:**
- Multiple Fault Zone Intersection.
 - Reef in hang (due to faulting).
 - Shear Zone within Fault Zone.
 - Obliquely running joints, parallel to fault sets.

- Support recommended:**
- Cable Anchors.
 - Specified blasting (blast down reef).
 - Brow of 80cm+ install cable anchors.
 - Sidewall support on exceeding mining height.

Appendix 2: March 2016 Red case study.

TARP TRIGGERS		Dome	Dyke	Pothole	Blocky Ground	Wedges	Water	Low Angle Joints	Faults	Shear Zones	Brow	Blast Damage	Over break	Substandard Support	>12" dip	Other
REACTION	Anchors	Shotcrete	TSL	Increase Bolt Density	STOP/ Barricade	Reduce Span	Re-Establish	Sticks	Specified Blasting	Straps/Mesh	Additional support	Other				
RIG Panel No.	OBSERVATIONS AND RECOMMENDATIONS										S/Supervisor Sign offs	ADDITIONAL INFORMATION/PLAN/SKETCH/PHOTOS				
	Multiple panels in one M/O Section can be captured on one report											NB NOT TO SCALE ILLUSTRATION ONLY				
	<p>Area not mined after month end measuring</p> <p>Area mined off line and muck behind face made observations difficult</p> <p>Panel and Up Dip Vent holing affected by multiple doming creating wedges and weak sides</p> <p>Overall blocky hanging wall surface exacerbated by random intersecting joints both near vertical and low angle.</p> <p>Loose partings and wedges observed from the start (breakaway) of the Panel</p> <p>Prior to any work engage in extensive barring and making safe (from start of Panel)</p> <p>Any bolts protruding more than 30cm to be replaced and additional support to be installed where required</p> <p>Quality Temporary Support (Jacks and Safety Nets) installation is important.</p> <p>For Panel</p> <p>Once all cleaning and making safe practices have been completed install a line of anchors along Dip just before the RH Cnr of the U'D Vent holing</p> <p>Once completed blast down all loose wedges and partings up to face of Sth Pnl 63</p> <p>Where stopping Width will exceeds 2.5m install Sidewall support (1.5m apart)</p> <p>Resupport the area with bolts 1m pattern (If any wedge or brow formed after the blast exceed 80cm (thickness) support with Undercut at face and reduce Panel to 4m (CL and 2m Both sides) Immediately after the blast install 2 anchors (One either side of Centre line)</p> <p>If no improvement recall the TARP Team</p> <p>For Vent hole along U'Dip</p> <p>Install 1 x additional anchor just on the inside of U'D vent hole breakaway</p> <p>An additional line of anchors must then be installed 1.8m from this anchor (refer above) in combination with Osro Straps (Spacing of Anchors 1.8m max)</p> <p>Bolt spacing in Vent hole to not exceed 1m and ensure that all wedges are barred to solid and pinned to standard.</p> <p>It is further recommended that 50mm Shotcrete be applied from start of Panel up to current face and including the Vent hole</p> <p>Ensure that Panel will be mined on Line</p>															

Geological features:

- Thrust faults (domes).
- Loose wedges between joints and weak side of thrust fault.
- Intersecting Joints cross cutting one another.

Support recommended:

- Clean panel of muck and water.
- Specified blasting.
- Mining height exceed standard install sidewall support.
- Reduce bolt spacing/Increase bolt density.
- Undercut face and install 4.5m Cable anchors.


