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Facies variation in the Merensky Reef at Bafokeng Rasimone Platinum mine

P. MOODLEY
Anglo Platinum

The Bafokeng Rasimone Platinum Mine (BRPM) is a joint venture between Rustenburg Platinum Mines Limited, the Royal Bafokeng Resources (Pty) Ltd and the Royal Bafokeng Nation, and is situated on the farm Boschkoppe 104JQ on the Western Limb of the Bushveld Complex.

The primary orebody currently being exploited is the Merensky Reef, which is geologically complex due structural influences, resulting in the highly variable characteristics of the Merensky Reef. This variability of the Merensky Reef at BRPM necessitated a classification of facies types. On the basis of this variability, the Merensky Reef at BRPM has been classified into 11 facies types.

The facies classification is largely a function of a footwall control and the stratigraphic position of the Merensky Reef, which directly influences the mineralization distribution. Other geological parameters taken into consideration include lithological and structural characteristics of the Merensky Reef. The 11 distinct facies types comprise Pegmatoidal facies, contact facies, shallow FW1 pothole facies, deep FW1 pothole facies, FW3 pothole facies, FW5 pothole facies, FW6 pothole facies, FW7 pothole facies, catastrophic pothole facies, abutment facies and pothole edge facies.

The pegmatoidal facies and contact facies occur on top of a full sequence stratigraphy and have a large component of footwall mineralization. However, the pothole facies contains greater mineralization in the hangingwall. The catastrophic pothole facies consists of a deep pothole environment associated with a complete disappearance of the reef. The pothole edge facies type is situated along the edges of potholes in a transition between facies types. The abutment facies type is a compressed stratigraphic sequence associated with major structural influences. The facies classification of BRPM assists in predicting the mineralization of the Merensky Reef, therefore allowing optimal grade extraction of the platinum within the ore. The availability of facies percentages, together with the identified structural domains has resulted in major developments in evaluation of the BRPM orebody.

Introduction

Bafokeng Rasimone Platinum Mine (BRPM) is a joint venture (JV) among Rustenburg Platinum Mines Limited (RPM), the Royal Bafokeng Resources (Pty) Ltd and the Royal Bafokeng Nation. At present, only the Merensky Reef orebody is being extracted from two operating decline shafts, North Shaft and South Shaft. There is limited development into the UG2 horizon, which varies from 30–80 m stratigraphically below the Merensky Reef. The Merensky orebody strikes northwest-southeast and dips from 10 to 17 degrees towards the northeast. BRPM is faced with challenging mining on a daily basis. One of the major contributory factors to the difficult mining conditions is the complex geology.

Previous exploration by Rand Mines and JCI considered the area to be too structurally complex, therefore limited mining took place before the development of BRPM (Lomberg *et al.*, 2004). There has been substantial amount of work since Anglo Platinum defined a mineable Merensky Reef reserve on the property. With reference to work by BRPM (Lionnet and Lomberg, 2007; Vermeulen, 2004), research clearly indicated the Merensky Reef is highly variable in nature, resulting in grade sensitivity.

Initial attempts to model the orebody raised many concerns, therefore it became of utmost importance to fully understand the geology (Lionnet and Lomberg, 2007). The Anglo Platinum Geology Department and The Mineral Corporation (acting on behalf of the Royal Bafokeng Resources in 2002–2003) pioneered the focus on the facies types that govern the Merensky Reef orebody, giving rise to the definition of 11 facies types.

Facies is a sedimentary concept defined as 'the appearance and peculiarities that distinguish a rock unit from an associated or adjacent unit' (Lapidus, 1990), which is applied in the igneous environment to assist with geological interpretations. The compilation of a useful facies plan assists in expanding the geological knowledge of BRPM for successful mining.

Locality

BRPM is located 30 km northwest of Rustenburg between Anglo Platinum's mining sections of Rustenburg Section and Union Section. BRPM is updip or immediately west of Impala Platinum's mining section (Figure 1). The current mining operations of BRPM North Shaft and South Shaft are situated within the farm boundary of Boschkoppe

