The application of facies classification in evaluating the Merensky Reef at Bafokeng Rasimone Platinum Mine, South Africa

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Synopsis

The Bafokeng Rasimone Platinum Mine (BRPM) is a joint venture between Rustenburg Platinum Mines Limited and Royal Bafokeng Resources (Pty) Ltd (Bafokeng). The mining lease has been granted over Boschkoppie 104JQ and is located approximately 10 km south of the Pilanesberg Alkaline Complex. The Merensky Reef, which constitutes the principal orebody, is geologically complex. A relationship between its geological variability and the associated mineralization has been established by defining a number of facies types. The Merensky Reef has been subdivided into seven distinct facies types: the pegmatoidal facies, contact facies, FW1 pothole facies, FW3 pothole facies, FW6 pothole facies, and FW7 pothole facies. The Merensky Reef, which does not form part of the potholed reef, has a large component of footwall mineralization. The pothole facies, in contrast, has mineralization located in the hangingwall. Statistical analysis of the facies types indicates that they are unique populations and hence need to be evaluated independently. The mining lease has distinct structural domains that have added additional complications to evaluation of the Merensky Reef. The Merensky facies on BRPM exhibit unique geological and statistical characteristics within well-defined structural blocks. Due to the extreme variability of the Merensky Reef on BRPM a unique approach has been developed,within Anglo Platinum, to evaluate the deposit. Mining cuts are defined and composited for the individual facies types, and then modelled individually by applying known geological controls. The resultant grade models are weighted based on statistical and local geological knowledge. The object of weighting the facies is to replicate the variability observed in the orebody. The introduction of stringent geological controls to the evaluation process has resulted in increased confidence in the *in situ* grades estimated as an input to the mine planning process.

Introduction

The Bafokeng Rasimone Platinum Mine (BRPM) is part of the BRPM Joint Venture (JV) with the Royal Bafokeng Resources (Pty) Ltd (Bafokeng), on whose land the mine is located. The existance of the Merensky Reef was identified on the Boschkoppie property as early as 1920 (Wagner[3]). Several exploration programmes have been run over the years. Due to the geological complexity, on the area covered by the lease, limited mining took place until the late 1990s. In the 1950s Rand Mines undertook limited excavations. Later exploration by Anglo Platinum defined a mineable reserve for the Merensky Reef on the property. Anglo Platinum initiated mining development on 1 January 1998, and BRPM reached full production in July 2003.

The initial studies found that the Merensky Reef on Boschkoppie was variable in its nature. It is hence not surprising that the evaluation model developed for BRPM should take cognizance of the geological variability. The BRPM evaluation model has been developed over the last four years, and is a classic example of how important it is to understand the geology of any deposit and the importance of applying that knowledge in the evaluation model.

Locality

BRPM is located 30 km northwest of the city of Rustenburg, and comprises the farms Boschkoppie and Styldrift (Figure 1). The current mining authorization is located on the farm Boschkoppie 104JQ and exposes a strike length of approximately 6.5 km of Merensky Reef on outcrop, dipping at an average 11° towards the north-west.

Geology

Regional setting

BRPM is situated approximately 10 km south of the Pilanesberg Alkaline Complex on the Western Limb of the Bushveld Complex (Figure 1). To the immediate west is the underlying Transvaal Sequence, which forms a range of hills (Lomberg *et al.*). The Rustenburg Fault can be traced through the sequence of hills, which lie 5 km west of the mine. The area has been affected by a number of dunite intrusions, which have had a major impact on both the geology and mining of the Merensky Reef on BRPM.

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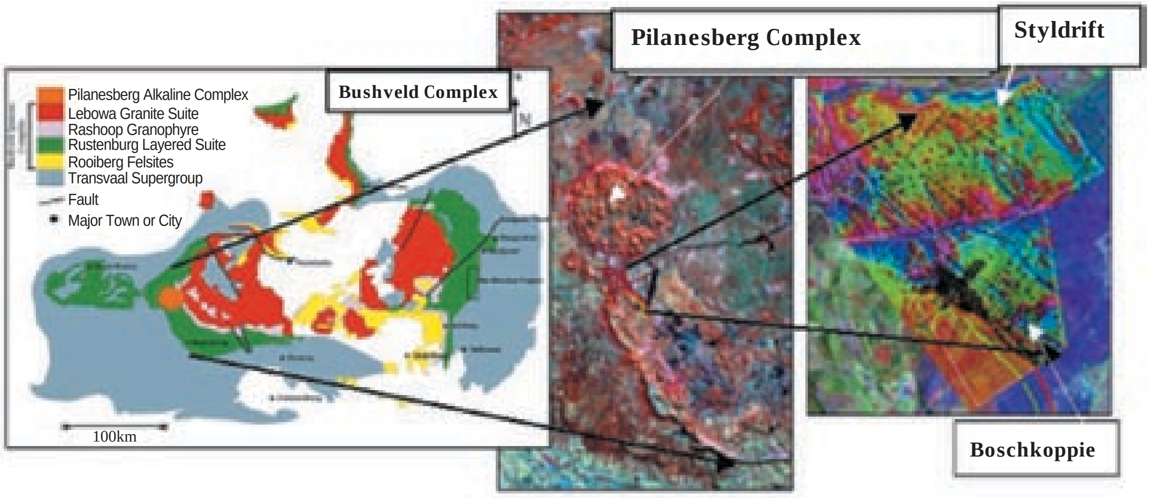