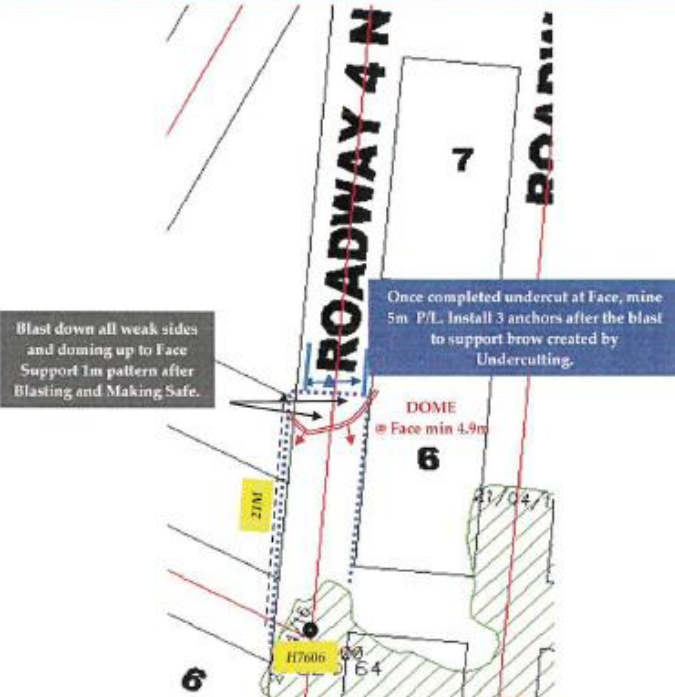
Appendix 3: April 2016 Red case study.

TARP TRIGGERS		Dome	Dyke	Pothole	Blocky Ground	Wedges	Water	Low Angle Joints	Faults	Shear Zones	Brow	Blast Damage	Over break	Substandard Support	>12° dip	Other	30Days + No Mining
REACTION	Anchors	Shotcrete	TSL	Increase Bolt Density	STOP/ Barricade	Reduce Span	Re-Establish	Sticks	Specified Blasting	Straps/Mesh	Additional support	Other					
RIG Panel No.	OBSERVATIONS AND RECOMMENDATIONS										S/Supervisor Sign offs	ADDITIONAL INFORMATION/PLAN/SKETCH/PHOTOS					
	Multiple panels in one M/O Section can be captured on one report											NB NOT TO SCALE ILLUSTRATION ONLY					
	<p>Face of the Panel at Peg (77) + 13.5m Panel and Up dip vent holing refers Oblique doming features have intersected the Panel and Up Dip vent holing resulting in wedges due to fallouts along weak sides. Brows varying in thickness have been created by the piggy back doming. Ensure that all areas where work will be conducted are barred to solid. Install 1 Line of anchors in-between the First and Second dome feature to support weak side (Spacing max 1.8m apart)</p> <p>Vent hole (U/Dip) Blast down wedges behind the face in the Up Dip vent hole Install Support 1m pattern</p> <p>Face area of Panel 38 Install a second line of anchors behind the current face position (Spacing 1.8m apart) Take 1 blast and install an additional line of Anchors (Spacing 1.8m apart Dip and Strike) NB: If there is no improvement in the Panel and U/Dip vent holing STOP, BARRICADE AND RECALL THE TARP TEAM Adhere to all Support (Temporary and Permanent), Barring / Making safe as well as TARP Procedure. See also previous TARP Reports re this area</p>																

- Geological features:**
- Multiple thrust fault features (domes).
 - Wedges formed on the weak side of the thrust faults.

- Support recommended:**
- Barr area to solid.
 - Install 4.5m cable anchors on specified locations.
 - Specified blasting.
 - Reduce bolt spacing/Increase bolt density.

Appendix 4: May 2016 Red case study.