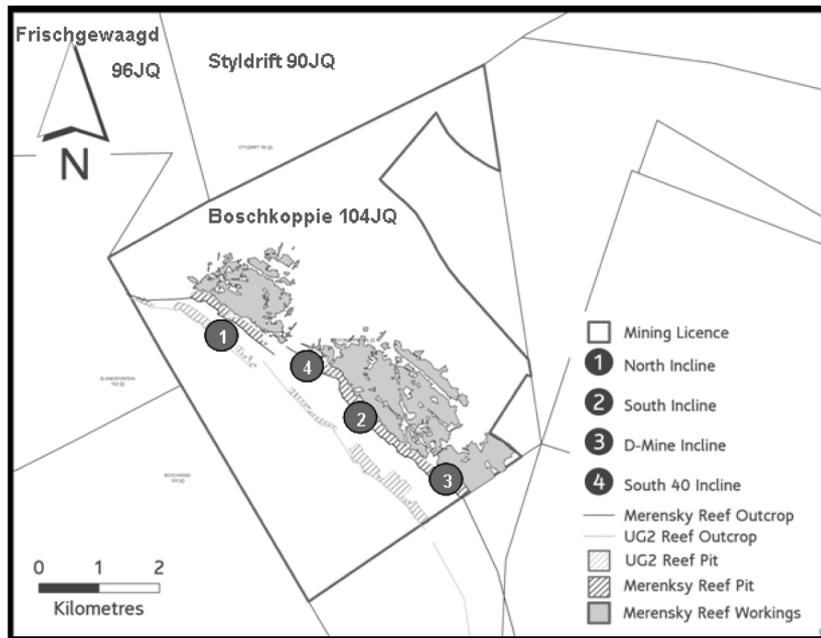


Figure 1. Locality of the farm Boschkoppie 104JQ

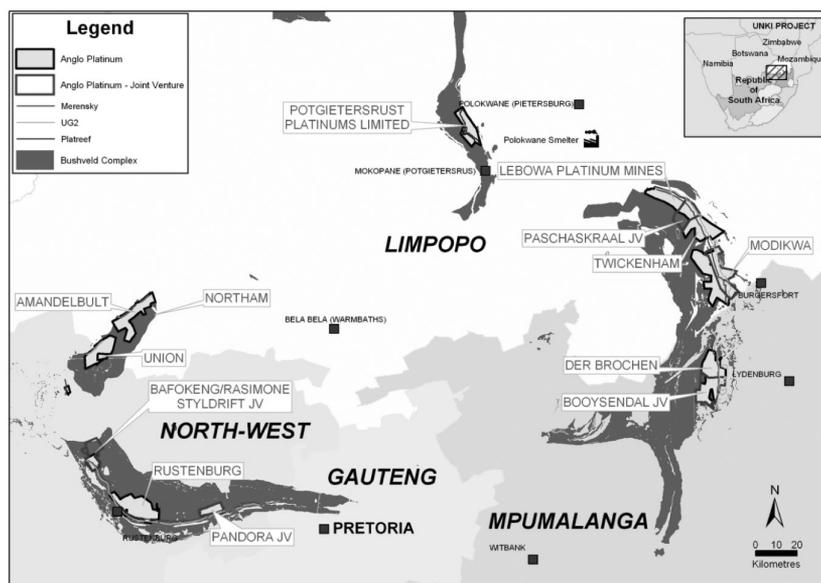


Figure 2. Western Limb of the Bushveld Complex

104JQ. The farm Boschkoppie 104JQ was contributed to the JV by RPM. North of the Boschkoppie are the farms Styldrift 90JQ and Frischgewaagd 96JQ, where exploration projects as part of the JV agreement are currently evaluating the PGM mineral resources. (See Figure 1.)

Geology

Regional Setting

BRPM is situated on the Western Limb of the Bushveld Complex (Figure 2). Approximately 10 km north of BRPM is the Pilanesberg Alkaline Complex, which is an igneous intrusion that forms a distinct topographic feature. In the northern Pilanesberg area, rocks of this complex form a prominent ridge. Immediately west of BRPM is a range of

low-lying quartzite hills of the underlying Transvaal Sequence. The proximity of the Upper Critical Zone rocks to the quartzites is believed to be a factor in the BRPM geology. The Rustenburg Fault can be mapped through these hills (Lomberg *et al.*, 2004). Iron replacement pegmatite (IRUP) intrusions are located in the northwestern part of BRPM and add to the complexities of both the geology and mining as a result of the thinning or pinching out of stratigraphy as development approaches these iron rich replacement bodies.

The stratigraphic layering strikes northwest to southeast over a distance of approximately 7.3 km, and dip to the northeast between 10 and 17 degrees with an average dip of 11 to 12 degrees. Close to the IRUP intrusions, the layered sequence becomes more undulating with steeper dips.

Stratigraphy

The stratigraphic nomenclature currently used at BRPM (Figure 3) is similar to that applied by the Impala Platinum Mines, adapted by E.S. Martin from the work of Leeb-du Toit (1986). In this naming convention, the footwall units which are noritic, are assigned odd numbers (FW1, FW3, FW5 and FW7) whereas the footwall layers comprising poikilitic anorthosite have even numbering (FW2, FW4, FW6). A clear comprehension of the local stratigraphy is essential as it provides the basis of the facies classifications. The key facies types are classified according to the reef position in the footwall stratigraphy.

Brief stratigraphic descriptions of footwall and hanging wall lithology

FW1 is 1.5–3 m thick and consists of three divisions (i.e. FW1A, FW1B, FW1C). The FW1 unit has an upper poikilitic anorthosite layer with thicknesses ranging from a few centimeters to 0.5 m. The thickness of this layer tends to increase moving away from North Shaft into the South Shaft area. The poikilitic anorthosite of FW1A grades into a leuconorite (FW1B) and ends in a norite (FW1C), whereby the total FW1 unit can reach a thickness of up to 3 m (Figure 3).

FW2 is a pink poikilitic anorthosite band as shown in Figure 3. It ranges in thickness from 10cm to 30cm and has a characteristic 1–3 cm pyroxenite band below. The thickness of the poikilitic anorthosite increases with a greater prominence of the pyroxenitic band moving away from North Shaft into South Shaft.

FW3 is a noritic unit that grades from a melanorite on top to a leuconorite at the base (Figure 3).

