NEGOTIATING COMPLEX GEOLOGICAL STRUCTURES BY APPLYING NEW MINING STRATEGIES

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SYNOPSIS

Millsell Mine has one of the most structurally disturbed geological areas in the western limb of the Bushveld Complex. The occurrence and high frequency of geological structural elements within the mining area requires careful design considerations and proactive strategies to maintain a stable production system. The mine invested in Ground Penetrating Radar (GPR) technology to detect the presence of structural elements within the hanging wall strata. This technology is supported by design considerations that seek to protect the integrity of the excavations thereby reducing the number of uncontrolled Falls of Ground (FOG). To this end, the mine has been able to reduce the number and size of FOGs through the application of new mining strategies to negotiate geological structures in a safe and acceptable manner.

1 INTRODUCTION

Various types of structural discontinuities and complexities are exposed in underground excavations. These structures cause hazardous ground conditions as well as instability in underground excavations. Previous rock mass failures in the underground workings have led to injuries, near fatalities, loss of equipment and production which highlighted the major role geological structures and discontinuities play in the design of mines.

The GPR technology has proven to be successful in detecting geological discontinuities not visible to the naked eye for up to 6m into the hanging wall rocks. This allows for proactive measures to be implemented including leaving the mining blocks behind as regional / local support pillars.
In addition, the mining direction can be changed for an optimal layout design to support the geological structures to acceptable levels.

1.1 Location

Millsell Mine is situated about 5km east of Rustenburg, next to the old Pretoria / Kroondal road on the farms Waterkloof 305 JQ, Waterval 306 JQ, Waterval 307 JQ and Kroondal 304 JQ. The mine is located on the rim of the western lobe and mining the LG6 and LG6A chromite layers confined to the Lower Critical Zone of the Rustenburg Layered Suite.

1.2 Mining Operations

The mining method currently employed at Millsell Mine comprises of mechanised breast method. The average thickness of the LG6 and LG6A package is 1.7m, which lends itself to mechanization. Mining panels are established on breast and divided by the panel pillars with varying sizes depending on the depth below surface and prevailing ground conditions. Drilling is done by means of drill rigs at most of the mining sections and cleaning by load haul dumpers (LHDs) to a strike conveyor belt that feeds onto the dip conveyor in the decline shaft. Access to underground is gained via three decline shafts. The declines run along true dip. A further four declines were established on reef to convey material/equipment and ore to and from the mining sections. These declines allow for flexibility and extra face length availability.

2 GEOLOGICAL SETTING

The chromitite layer resources in South Africa are situated within the Rusternburg Layered Suite (RLS) of the Bushveld Complex (BC). Figure 1 depicts the regional geology and Millsell Mine location.

The RLS has been subdivided, from base to top, into five zones, known as the Marginal, Lower, Critical, Main and Upper Zones (Schurman, Grabe & Steenkamp, 1998). The general sequence and composition of the different zones is shown in Figure 2. The Critical Zone is the host to all chromium and PGM mineralisation within the BC. It may be subdivided into lower and upper sections and is made up of cyclic units consisting of chromitite, pyroxenite, norite and anorthosite. Cycles in the Lower Critical Zone are entirely ultramafic in character. Cycles in the Upper Critical Zone comprise ultramafic lithologies and also norite-anorthosite.

Chromitite layers occur throughout the Critical Zone, usually, but not always, at the base of crystallisation cycles. The chromitite seams have been classified into lower, middle and upper groups, with the Lower Group occurring in the Lower Critical Zone and the Upper Group in the Upper Critical Zone. The chromitite seams are named according to their location within the layered succession, with numbers commencing from the bottom up, with the lowermost group being named LG1, followed by LG2, LG3, etc. in the Lower Group (consisting of 7 layers), progressing to MG0, MG1, MG2, etc. (consisting 4 layers) in the Middle Group, and then on two layers in the Upper Group, UG1 and UG2 (Schurman, *et al*., 1998). The thickness of these chromitite layers ranges from several millimetres to several metres and named chromitite layers may comprise of multiple, composite layers of chromitite separated by interlaminated silicate rocks. The thickest chromitite layers, specifically the LG6 and MG1, are mined for their chrome content.
This paper will focus on the LG6 chromitite seams and the geological structures confined to these seams.

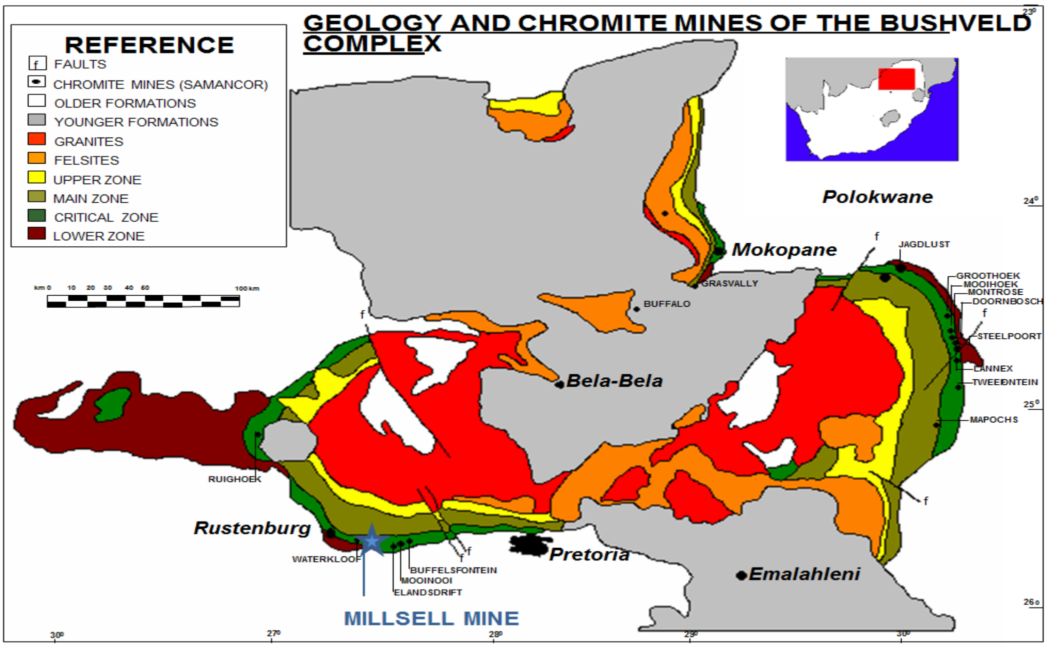

Figure 1: Regional geological map indicating Millsell Mine (Steenkamp, 2006)