TARP TRIGGERS		Dome	Dyke	Pothole	Blocky Ground	Wedges	Water	Low Angle Joints	Faults	Shear Zones	Brow	Blast Damage	Over break	Substandard Support	>12° dip	Other						
REACTION	Anchors	Shotcrete	TSL	Increase Bolt Density	STOP/ Barricade	Reduce Span	Re-Establish	Sticks	Specified Blasting	Straps/Mesh	Additional support	Other										
RIG Panel No.	OBSERVATIONS AND RECCOMENDATIONS										S/Supervisor Sign offs	ADDITIONAL INFORMATION/PLAN/SKETCH/PHO										
	<p>MERCC NTH RWAY 4 refers</p> <p>Area behind face affected by Doming (15°-20°) dipping away from direction of Mining as well as LA Joints</p> <p>Some of the Dome plane areas shows signs of separations from the Hang wall</p> <p>From where the brow starts blast down all loose wedges, partings and weak side of Doming up to the current face</p> <p>Ensure to not damage Hanging wall during blasting down of loose areas (Dome weak sides)</p> <p>A fault runs obliquely across the panel, monitor the fault for deterioration of panel conditions and recall TARP team if unsure.</p> <p>Support the area with bolts 1m spacing up to the face (after proper barring and making safe was carried out/completed)</p> <p>Once completed up to the face reduce Panel length to 5m (2.5m+CL-2.5m) and undercut at the Face with the first blast</p> <p>Bar, make safe and then install 3 x Anchors below the brow (created by undercut) and recall the TARP Team if there is no improving.</p> <p>NB: Where stoping exceeds 2.5m (blasting down of dome weak sides) install additional bolts in adjacent sidewalls.</p>																					

- Geological features:**
- Thrust Faults (domes)
 - Wedges
 - Faults
 - Shear Zones
 - Brow

- Support recommended:**
- Cable Anchors
 - Increase Bolt Density
 - Reduce Span
 - Specified Blasting
 - Straps/Mesh
 - Additional support

Appendix 5: June 2016 Red case study.

TARP TRIGGERS		Dome	Dyke	Pothole	Blocky Ground	Wedges	Water	Low Angle Joints	Faults	Shear Zones	Brow	Blast Damage	Over break	Substandard Support	>12° dip	Other
REACTION	Anchors	Shotcrete	TSL	Increase Bolt Density	STOP/ Barricade	Reduce Span	Re-Establish	Sticks	Specified Blasting	Straps/Mesh	Additional support	Other				
RIG Panel No.	OBSERVATIONS AND RECOMMENDATIONS										S/Supervisor Sign offs	ADDITIONAL INFORMATION/PLAN/SKETCH/PHOTOS NB NOT TO SCALE ILLUSTRATION ONLY				
	<p>Overall blocky conditions due to intersection of Fault zone Back area of Winze intersected oblique running Joint sets resulting in Brow features and blocky areas</p> <p>Recomm:</p> <ol style="list-style-type: none"> Before any work bar down all loose areas and blocky zones Joint-zones in back-area to be sprayed with 50mm Thick Shotcrete Once barred to solid - Joint zone with 1m overlap either side Start at Face minus 14m and extensively bar down all loose areas (Winze and U/D Breakaway) Bolts protruding 30cm+ to be replaced <i>Important!!</i> Mesh and bolts to be installed as support (Bolt spacing max 1m apart and use of bigger washer plates encouraged) If no mesh is available then use Osro Straps spaced 0.75m apart (D+ S) Apply Shotcrete min 50mm Thick along Hang wall and 1m down all Sidewall areas. Once completed up to the current faces (Winze and Up Dip breakaway) the following to be implemented Stop Up Dip breakaway - No blasting Reduce Winze P/L to 4M + CL MIN 2M. Continue with above recommendations until out of blocky zones Recall the TARP Team should there be any uncertainty or change in Ground conditions. Adhere to all Standards and Procedures of Eastern Chrome Mines. The opportunity was also used to do training and coaching to the Shift Supervisor (B v/d Merwe) and Miner ("Doctor") 															

Geological features:

- Blocky ground and Wedges
- Joints (low angle joints)
- Faults
- Brow feature

Support recommended:

- Cable anchors
- Aerial coverage (shotcrete).
- Reduce Span.
- Straps and Mesh
- Additional Support.






Appendix 6: July 2016 Red case study.