FW4 is characterised by a pink poikilitic anorthosite band with a thickness of 0.5–1 m, as depicted in Figure 3. Occasionally, there is 1cm to 2cm hartzburgitic band at the base of the unit. In the North Shaft area, the poikilitic anorthosite is well developed but tends to thin towards South Shaft area and if present, the hartzburgitic band begins to shear out. In the South Shaft area, the characteristic FW4 is absent with only sheared remnant remaining.

FW5 is a banded olivine bearing leuconorite, ranging from 1–4 m in thickness. FW6 is a pink poikilitic anorthosite band is 0.5 m–6 m thick.

The FW6 unit is a critical marker within the stratigraphy that consists of two characteristic features. FW6 contains boulders of pegmatoidal pyroxenite near the base. As a result, this unit is also referred as the Boulder Bed. An additional distinguishing feature of the FW6 is the 1mm to

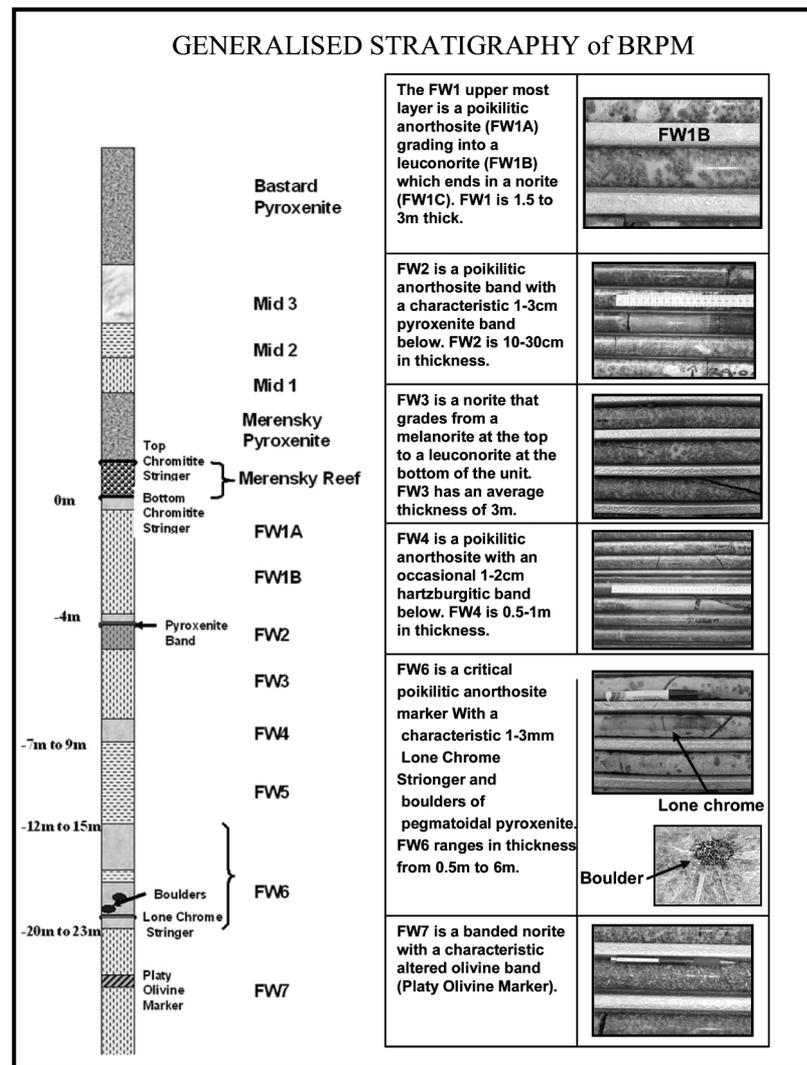


Figure 3. Generalized stratigraphy of BRPM

3mm chromitite stringer known as the Lone Chrome stringer. The Lone Chrome stringer generally occurs towards the base of the FW6 unit at North Shaft and towards the top at South Shaft. The FW6 layer decreases in thickness from 6m at North Shaft to 0.5 m at South Shaft.

FW7 is a typical banded norite with discontinuous leuconorite and poikilitic anorthosite bands. FW7 consists of a characteristic platy olivine marker (POM). The POM is an altered olivine bearing band which has a tendency to break up into thin discs along the preferential orientation of the serpentinized olivine-magnetite grains.

The Merensky pyroxenite is the hangingwall of the Merensky Reef. It is a feldspathic pyroxenite of 0.8–1.2 m in width. Above the Merensky pyroxenite is the middling, which grades from a melanorite (Mid 1) through a norite (Mid 2) to a leuconorite (Mid 3).

Above the middling is the bastard pyroxenite, which is a feldspathic pyroxenite layer approximately 2 m thick and 9 m above the Merensky Reef. During mining the bastard pyroxenite is sometimes mistaken for the Merensky pyroxenite due to a similar resemblance; however, the bastard pyroxenite is much thicker, relatively flat or much less undulating than the Merensky pyroxenite.

Objectives of the facies plan compilation

Discrepancies between the estimated grade values and the actual achieved during initial mining raised concern. Work by The Mineral Corporation and BRPM revealed that there were different reef types and distinct footwall controls that influenced the grade. This gave rise to the ‘facies’ concept, whereby the evaluation of the Merensky Reef needed to be considered as different facies types.