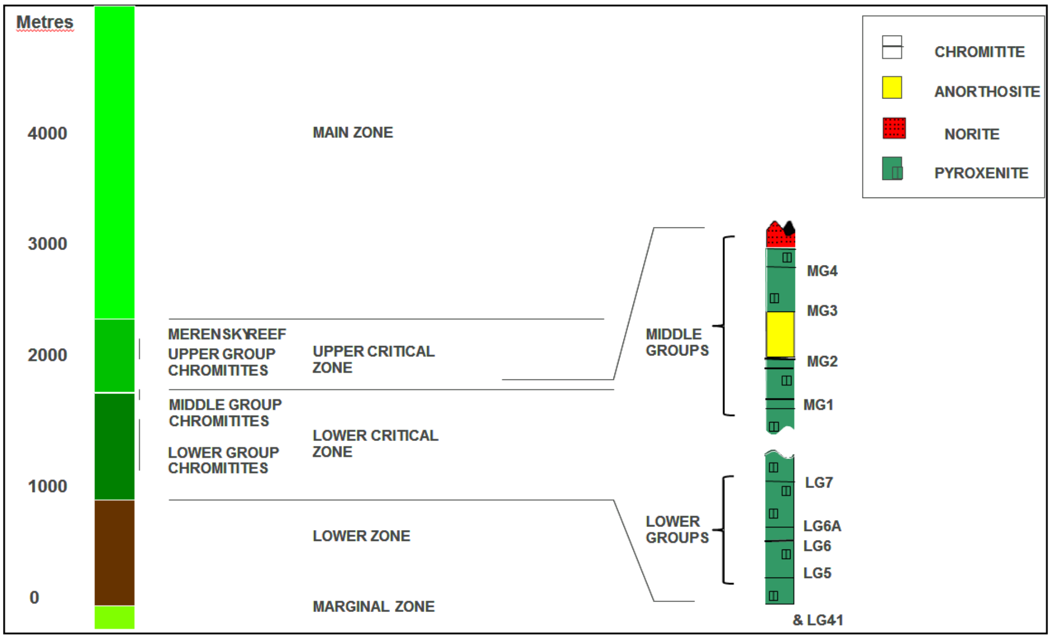

Figure 2: Generalized Stratigraphy of the Middle and Lower chromitite seams (Modified from Schurman, Grabe & Steenkamp, 1998)

2.1 Chromitite Layers

The Lower Group chromitite layers strike at 135° with an average dip of 9.5°. Hanging wall dip measurements at Millsell Mine indicate a range of between 5° and 20° (Pothole structures contribute to the steep dips measured). The sub-outcrop of the deposit has a strike length of approximately 3700m. The length parallel to the dip of the deposit is approximately 3200m (Steenkamp, 2006).

Economically the most important of the LG chromitite layers is the LG6 (average 0.96m thick) and the overlying LG6A (average 0.26m thick), separated by an internal middling pyroxenite parting (average 0.66m thick). The pyroxenite layer separating the LG6 and LG6A chromitite layers varies in thickness laterally. The internal middling pyroxenite increases in thickness to more than 2.0m on the north-western portion of the farm Kroondal 304 JQ. The stratigraphic column of Millsell Mine is illustrated in Figure 3 (Steenkamp, 2006).

The LG6A chromitite layer is slightly poikilitic in parts and fine grained. The contacts of the chromitite layers range from gradational to sharp. Gradational disseminated zones of 2.5 to 0.04m in thickness also occur at the bottom and top contacts of the LG6A chromitite seam. A frozen hanging wall contact is primarily associated with gradational to disseminated contacts and predominates in the Southern region of the mine (Steenkamp, 2006).

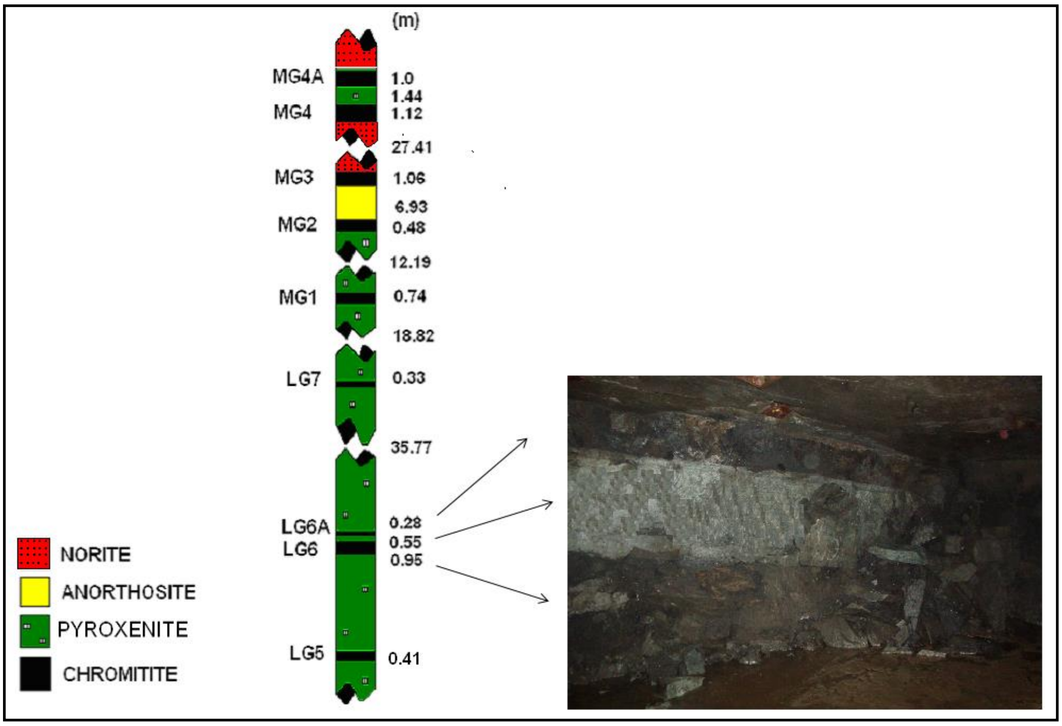

Figure 3: Stratigraphic column of the LG6 package at Millsell Mine (Steenkamp, 2006).

2.2 Depth of the seams below surface

The deposit sub-outcrops below the black turf on the farms Waterkloof 305 JQ and Waterval 306 JQ, and dip north-eastwards. On the farm Kroondal 304 JQ the depth of the deposit in the north-western extent is estimated at approximately 410m below surface within the mining right area. On the farm Waterval 307 JQ the depth of the deposit is estimated at approximately 380m below surface in the northern extent of the farm up to the boundary of the mining right area. The mineral resource extends to on the farm Waterkloof 305 JQ with a maximum depth of approximately 360m below surface.