TARP TRIGGERS		Dome	Dyke	Pothole	Blocky Ground	Wedges	Water	Low Angle Joints	Faults	Shear Zones	Brow	Blast Damage	Over break	Substandard Support	>12° dip	Other	
REACTION	Anchors	Shotcrete	TSL	Increase Bolt Density	STOP/ TNA	Reduce Span	Re-Establish	Sticks	Specified Blasting	Straps/Mesh	Additional support	Other					
RIG Panel No.	OBSERVATIONS AND RECOMMENDATIONS										S/Supervisor Sign offs	ADDITIONAL INFORMATION/PLAN/SKETCH/PHOTOS NB NOT TO SCALE ILLUSTRATION ONLY					
	<p>Multiple panels in one M/Q Section can be captured on one report</p> <p>The Last Up Dip Vent hole just behind Survey Peg 7502 refers. At the entrance to vent holing an oblique brow in excess of 80cm present. In-between brow and face near vertical joints running obliquely (strike direction) within the holing Area behind the face intersected Shear zone with friable conditions Overall conditions remains blocky due to joint nature. Before any work bar down all loose rocks, wedges and partings (from breakaway of U'Dip vent holing up to current face Install at least 2x anchors to support brow feature at entrance to vent holing. Resin anchored bolt spacing within the Vent holing should not exceed 1m pattern and ensure that all wedges are pinned. The shear zone to be sprayed with 50mm thick Shotcrete. Replace bolts that will protrude more than 30cm (Barring) If any wedge within the panel exceeds 810cm in thickness it should be supported with anchors. Please note that all support related work must be completed before any face advance. Take note of Up Dip direction of mining (To not create overhang/ comply to 5P's of Barring) Temporary and Permanent support must be installed within standard.</p>																
	<p>Shear zone intersected</p>			<p>Overall friable overhead conditions.</p>			<p>Brow at entrance</p>										

- Geological features:**
- Thrust Faults (Domes).
 - Dolerite Dyke.
 - Wedges/Blocky Ground.
 - Joints (Low angle).
 - Shear Zones
 - Brow.

- Support recommended:**
- Cable Anchors.
 - Aerial Coverage (Shotcrete + Thin Skin Liner)
 - Increase bolt density/reduce bolt spacing.
 - Reduce mining span.
 - Specified blasting.
 - Additional Support.

Appendix 7: August 2016 Red case study.

TARP TRIGGERS		Dome	Dyke	Pothole	Blocky Ground	Wedges	Water	Low Angle Joints	Faults	Shear Zones	Brow	Blast Damage	Over break	Substandard Support	>12° dip	Other	
REACTION	Anchors	Shotcrete	TSL	Increase Bolt Density	STOP/ Barricade	Reduce Span	Re-Establish	Sticks	Specified Blasting	Straps/Mesh	Additional support	Other	Limit H/Wall damage				
RIG Panel No.	OBSERVATIONS AND RECOMMENDATIONS										S/Supervisor	ADDITIONAL INFORMATION/PLAN/SKETCH/PHOTOS					
Multiple panels in one M/O Section can be captured on one report											NB NOT TO SCALE ILLUSTRATION ONLY						
	<p>The Forward face of Nth Pnl 25 refers. L/A Joint features intersect along Dip and Strike to create wedge fallouts and Brow feature. Loose wedge and overhang present adjacent the Up Dip sidewall. Blast down loose wedges and Overhang along Up Dip (Pillar area)/Limit damage to immediate surroundings The area just at the entrance to forward to be supported with anchors max 1.8m apart (Dip Direction) Ensure that all wedges and partings are barred to solid and install bolts normal pattern and additional Wedges and prominent features to be supported to standard Recall TARP Team if unsure or if conditions do not improve. Adhere to all Standards and Procedures of Eastern Chrome Mines.</p>																
						<p>Wedges and partings due to Joint nature . All bolts protruding 30cm + must be replaced.</p>				<p>Overhang and loose wedges along Up Dip Sidewall. Blast down loose wedges and overhang. Replace all damaged support.</p>							

- Geological features:**
- Thrust faults (domes).
 - Wedges.
 - Joints (Low Angle Joints)
 - Brow feature.