Figure 1—Locality of BRPM within the Bushveld Complex

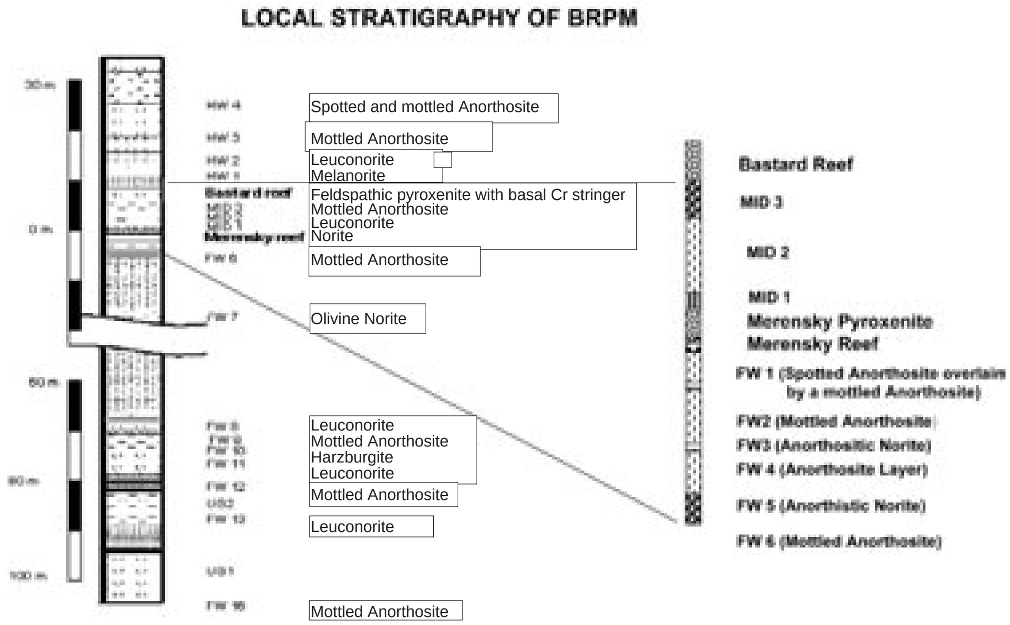

Figure 2—Generalized stratigraphic column for BRPM

Stratigraphy

BRPM geologists have undertaken a substantial amount of work to improve understanding of the stratigraphy on the property. Figure 2 illustrates the nomenclature currently used, which has been adapted from work documented by Leeb-du Toit[1]. The detailed stratigraphic classification plays a major role in assisting the geologists to identify the different reef facies, as well as to understand the variability that occurs in the Merensky Reef. For the purpose of local stratigraphic naming convention, the rocks are classified in terms of the type of lithology. The leuconorite footwall units are given odd numbers (FW1, FW3, etc.), while the anorthositic footwall units are given even numbers (FW2, FW4, etc.) up to the FW6 unit.

In relation to the Merensky Reef, the FW6 marker and the Bastard Pyroxenite horizon (which occurs approximately 9m above the Merensky Reef) are critical 'end markers' that the mine geologists use for evaluation and understanding structural and local reef variations on BRPM.

Definition of structural blocks

Prior to any evaluation, it is critical to understand the impact of the structural domains. On Boschkoppie three major structural blocks have been defined (Figure 3). The structural blocks are referred to as the Southern, Northern and North Shaft Deeps fault blocks.