2.3 Major Geological Structures

2.3.1 Faulting

Minor faulting occurs throughout the Millsell Mine ranging between 0.05m to 3m. Three prominent fault sets are known from underground mapping and the orientations are quantified on a rose diagram in Figure 4. The two most dominant fault orientations are NNW - SSE and ESE-WNW. The faults striking in a NNW-SSE direction are generally normal faults, dipping in a WSW direction and locally classified as the f1 set. The ESE-WNW trending faults are classified as the f2 set and are dominated by reverse faults, dipping mainly in a SSW direction. These f2s are normally associated with pegmatite veins. The thrust or low angle faulting formulates a third set of faults f3, striking WNW, dipping mostly in a southern direction.

A major fault trending north-south to the east of the Millsell Mine, with a downthrown to the east, has a scissor effect northwards with a downthrown to the west, and peters out further northwards (Steenkamp, 2006). The photographs below depict the typical faults found at Millsell.

Photo 1: NNW - SSE trending normal faults

Photo 2: E-W trending reverse fault

Photo 3: E-W trending thrust faults

The rose diagrams in figure 4, 5 and 9 are an orientation defined circular representation of the faults, joints and dome planes, data measured at Millsell mine. The azimuth (measured as strike direction) for each individual plane is plotted as a line on the circular diagram. The density distribution of the lines are plotted in fixed intervals and displayed as a circular histogram. The density distributions are symmetrically represented around a hypothetical perpendicular line, creating an inverse distribution over 180°.

The Fault rose diagram in figure 4 is set at 15° increments. The dominant orientation is 90 to 105 °. This represent 32% of the total fault population of the fault orientations measured at Millsell Mine (number of fault measurements N= 1132). A secondary distribution peak is orientated between 150 to 180° representing the f1 set.

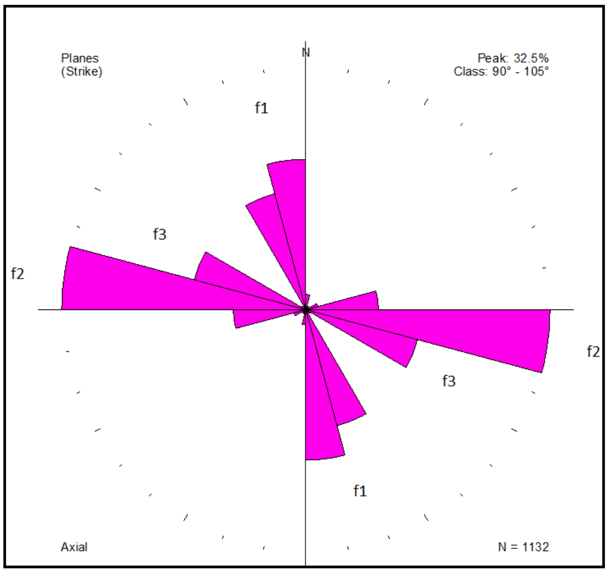

Figure 4: Rose diagram of the fault system

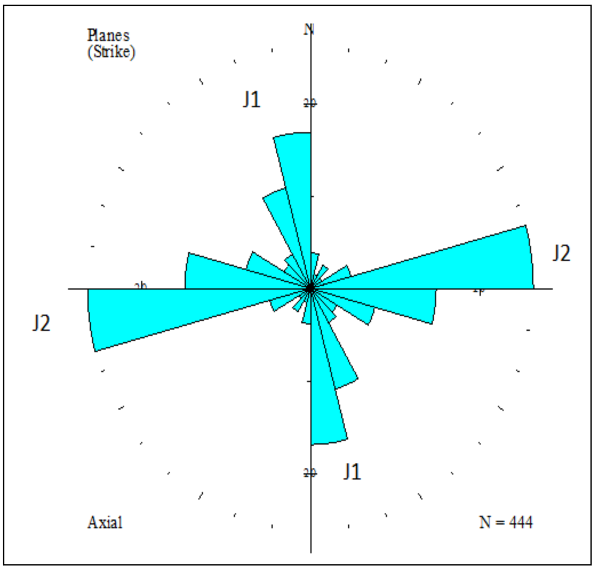

Figure 5: Rose diagram of jointing system

2.3.2 Jointing

A prominent joint system is developed throughout the underground workings trending NNW- SSE (156°), dipping mainly westwards and E-W (96°), dipping mainly south. The joint set trending at 156° is locally known as the J1 set, and the set trending at 96° is locally known as the J2 set. This conjugate joint system is sub vertical and the spacing frequency varies throughout the mining area. It may be continuous or discontinuous on strike and dip. The degree of joint roughness can be classified as smooth and separation is tight (Treloar and Steenkamp, 2000: 2).

When the J1 and J2 joints strike in different orientations, they may intersect each other during which key blocks form in the hanging wall and result in a FOGs (Fig 6). Joint alteration zones also occur (one meter wide) which results in altered rocks in the hanging and side wall. These joint sets can cause a channel type of failure and in conjunction with other discontinuities influence the stability of the hanging and side walls. Simple illustrative diagrams are shown below in Figure 6 and 7.

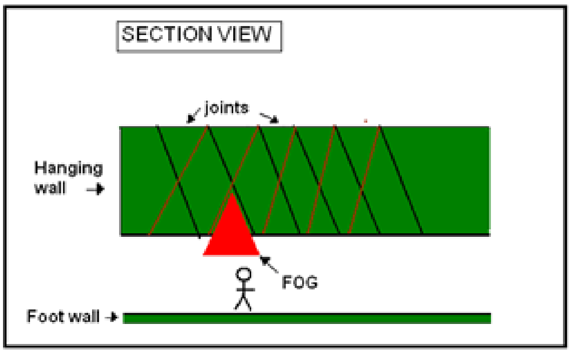

Figure 6: Intersecting joints and a FOG

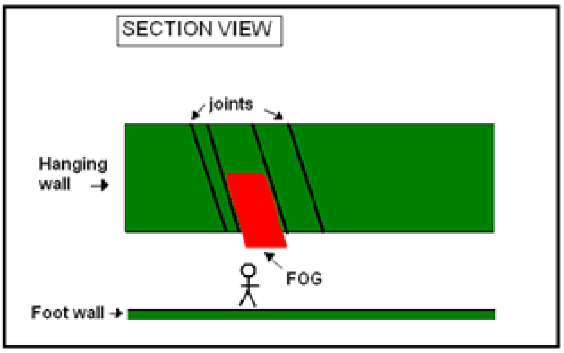

Figure 7: A channel type failure in a J1 set

2.3.3 Pegmatite veins

A vein is a fracture filled with mineral crystals composed of quartz, alkali feldspar and mica (phlogopite, minor tourmaline and hornblend) cutting both the chromitite and country rock that precipitated from a fluid solution. Some initiated as joints, whereas others initiated as faults or as cracks adjacent to faults. These veins indicate movement within the rock strata (Steenkamp, 2006).

The pegmatite veins are dyke like structures and often extend through the chromitite and pyroxenites, but may pinch out when intersecting the thicker underlying LG6 chromitite layer. The pegmatite veins at Millsell trend in an east-west direction. The J2s are possible indicators or precursor feeder zones of pegmatite bodies associated with potholes (Steenkamp, 2006). Pegmatite veins in conjunction with other geological structures will also result in poor and blocky hanging wall conditions.