- Support recommended:**
- Cable anchors.
 - Increase bolt density / reduce bolt spacing.
 - Specified blasting.
 - Additional support.
 - Other support recommendations include that damage to the hanging wall must be kept to the bare minimum.

Appendix 8: September 2016 Red case study.

TARP TRIGGERS		Dome	Dyke	Pothole	Blocky Ground	Wedges	Water	Low Angle Joints	Faults	Shear Zones	Brow	Blast Damage	Over break	Substandard Support	>12° dip	Other	VENT SH
REACTION	Anchors	Shotcrete	TSL	Increase Bolt Density	STOP/ Barricade	Reduce Span	Re-Establish	Sticks	Specified Blasting	Straps/Mesh	Additional support	Other	Adhere/Apply Standards and Procedures of Eastern Chrome Mines followed.				
RIG Panel No.	OBSERVATIONS AND RECOMMENDATIONS										S/Supervisor Sign offs		ADDITIONAL INFORMATION/PLAN/SKETCH/PHOTOS				
	Multiple panels in one M/O Section can be captured on one report												NB NOT TO SCALE ILLUSTRATION ONLY				
	<p>Area where vent shaft will be established</p> <p>Sleep doming present at face minus ± 8m</p> <p>Area in-between face and dome intersected by prominent joints along dip.</p> <p>Conditions are aggravated by Joints along strike to create random blocks / wedges.</p> <p>NB:</p> <p>Ensure that area from where the doming starts up to face position are daily inspected and barred to solid.</p> <p>Bolt spacing should not exceed 1m pattern and additional bolts are to be installed to pin wedges</p> <p>Ensure that exposed joint planes and weak zone areas of Geological anomalies are inspected after every blast- Any separation of these features to be addressed as per the TARP Procedure</p> <p>It is also recommended that once the "Pilot-hole" for the Vent shaft has been completed the wedges and weak sides combinations are blasted down before the "reaming" for the Vent-shaft proceeds. (During the reaming process weak sides may separate on parting planes can delay Vent shaft completion).</p> <p>Subsequently a TARP Visit has been arranged for Tuesday 2016/09/20</p>												<p>The diagram shows a plan view of a mine section. A large area is labeled 'Vent No 4'. To its north is '35AN' and '10'. To its south are '9' and '8'. A red line runs diagonally across the top left. A blue circle is drawn within the 'Vent No 4' area. Measurements include '89674.35' and '67227.53'. Several 'TARP REPORT' labels with IDs like 'HT20160916' and 'HT20160905' are scattered. Other labels include 'H7421', '82206', 'H7421', and '8180931'. A pink hatched area at the bottom right is labeled '25/08/16', '46.2m', and '200cm'.</p>				
	<p>Three photographs showing geological features. The first shows a close-up of a rock face with a prominent joint. The second shows a wider view of a rock face with doming. The third shows a close-up of a joint plane. All photos have a timestamp of '16/09/2016 12:15'.</p>																

- Geological features:**
- Thrust faults (dome feature)
 - Wedges
 - Joints (low angle joints)
 - Shear Zones.

- Support recommended:**
- Increase bolt density / reduce bolt spacing.
 - Additional support.
 - Other support recommendations include adhering to the standards and procedures at all times.

Appendix 9: October 2016 Red case study.