North Shaft began to incur a similar geological signature aligned to that of South Shaft as mining approached the boundary that divides the two, i.e. The Railway Fault. It therefore became necessary to create a standard of the facies types interpreted and produce a plan showing the distribution of the facies types over the mine lease area.

This therefore provided the following objectives:

- Classify all identified facies types that influence the grade significantly
- Research the geological parameters and characteristics that define the individual facies types
- Define an integrated facies model for the entire mine, encompassing both North Shaft and South Shaft

- Define the areas in which the different facies types occur
- Understand the importance in the application of facies classification.

Previous facies model

Initially the Merensky Reef at BRPM was classified according to 3 facies types or what was referred to as sub-facies (Lomberg *et al.*, 2004). These facies types were the pegmatoidal, contact and pothole sub-facies. The pegmatoidal and contact sub-facies were categorized as normal reef, they stratigraphically sit on a full sequence, whereas the pothole sub-facies is the potholed reef (Figure 4). The pegmatoidal sub-facies is a typical pegmatoidal feldspathic pyroxenite bounded by two chromitite stringers, where the lower chromitite stringer is more prominent and the upper chromitite stringer is much thinner or absent. The Merensky Reef has an average thickness of 20 cm (Lionnet and Lomberg, 2007). The contact sub-facies occur where the lower chromitite stringer is present and the pegmatoidal feldspathic pyroxenite is absent (Lionnet and Lomberg, 2007). Therefore, the immediate hangingwall above this lower chromitite stringer is the Merensky pyroxenite. The pothole sub-facies consists of a pegmatoidal feldspathic pyroxenite bounded by two chromitite stringers. The upper chromitite stringer is more prominent and the lower chromitite stringer is absent or poorly developed. Average thicknesses ranges from 60–80 cm (Lionnet and Lomberg, 2007). The degree to which the potholing has transgressed will determine the immediate footwall of the reef.

New facies model

Principles applied in defining potholes at BRPM

It is essential to understand that the term ‘pothole’ at BRPM is adopted only with certain types of rolling reef. The term pothole is strictly used when the reef rolls down, from sitting on a particular stratigraphic unit to settle on a completely different stratigraphic layer, e.g. if the reef rolls down from a FW1 down to a FW3. When the reef rolls down and settles within the same unit it was initially sitting on, this is merely termed a ‘slump’. It is important to note that at BRPM the rolling reef tends to become more stable when settling on FW1, FW3 and FW6, and rarely settles on

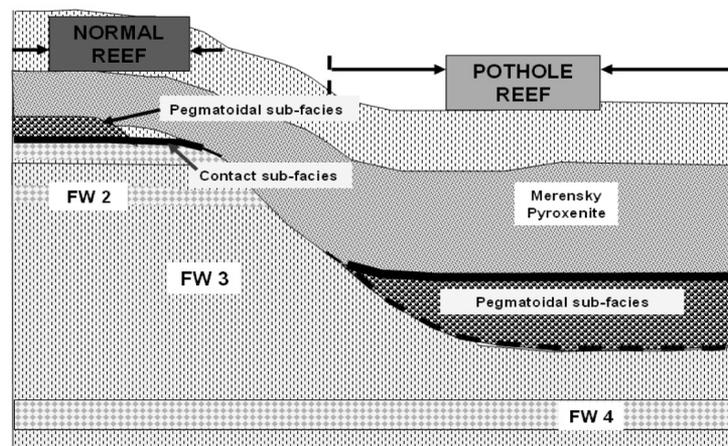


Figure 4. Section shows first 3 facies types defined

FW2 and FW4 but cuts through these layers to reach stability. It is these first principles that are applied when mapping reef positions within the stratigraphy.

Identification of additional facies types

Extending from the work of Lionnet and Lomborg's initial facies classifications (2004, 2007) it is now realized that the reef's position in terms of potholed elevation in the stratigraphy exhibits different grade profiles and associated mineralogical, metallurgical and geostatistical signatures. Referring to the section below the corresponding grade profiles (Figure 5) highlights the differing mineralization distributions depending on where the potholed reef sits in the stratigraphy. As a result, the pegmatoidal and contact facies remained in the facies classifications, but the pothole facies was further subdivided to accommodate the differing grade distributions exhibited when the reef settles on different footwall layers. Anomalies which could not be classified into the defined facies types were categorized separately.

Therefore, the following parameters used to classify the new facies types:

- Reef position within the stratigraphy
- Lithological characteristics
- Structural characteristics

Data sources

Drill holes

Data of facies intersections were collected and used from all underground and surface drill holes in the BRPM database.

Structural plans

The pothole structures are interpreted off the borehole reef intersections and confirmed using detailed underground mapping. These plots of the structural plan assisted in zoning the potholed reef occurrences and the degree to which the reef has potholed, i.e. identifying the type of footwall the reef sits on.

Interpretation

Microstation software was used to physically delineate the facies boundaries or zones by interpreting polygons from the reef intersection points and potholes from the structural plans.

The identified facies types were correlated across the mining boundary of North Shaft and South Shaft.

Facies type descriptions

Using the parameters discussed in the methodology above, a total number of 11 facies types were identified and these are divided into 3 main categories.