Photo 4: E-W striking pegmatite vein

2.3.4 Domes / Domal Splay

Low angled compressional structures, known as domes occur in the hanging wall of the LG6 package. These dome structures range in size and extent, and are usually characterized by slickensides with serpentinised or talc infilling along their contact planes. The major domes usually intersect the chromitite seams with associated displacement in centimeters. The amount of displacement of the chromitite seam usually gives an indication of the size of the dome. Photograph 6 is used to illustrate displacements along domal splays.

Photo 5: Fallen minor dome

Photo 6: Displacements along dome plane

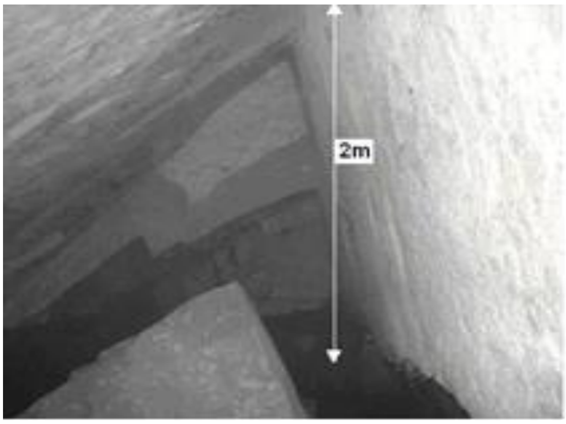

Photo 7: Fallen major dome

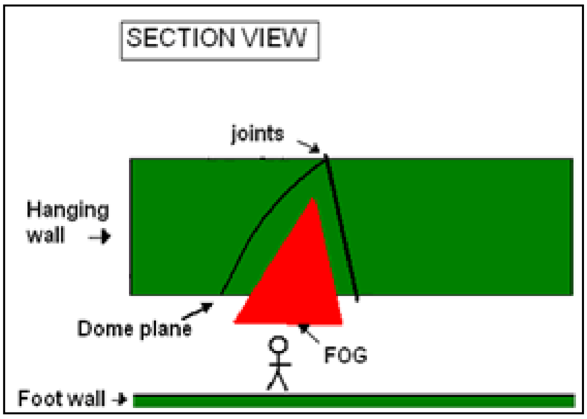

Figure 8: Dome structure fallen out along a joint

Although the major dome planes can be recognized when the dome plane cuts through the chromitite seam, the height and extent of the dome is an unknown factor. In most cases the dome planes have no cohesion, and contribute to incidences of FOGs (Treloar and Steenkamp, 2000: 2).

It is evident from underground mapping (and as illustrated in Figure 9 below), that there are two dominant dome orientations which are locally classified as d1 and d2. The dome planes classified as d1 are mainly orientated with their long axis sub parallel to the f1 and J1 sets. The d2 dome planes are orientated with their long axis parallel to the f2s. Certain dome planes seem to be related to E-W folding but geological mappings are insufficient to prove any relationship.

Although it seems like these structures are associated with each other, it is not proven and therefore further research is required.

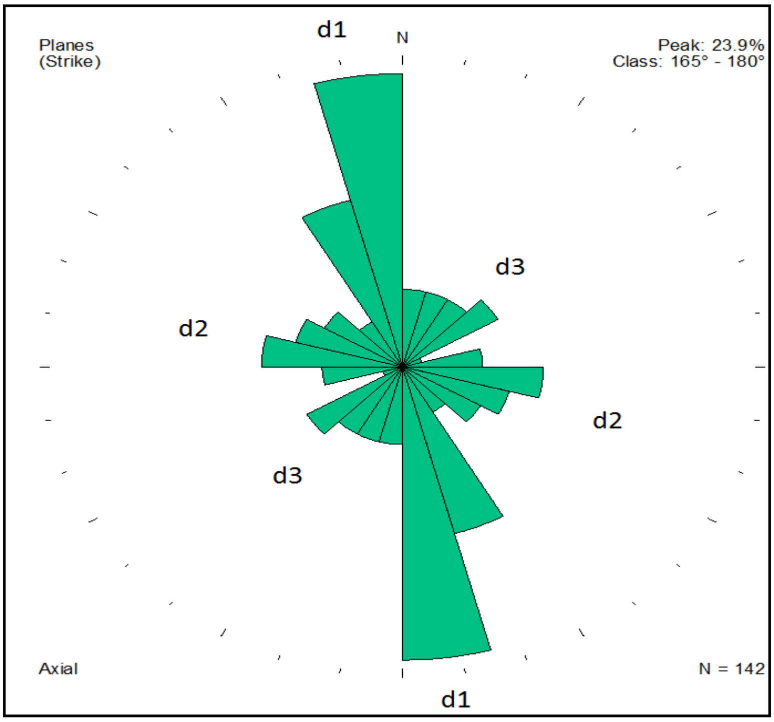

Figure 9: Rose diagram orientation's of the dome planes long axis

2.3.5 Dykes

A major dyke trending west northwest is situated to the north of the mining area dipping at various angles but mainly in a southerly direction. The thickness of the dyke is in the order of 15 to 25 metres as determined from geophysical modelling. This dyke has not yet been intersected by the underground workings.

2.3.6 Potholes

Pothole structures with diameters between 10 to 60m normally associated with pegmatite veining have been identified. These have a lower frequency of occurrence in comparison with the Middle Group Chromitite seams. They are large "dish-or-pear" shaped structures, usually associated with loss of the chromitite seam (Treloar and Steenkamp, 2000: 2).

Where chromitite seams are disturbed, pegmatite intrusions may be developed on the limbs of the pothole structure or even right through the pothole. In these cases chromitite "rafts" may be mixed within the pegmatite intrusion mass. The existence of shear zones and high frequency of jointing or faulting are typical to arise on the rim of these pothole structures, which contribute to significantly weaker zones of rock or loss of chromitite (Treloar and Steenkamp, 2000: 2). Areas defined as being potholed will have significant gradient variations (between 5 and 20 °). The LG6 uniform seam thicknesses becoming highly irregular or pinches out completely.

The different types of potholes are illustrated below in Figures 10, 11, 12, 13 and 14.