TARP TRIGGERS		Dome	Dyke	Pothole	Blocky Ground	Wedges	Water	Low Angle Joints	Faults	Shear Zones	Brow	Blast Damage	Over break	Substandard Support	>12° dip
REACTION	Anchors	Shotcrete	TSL	Increase Bolt Density	STOP/ Barricade	Reduce Span	Re-Establish	Sticks	Specified Blasting	Straps/Mesh	Additional support: Sets	Other	Adhere/Apply Standards and Procedures followed.		
RIG Panel No.	OBSERVATIONS AND RECCOMENDATIONS										S/Supervisor Sign offs	ADDITIONAL INFORMATION/PLANS			
	<p>Multiple panels in one M/O Section can be captured on one report</p> <p>Rock Engineer Manager visit</p> <p>The following to be taken into account:</p> <p>Area is still within the Major Fault Zone</p> <p>Mining on grades remains a high priority. Take care that mining is done at +12° and therefore always a possibility of overhang face.</p> <p>This is a hand-held section. Ensure that all risk assessments and COM are in place and workforce comply.</p> <p>The Osro strap installation are made difficult due to irregular hanging wall surface and wedge failures.</p> <p>The following recommended:</p> <p>Replace Osro straps with mesh and pin with bolts 1m pattern (Ensure the use of bigger washer plates (mesh apertures)).</p> <p>As soon as the panel is fully established (5m P/L) and has advanced 2.5m the installation of Sets must commence.</p> <p>Except for Shotcrete application all other work (Support and face drilling) must be carried out beneath and behind the protection of safety nets and correctly installed camlok jacks.</p> <p>To limit possible overhang ensure that with every second blast the two uppermost shothole-lines are drilled 1.5m long.</p> <p>All support related work must be completed up to the face before any face advance.(Shotcrete application must not lag more than 2 x blasts from face). Ensure that all blast damaged support (mesh and bolts) are redone before any face advance.</p>														

- Geological features:**
- Wedges and blocky ground.
 - Faults.

- Support recommended:**
- Apply aerial coverage (shotcrete).
 - Increase bolt density/ reduce bolt spacing.
 - Reduce span.
 - Specified blasting.
 - Straps/Mesh.
 - Additional support – Installation of Sets.

Appendix 10: November 2016 Red case study.

TARP TRIGGERS		Dome	Dyke	Pothole	Blocky Ground	Wedges	Water	Low Angle Joints	Faults	Shear Zones	Brow	Blast Damage	Over break	Substandard Support	>12° dip	Other	
REACTION	Anchors	Shotcrete	Tunnelguard	Increase Bolt Density	STOP/ Barricade	Reduce Span	Re-Establish	Sticks	Specified Blasting	Straps/Mesh	Additional support	Other	Adhere/Apply Standards and Procedures of East followed				
RIG Panel No.	OBSERVATIONS AND RECOMMENDATIONS										S/Supervisor Sign offs	ADDITIONAL INFORMATION/PLAN/SKETCH NB NOT TO SCALE ILLUSTRATION					
	<p>The last D/Dip Vent holing behind the current face refers. From the breakaway up to the face of the Vent holing the area is blocky. These conditions are aggravated by L/A joints creating wedges. (Separation on some joint planes could be observed with Serpentine Infill throughout)</p> <p>Recommendations: Blast down/ bar down all loose wedges and partings. Any brow or wedge that exceeds 80cm in thickness are to be spot-anchored. Resin anchored bolts must be max 1m apart (Dip and Strike). This area to be covered by Tunnelguard. All of the above to remain in place until out of aforementioned conditions. NB- Barraging and making safe a high priority and apply 5P's of Barraging. Temporary Support must be well within the Standard. (Safety nets against H/Wall and Camlok jack spacing). Ensure effective communication when tasks are given /Apply SLAM & SEEP.</p>																
									<p>Indications of irregular H/Wall surface and overall blocky conditions. Note serpentine infill along joint planes.</p>								

- Geological features:**
- Wedges/Blocky ground
 - Joints (low angle)
 - Faults
 - Brow feature

- Support recommended:**
- Cable anchors
 - Aerial Coverage (tunnel guard)
 - Increase bolt density / reduce bolt spacing.
 - Stop/barricade and hole from another panel.