Full sequence facies types

The full sequence facies types, otherwise known as the normal reef facies, sits directly on the poikilitic anorthosite of FW1A, the upper most layer in a complete stratigraphic footwall sequence as shown in the section of Figure 6.

Pegmatoidal facies

The pegmatoidal facies consists of a pegmatoidal feldspathic pyroxenite bounded by a top and bottom chromitite stringer. The lower chromitite stringer is more

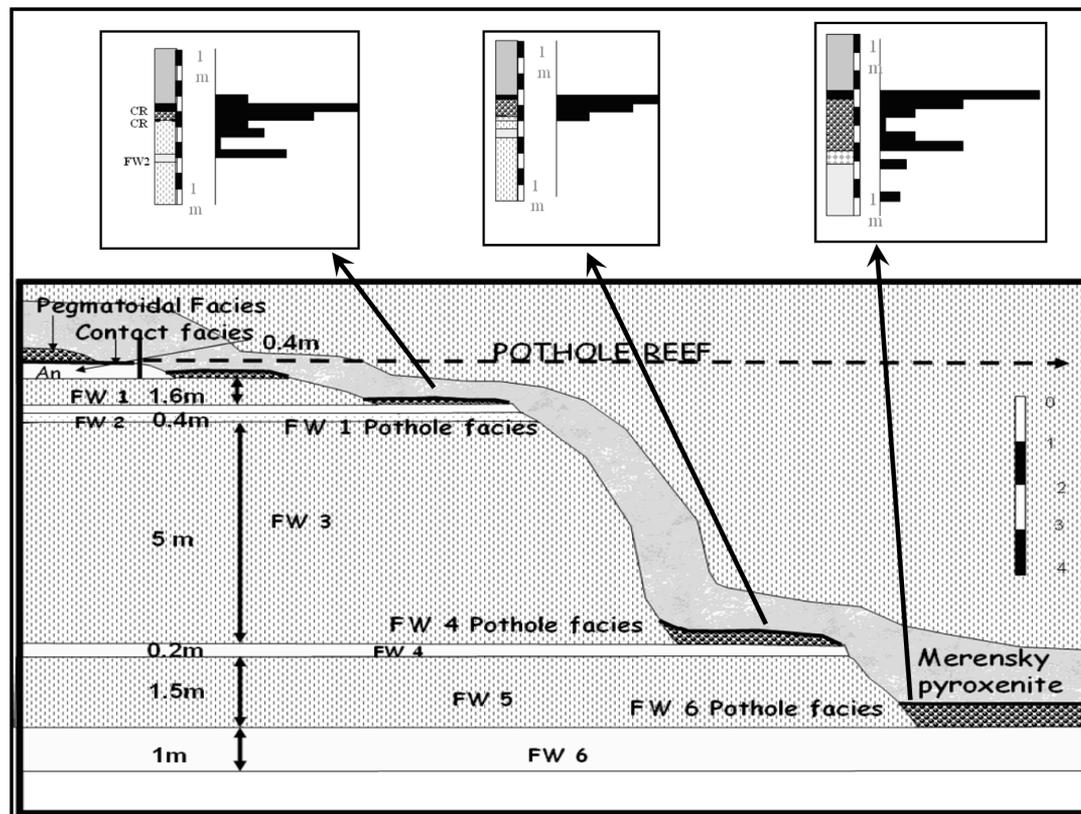


Figure 5. A schematic section showing different degrees of potholing with different grade distributions

prominent with a thickness up to 5 cm. The upper chromitite stringer is less than 1 cm. The pegmatoidal facies type has an average thickness of 9–11 cm. The pegmatoidal feldspathic pyroxenite has interstitial sulphide blebs of pyrrhotite and chalcopyrite. The pegmatoid consists of 10 to 20 mm diameter cumulus bronzite with interstitial feldspar (Lionnet and Lomberg, 2007).

Contact facies

In the contact facies, the pegmatoidal feldspathic pyroxenite is absent and consists only of the bottom chromitite stringer. The chromitite stringer is directly overlain by the medium grained Merensky pyroxenite (Figure 6). The Merensky hangingwall pyroxenite typically contains sulphides mineralization approximately 50 cm from the basal contact and also extends into the footwall (Lionnet and Lomberg, 2007).

It is important to note, the contact facies can be confused with the chrome edge reef type, which develops on pothole edges. The contact facies sits on a full sequence poikilitic anorthosite of the FW1A.

Pothole facies type

This facies type is classified based on the reef settling on a lower elevation or a lower stratigraphic footwall layer to the FW1A. The potholed facies has a thick pegmatoidal feldspathic pyroxenite bounded by two chromitite stringers. The pegmatoidal pyroxenite of the potholed reef has an average thickness between 60–80 cm. The upper chromitite stringer is prominent reaching thicknesses up to 5 cm. The lower chromitite stringer is poorly developed or absent.