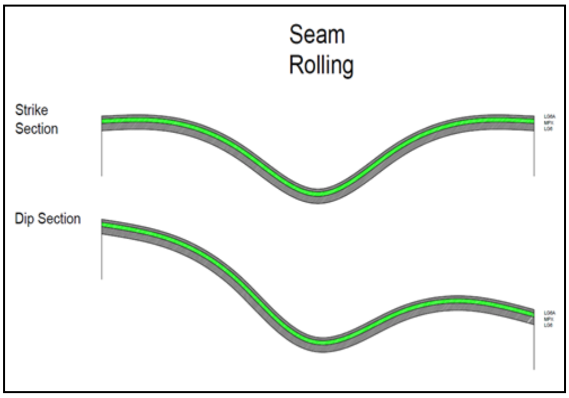

Figure 10: A slump / rolling behaviour

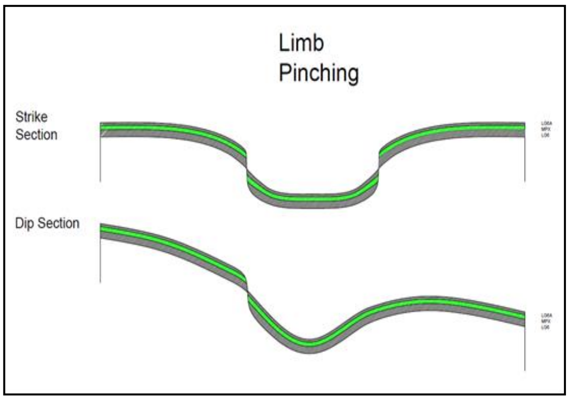

Figure 11: Chromitite layer steepening and pinches

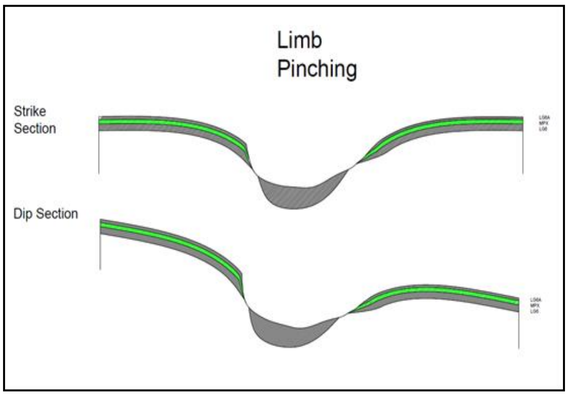

Figure 12: Chromitite layer pinches out and thickens into one chromitite seam or mass

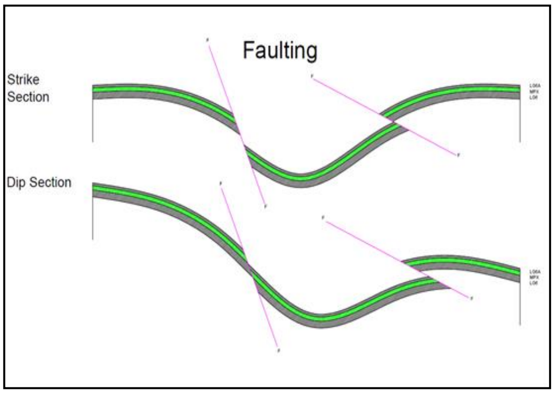

Figure 13: Pothole type with shearing and faulting along the limbs

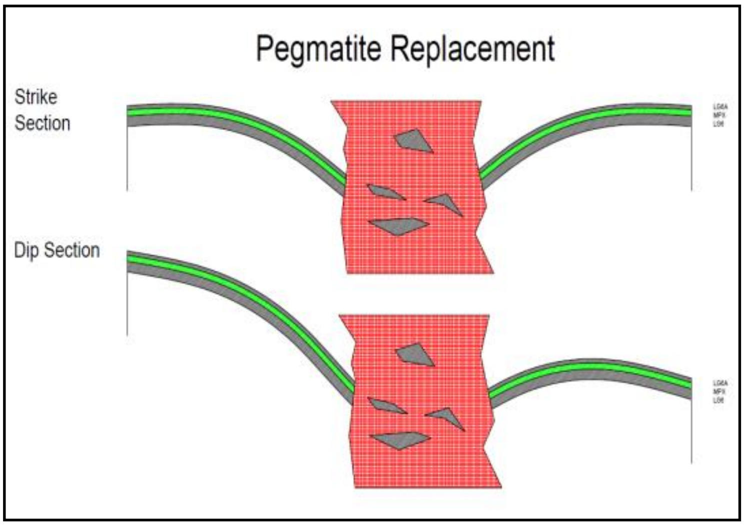

Figure 14: Pothole type associated pegmatite body

2.3.7 Pegmatoid areas

A series of ultramafic pegmatite bodies are identified from geomagnetic information immediately north and north-east of the mined out workings of the mine.

A wide disturbed zone of approximately 200m wide trending WNW is developed to the northwest of the mining operation on the farm Waterval 307 JQ, indicating that these bodies may be dyke-like structures or massive deep rooted replacement bodies. Due to the mineralogical composition of pegmatoids, alteration may occur which could affect rock wall stability (Treloar and Steenkamp, 2000: 2).

2.3.8 Disseminated layering

Thin disseminated chromite stringers or bands situated in the immediate hanging wall can occur and contribute to thin beam type failures. The beam thickness between the LG6A and the disseminated layer increases in thickness in the southern portion >0.2m of the mine to >3.0m in the northern portion of the mine (Treloar and Steenkamp, 2000).

Photo 3: Disseminated layering 0.2 to 0.3m above the LG6A seam

2.3.9 Shear zones

Near horizontal shear zones, which vary in thickness, can occur along contacts of the various lithological units of the LG6 package, causing unstable support pillars or heave of footwall rock (Treloar and Steenkamp, 2000: 2).

3 PROBLEM STATEMENT

In any mining environment, falls of ground are an ever present danger to the safety of mine employees and sustainability of mining operations. The occurrence and high frequency of geological structural elements within the mining area of Millsell increases the propensity for rock fall incidents to occur. The significance of the possibility of the falls of ground together with the available risk mitigation measures determine the ability to mine safely. Where the risk measures fail or prove to be inadequate, mines are constantly faced with the challenge of looking for improved technology and intelligent ways to combat the risk of FOGs.

FOGs cause injuries to persons resulting in costly safety stoppages and massive production losses. The Mine Health and Safety Act (MHSA), chapter 23 requires the employers to report FOG occurrences of a certain magnitude even if no person has been injured. For most of the above scenarios, the Mine Health and Safety Inspectorate (MHSI) often halted mining operations in that section or mine pending the investigation and the perceived health and safety threat.

In almost all FOG cases recorded, the production potential of the mining section is reduced and the production budget cannot be met. Redevelopment is required to re-establish and re-equip the mining area. During this period, continued production losses are recorded if the section does not have the redundancies required to maintain budget requirements.
In its endeavour to remain viable, Millsell adopted the latest technology along with new mining strategies to mitigate the risk to the operations presented by the FOGs.
New mining strategies to negotiate geological structures in a safe acceptable manner are described with positive outcomes.

4 FALL OF GROUND OCCURRENCE HISTORY

In the past five to six (5-6) years, the mine recorded more than five hundred (500) fall of ground occurrences. (Source: WCM Rock Engineering Database, 2016). Figure 15 below shows all FOG incidents, observations and near misses where a rock has been displaced from either the hanging and/or sidewall. Over 90 percent of the above incidents were non casualty events.