FW1 pothole facies

The FW1 pothole facies (Figure 6) stratigraphically overlies a FW1B or FW2 and has the least developed pegmatoid of the potholed reefs. At the time of the compilation of the facies plan, it was suggested by Lionnet (2006) to subdivide the FW1 pothole facies into two categories, namely the shallow FW1 pothole facies and the deep FW1 pothole facies. The immediate footwall of the shallow FW1 pothole facies is the upper noritic FW1B just below the FW1A. The elevation difference between the normal reef elevation and shallow pothole ranges from 10 cm to 60 cm. The immediate footwall of the deep FW1 pothole facies is the lower portion of the FW1B, or the FW2. The reason for the subdivision was supported by the fact that the two categories exhibited significantly different grade profiles. However, during the 2008 geological resource modeling of the Merensky Reef by Iain Colquhoun, the FW1 pothole facies was not subdivided for reasons of simplification.

FW3 pothole facies

The Merensky Reef overlies the norite of the FW3 or the poikilitic anorthosite of FW4 and tends to have the lowest grades, where the grade profile is confined to the pegmatoid. (Figure 6).

FW5 pothole facies

In the FW5 pothole facies, the Merensky Reef overlies a medium to coarse grained olivine leuconorite of FW5 as depicted in Figure 6.

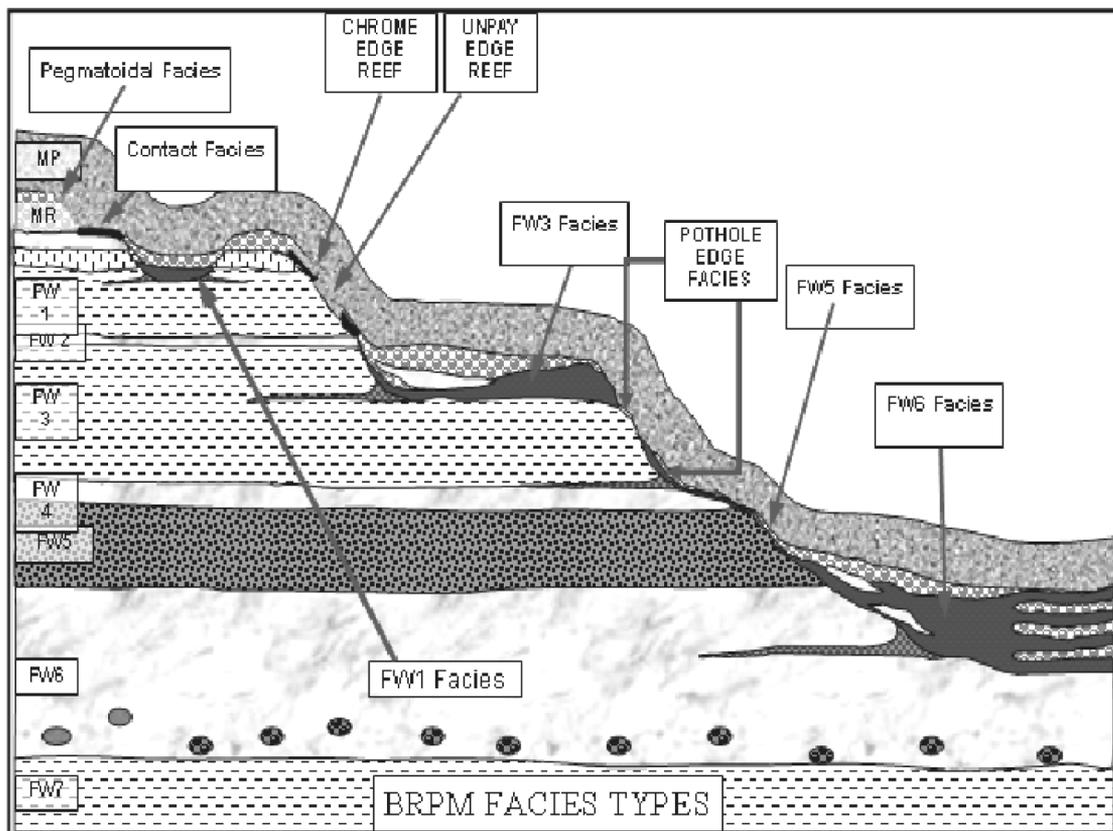


Figure 6. Section depicts BRPM facies types and their stratigraphic positions

FW6 pothole facies

This is the best developed of the potholed facies types and tends to have the thickest reef widths up to 1.2 m as shown in the section of Figure 6. There are occurrences of a hartzburgitic footwall with sporadic grades. The hartzburgite is associated with all potholed facies types but is better developed within the FW6 pothole facies.

FW7 pothole facies

The immediate footwall of the Merensky Reef in the FW7 pothole facies is the medium grained norite with discontinuous leuconorite and anorthosite bands (banded norite) of the FW7.

Catastrophic pothole facies

This facies type is similar to that of the FW7 pothole facies, whereby it is generally found deep in the footwall stratigraphy. However, in the catastrophic pothole facies the stratigraphy is completely disrupted, expressed as an inconsistent occurrence of pyroxenite, footwall norite and poikilitic anorthosite, typically associated with hanging-wall and footwall. Compared to the FW7 pothole facies the reef is poorly developed and becomes very difficult to identify, if present it consists of discontinuous erratic feldspathic pyroxenite lenses.