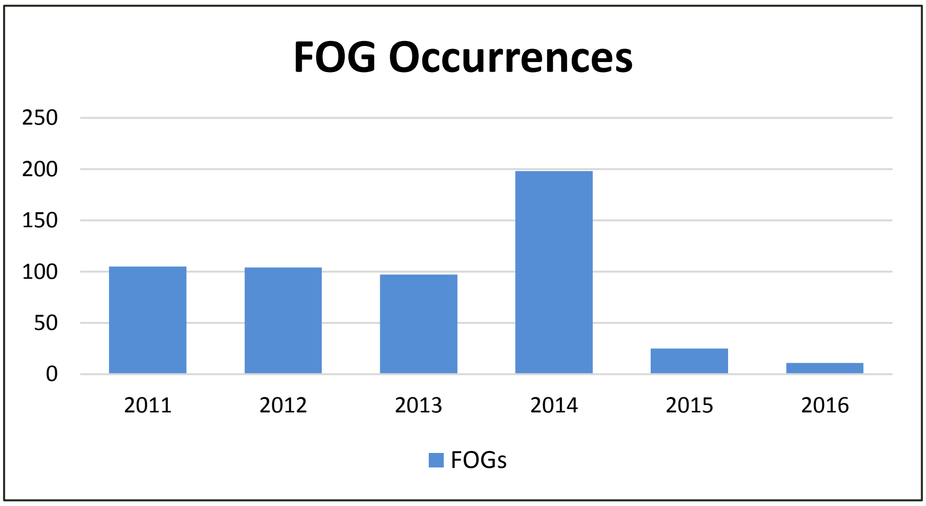

Figure 15: Fall of Ground occurrences from period 2011 to April 2016

Ninety-five percent (95%) of the FOG's are within the cumulative fall out height of 1.3m, which still falls within the support design criteria.

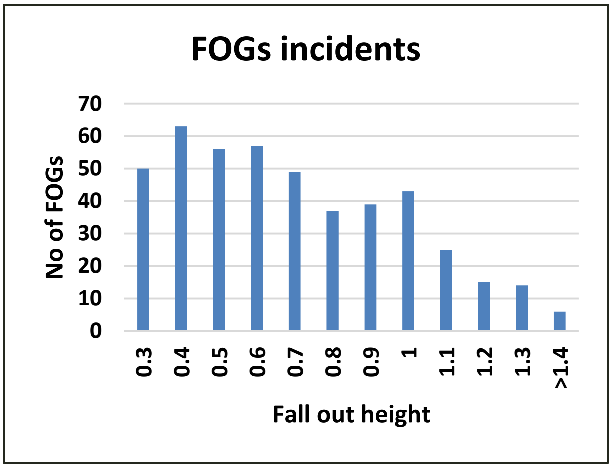

Figure 15: FOGs and fall out height comparison

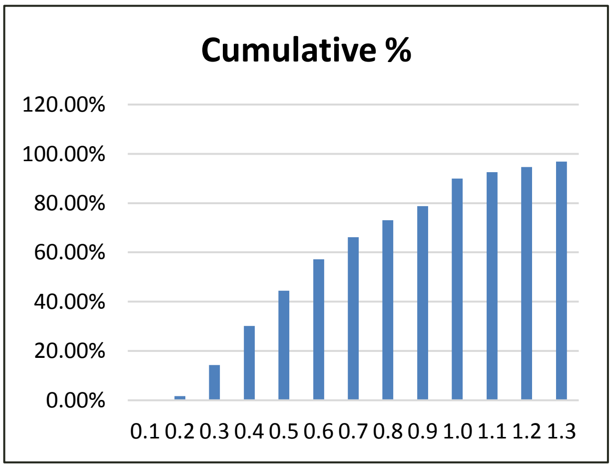

Figure 16: Cumulative fall-out height percentage

Although in the majority of cases, no permanent disabling or fatalities were recorded as a result of falls of ground, this was nevertheless an alarming trend and required critical rethinking of the mining strategies employed. A few of these FOGs resulted in fallout thickness of more than 2.0m, which extends beyond the support zone of up to 1.5m.

5 THE ANALYSIS OF FALLS OF GROUND

As depicted in Part 4 of this paper, the FOG trend has been alarming and in 2014 the mine experienced the highest number of FOGs. Samancor Chrome's risk management system requires that all FOG related incidents are recorded on the database and fully investigated using the Incident Cause Analysis Method (ICAM).
The analysis of FOG incident causes is summarized below. According to the analysis, FOGs can be classified in six categories.

- **Wedge failures** brought about by the interaction of the normal near vertical joints and faults intersection with flatter low angle joints or domal splays. A number of these FOGs resulted in fall out thickness of more than 2.0m, which extends beyond the support zone of up to 1.5m.

Photo 9: FOG due to near vertical joint

Photo 10: FOG and low angle joint

- **The occurrence of disseminated layering or chromitite stringers** above the LG6A seam contributes to beam type failures (Treloar and Steenkamp, 2000 2). Large falls of hanging were recorded in cases where the thickness of this beam is less than 1.0m. Observations indicate that beam thickness of less than 1.0m tends to fall out mainly during blasting, but beam thicknesses of more than 1.0m tend to be fairly stable.

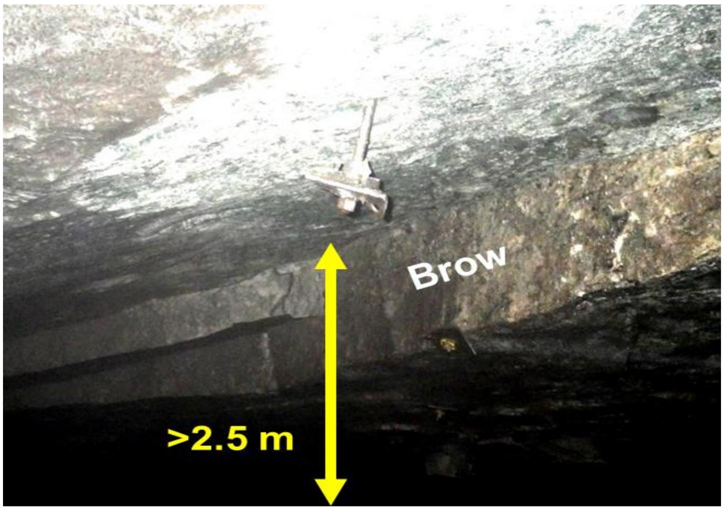

Photo 11: Brow created from FOG (disseminated layering)

- **A frozen hanging wall contact** mainly due to a gradational disseminated top contact of the LG6A in the southern region of the mine was found to be contributing to FOGs. These are mainly small in size and are localized to a specific panel.