Other facies types

Pothole edge facies

This facies is found along the pothole edges during facies transitions, where the reef rolls down to settle on a lower footwall layer. It is on this transitional edge where the pegmatoidal feldspathic pyroxenite thins to a chrome edge reef type (Figure 6), which is a chromitite stringer that sits between the footwall and hangingwall (Merensky pyroxenite). The chrome edge reef then further thins to a point where the Merensky pyroxenite directly overlies the footwall which is known as an Unpay Edge Reef shown in the section below. Associated at the bottom edge of the pothole is the pseudo-reef formed as a result of the rolling reef. The pseudo-reef is a goose-neck feature, whereby a tail of the same lithological composition forms within the footwall. Therefore, the pseudo-reef is overlain and underlain by footwall rocks. Mineralization diminishes toward the tail end. The true reef and Merensky pyroxenite rolls up into the hanging creating unsafe conditions.

Abutment facies

This facies type is geographically located in the NW block of the mine. The stratigraphy is significantly thinner to a point where the Bastard Reef is situated directly on top of the Merensky Reef or the Merensky Reef overlies footwalls ranging from FW1 down to LG6, and dips at a steep angle of 35°. In some areas, the reef is only developed in pockets or depressions and is described by Lionnet (2006) as a series of sequences on the edge of a magma chamber. Currently, there is research being carried out to gain a better understanding of the abutment facies.

Facies types applied for the BRPM Merensky geological resource modelling

A simplified classification of facies types according to Facies 1.1, Facies 1.2, Facies 3 and Facies 6 were used during the 2008 resource modelling by Iain Colquhoun. The full sequence facies, i.e. the pegmatoid facies and contact facies were classified as facies 1.1. The FW1 facies was used as a single category called facies 1.2 without the subdivisions discussed in section 6.1. FW5 pothole facies and FW6 pothole facies were classified as facies 6. FW7 pothole facies due to their catastrophic nature, was excluded as a geological loss (Colquhoun, 2008). The 'other facies types' were excluded for reasons of simplification.

Grade distribution of facies types

The mineralization of the Merensky Reef is confined to the pegmatoidal feldspathic pyroxenite and limited to a certain extent, into the hangingwall and footwall, with highest PGE concentration peaking at the chromitite stringers. The histograms of the grade profiles clearly illustrate the full sequence facies types have an optimal cut being a footwall cut with greater mineralization from the reef contact into the footwall, highlighted by the profiles in Figure 7. Grade profiles of the pothole facies in Figure 8 clearly show a hangingwall cut as the optimal cut, with greater mineralization distributed from the reef contact towards the hangingwall. The FW3 pothole facies has a limited width of mineralization confined to the pegmatoid only (Lionnet and Lomberg, 2007). FW6 pothole facies exhibits some of the highest grades as a result of the thicker reef widths and the mineralization in the hartzburgitic footwall. The differing grade profiles of the facies types highlights the importance

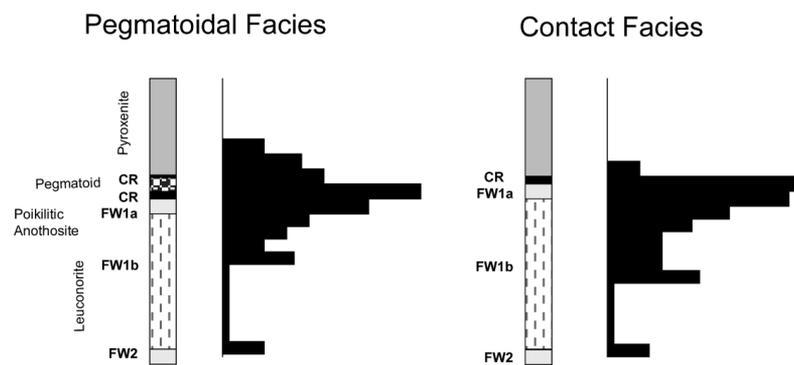


Figure 7. Grade profiles of the full sequence facies types

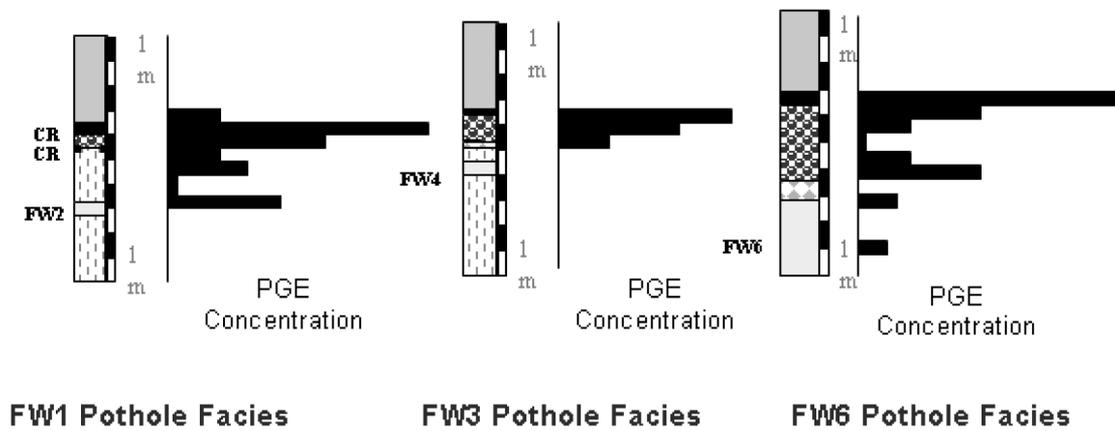


Figure 8. Grade profiles of the pothole facies types

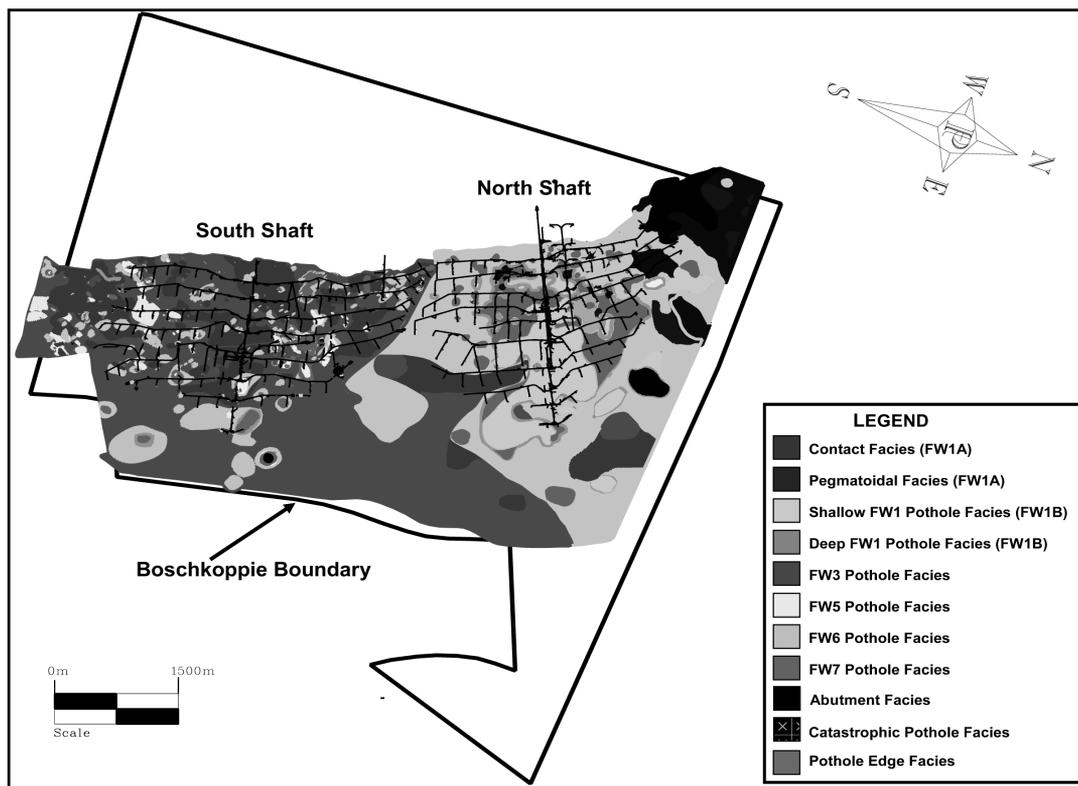


Figure 9. BRPM Merensky facies plan depicting the distribution of the newly defined facies types

of mining a certain facies at its optimal cut, and how grade sensitive the geology can be with mining at the incorrect cut or keeping the cut the same over the different facies.

Interpretation of the facies plan

With each shaft working independently on their defined facies, the newly correlated and combined facies creates a single standard across BRPM. This helps in establishing a common understanding. The facies plan illustrates a clearer picture and completely different environments of the two shaft areas (Figure 9). South Shaft is dominated by the full sequence facies types and North Shaft has more of a

pothole sequence. By studying the final facies plan produced in Figure 9, South Shaft consists of smaller erratically distributed potholes, whereas North Shaft potholes are much larger in size. The application of the facies plan increases the confidence in grade estimations and therefore allows the Geology Department to have a greater input in mine planning. With timely estimations, optimal grade extraction can be ensured for each facies type as they have been classified together with their mineralization characteristics. Therefore, South Shaft area will be dominated by a footwall cut for optimal extraction whereas North Shaft will apply hangingwall cuts to the potholed areas for optimal extraction.

Conclusion

Correlation of the facies types across BRPM boundaries creates a single facies plan bringing about a standard and a common understanding of the Merensky Reef. Classification into facies types that significantly influence grade helps better understand the local geology and thereby assists in predicting mineralization and applying this knowledge to gain an optimal cut. Identifying more definite zones of where the facies offers the potential to improve evaluation and the consequent planning. By understanding the importance and how the facies plan can be applied, it is now a relatively simple tool used practically in mining by the Mining, Survey, Planning and Geology departments.

The BRPM team has come along way in overcoming the difficulties of this grade sensitive orebody by taking the initiative to understand the Merensky Reef in terms of facies. By classifying the Merensky Reef according to facies types, using the parameters discussed in this paper, has converted what was once perceived as difficult and very challenging areas into an economically viable orebody.

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Prinushka Moodley

Geologist, Anglo Platinum

Prinushka as a bursar with Anglo Platinum, completed degree at Wits University and began as a Graduate in Rustenburg Section of 2006, appointed at BRPM as Section Geologist at North Shaft in 2007. Recently promoted to Shaft Geologist, managing the drillhole database for BRPM.