- **Combination or intersection of multiple geological structures.** When geological structures intersect, wedge structures are developed in the hanging wall that collapse due to low cohesion and normal gravity. These FOG's may vary between small (less than 10m³) to massive (more than 10m³).

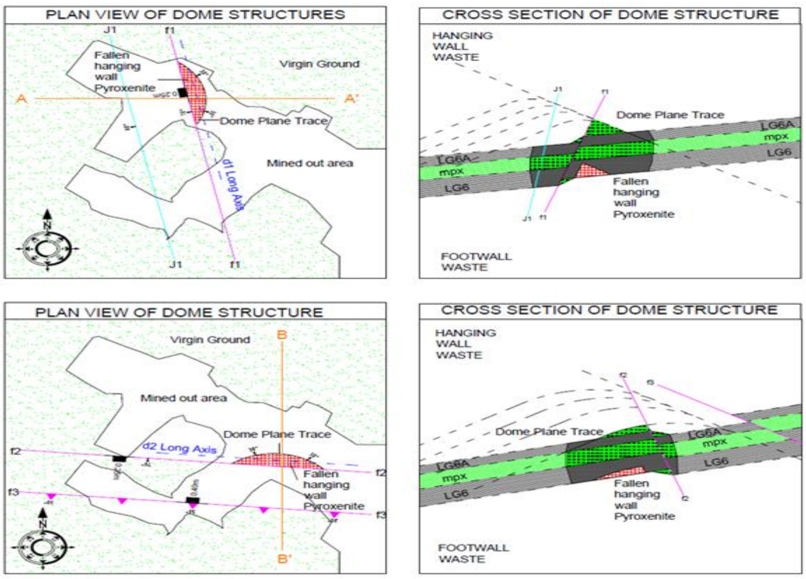

Figure 17: Illustration of the intersection geological structures

- **Low angle curved joints intersections** often results in FOGs. Production personnel often find it difficult to identify these structures with the naked eye. The application of technology to identify these structures has proven critical to the correct decision making in addressing the geological structures.

Photo 12: FOG on low angle curved joint

- **The previous mine design** comprised of rectangular board and pillar with bearing NW / SE layout. Board face length were typically 14m wide with 6m holings. The long length of the board exposes the geological structures over their critical span, and this was found to be contributing to the large scale falls of ground.

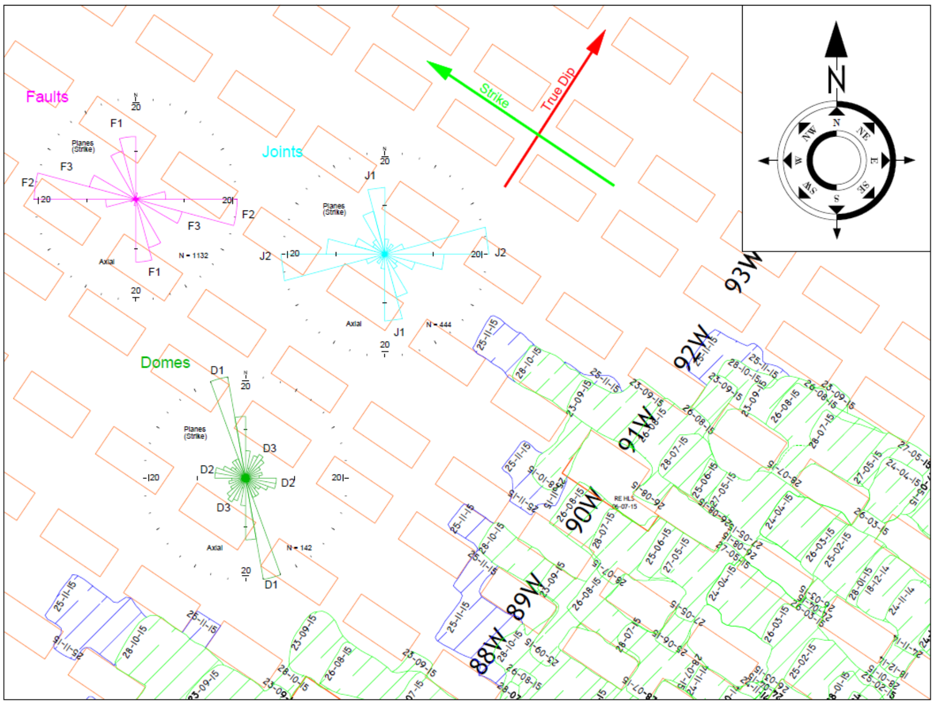

Figure 18: Previous design was 14m board widths with 12m X 6m pillars

6 NEW STRATEGIES IMPLEMENTED

6.1 Geological data collection and interpretations

Mining sections are monitored by geologists and routine visits are done on a monthly basis. Prominent geological structures are identified and compiled into a comprehensive geological report, which is submitted to rock engineering for inputs and sign off.
A LEICA instrument is used to measure and elevate geological structures. This method allows information to be imported directly from the device to AutoCAD mine planning system for faster availability of geological information. This mapping method improves the accuracy, quality and quantity of the underground mapping data.

Underground cover boreholes which are drilled for groundwater and gas control, are also logged in detail to delineate highly weathered and fractured structural zones ahead of mining.

6.2 GPR Technology Application

Numerous structures described in this paper are found exploiting the LG6 chromitite seams and are virtually unidentifiable to the eye, especially near horizontal shear discontinuities, dome structures, low angle curved joint structures. Intersection of one of the aforementioned structures with a near vertical structure results in to FOG.

Production personnel are unable to successfully identify unexposed low-angle structures, dome-structures or other discontinuities in the hanging wall rock. For this reason, the mine adopted the Ground Penetrating Radar (GPR) technology to detect the above mentioned structures.

All working panels are assessed using the GPR for presence and extent of geological structures. The frequency of the assessments per working place was increased to every third blast. Panels are not allowed to advance more than nine metres without being scanned. Working panels are classified according to Low, Medium and High risk using the GPR results and in conjunction with near vertical structures mapped by the geologist.

Planned pillar size and layouts are constantly adjusted in order to stabilize the perceived “domes” as per the GPR scanning results. The Low and Medium classification determines the support spacing required. High risk panels or areas with major dome structures and faults intersections are left unmined to prevent off-reef mining and exposure of employees to hazardous ground.

6.3 Mine planning / design and layouts

The planned pillar dimensions and critical board spans were scrutinised in order to determine the optimum layout. Inevitably the design of the mine was revised. By influencing the input process of the mining strategy combined with layout redesign, a more predictable outcome was achieved. Changing from 14m board widths with rectangular 12m by 6m pillars to the 10m by 10m square configuration with board width of 10m for mining at a depth below surface of 400m, result is a 5% reduction in extraction ratio but improves pillar stress with a 60 % reduction and yielded a 54% increase in pillar factor of safety.

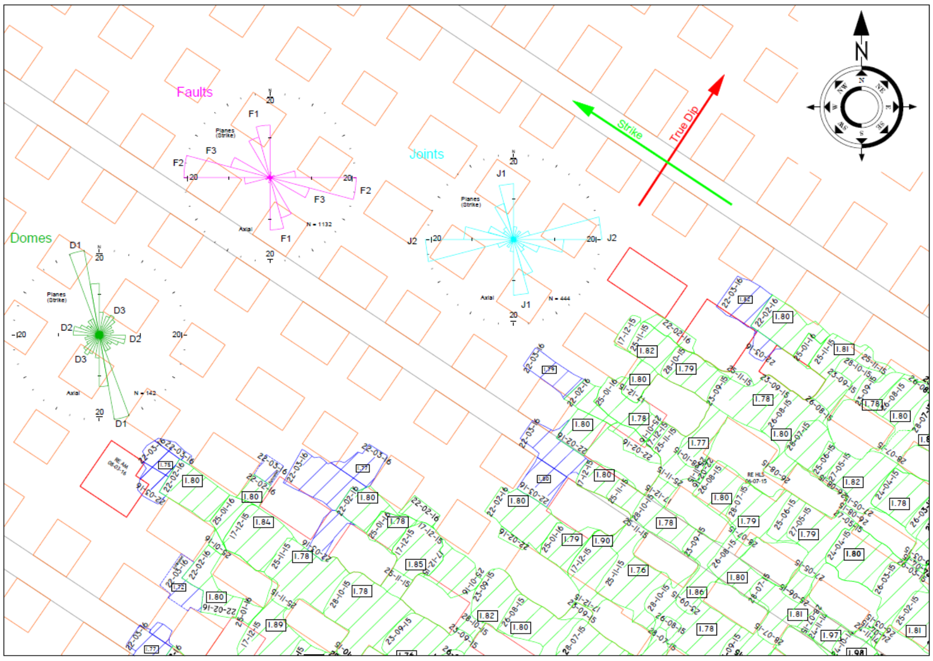

Figure 19: Revised pillar design with 10m X 10m pillars

The table bellows illustrates the impact of revised layout to the extraction ratios and factor of safety calculations.

Pillar stress and resultant pillar factor of safety calculator																		
Depth below surface	Overburden density	Gravity	Virgin stress at DBS	Pillar dimensions			Tributary area theory								Pillar Strength	Pillar Stress	Factor of safety	Extraction
				P L	P W	h	L		B	e	W eff	DRMS	W(0.5)	H(0.75)				
400	3150	9.8	12348000	12	6	1.7	18	360	20	0.7	8	35	2.82843	1.4888	66.49	41.16	1.62	80.00%
400	3150	9.8	12348000	10	10	1.7	20	400	20	0.7	10	35	3.16228	1.4888	74.34	41.16	1.81	75.00%

Table 1: Pillar calculations for 12m X 6m vs 10m X 10m pillars at 400m BS (Salamon and Munro, as cited in Ryder and Jager, 2002).

Effective face length has been reduced by 28%, i.e. more than a quarter. When extrapolating the mean azimuth of the individual geological discontinuities as obtained from the Rose diagram plots on to the mines plan it is observed that the reduction of exposed discontinuity, not supported by a pillar as per individual layout is directly proportional to the reduction of face length. The revised layout resulted in a 28% reduction in the unsupported length of the geological discontinuities.

As in-stope support, 1.5m long by 14mm diameter mechanical end anchor bolts are installed spaced 1m x 2.5m apart. Where the need to support a major dome structures in the hanging wall is identified by the GPR technology, additional support in the form of 4.5m long, 18mm diameter (380 kN) pre-tensioned, full column grouted cable anchors are installed in long term excavations.

This system is assisted by additional in-panel pillars for local hanging wall control as dictated by geological weaknesses and at shallow depths the protection of specific surface structures.

6.4 Mining Method application

Predominantly drilling of the blast round in the boards is done with drillrigs drilling an effective round of 3.0m. The presence of chromitite stringers in the hanging wall associated with low tensile strength have an impact on the stability of the excavations. This implies that strict mining discipline has to be enforced at all times. A break in the continuity of the beam in most cases results in localized FOGs which are likely to result in injuries to persons. Total suspension of the pyroxenite beam is required under these conditions. Hence it was decided that in areas with more complex geological challenges and where the chromitite stringer is thinning out, to drill by means of hand held techniques. The shorter round of 1.8m and smaller diameter blast hole further minimises blasting damages to the excavation hanging walls.
Due to the poor competency of the hanging wall of these areas, in-stope safety nets have been introduced along with continuous barring to ensure the safety of the excavation.

6.5 Blast Techniques

The destabilization of these geological structures were observed to occur predominantly after the blast, subsequently the blasting medium was changed from high density Anfex 300 to low density Anfex 200 in order to minimise the propagation of gasses into the discontinuities.
Reducing the effective face length from 14m to 10m, i.e. 28% reduction in face length, resulted in a similar decrease in the amount of explosives used per blast and more than a quarter reduction in the discontinuity span exposed to the effects of the propagation of gasses into these geological discontinuities, consequently less energy from the explosives is transmitted into "shaking" these geological structures from a state of equilibrium.
In using explosives with a reduced velocity of detonation together with the reduction of the critical span delivered significant potential in stabilising the impact of complex geological structures.

7 CONCLUSIONS

The importance of identifying the variation and the behaviour between the different types of geological structures is by far the most important factor to consider during mine the design, planning and scheduling.

The availability, accuracy and quality of geological information have improved by using the LEICA instrument to measure geology structures underground. The increased GPR scanning of working places allows for proactive decision making by production personnel on ground conditions. The combination of the GPR interpretations in and structures mapped by the geologist have enhanced the accuracy of the Rock engineering risk rating system.

The modification in the pillar design (a square board and pillar design of 10 x 10 m) has optimised flexibility and decrease production risk due to the increase in contingency faces.
In addition in-stope safety nets have been implemented along with continuous barring to decrease risks of potential FOG.

Optimising mining spans by reducing 28% of the unsupported length of geological structures, minimising induced stress realised a significant improvement in effectively managing the impact of geological structures within the excavations.

Due to the numerous variables influencing the over and under mining of pillars, no clear data could be obtained to determine if the change in lay-out could balance the planned extraction ration with the actual extraction ratio.

Blast damages to surrounding rockwalls are minimised by changing the blasting medium to low density Anfex explosives, replacing drill rigs with the hand held drilling technique, resulting in shorter and smaller diameter blast holes. In addition, by changing the drilling and blasting technique the downstream process of tip handling, hauling, belt damages, screening, processing and recovery are improved.

The results and application of these new systems, strategies, technology, revised blasting techniques and mining methods assisted in reducing the risk of uncontrolled major FOGs and simultaneously increasing the production and profitability.

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