The three major structural blocks have fundamental geological variations that have strongly influenced the nature of the Merensky Reef. Detailed understanding of the stratigraphy has allowed for fundamental local variations within the stratigraphy to be identified. The critical variations are summarized below:

- ➤ The Southern fault block: The FW 4 poikiliktic anorthosite units are not developed
- ➤ The Northern fault block: The full stratigraphic sequence is developed. The Merensky Reef has, however, been identified only on full sequence on a limited number of occasions

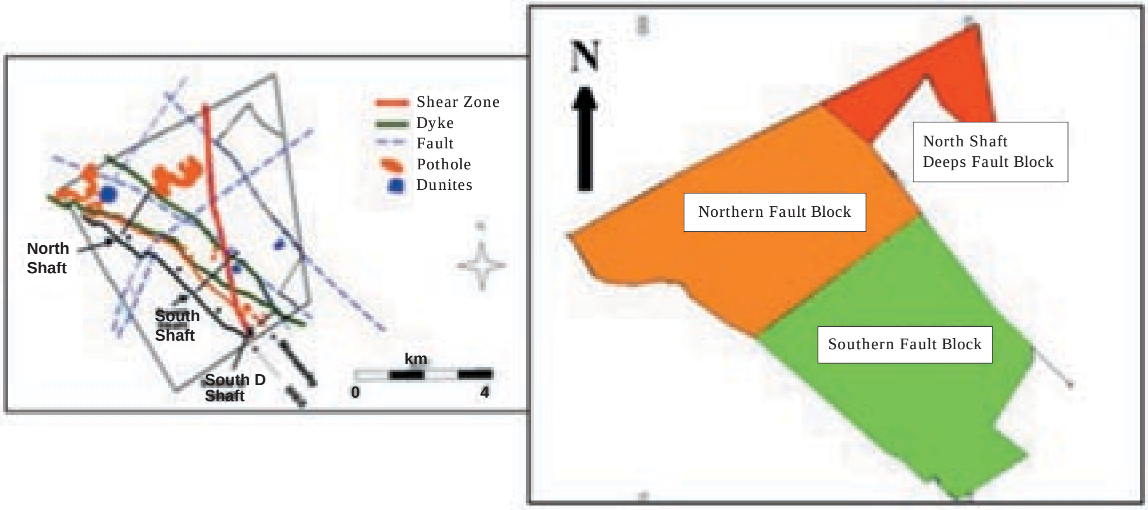

Figure 3—Structural blocks influencing the evaluation of BRPM

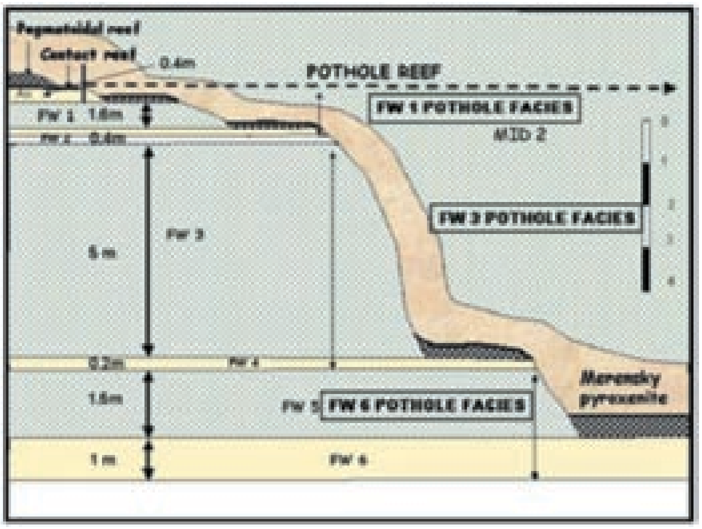

Figure 4—Facies distribution at BRPM

- The North Shaft Deeps fault block: this block has a uniquely different stratigraphic sequence compared with any other portion of the Boschkoppie property. A 5m thick FW1a unit is developed, and mineralized zones can exceed 1.5 m.

The variations in the development of stratigraphic units and the nature of the Merensky Reef imply a strong structural influence during the formation of the Critical Zone on BRPM. The control of the local variations in structural domains suggests that syntectonic activity played a major role during formation of the lithological units. The tectonic activity within the chamber would appear to have continued during the formation of the Merensky Reef and resulted in the facies distinctions identified on BRPM. The variations in the population statistics for the facies types in the structural domains would appear to support this theory.

The assumption that the Merensky Reef has been classified into unique populations is not enough. Due consideration of the effects of structural domains needs to be taken during the evaluation process.

Merensky Reef facies classification

The Merensky Reef at BRPM occurs in the transition zone between the traditional Rustenburg and Swartklip facies. On the mine, a number of Merensky Reef-type facies, namely the pegmatoidal, contact and pothole reef facies (Figure 4), have been identified.

Pegmatoidal facies

The pegmatoidal Merensky Reef is typically a pegmatoidal feldspathic pyroxenite, with an average thickness of between 9–11cm, bounded by thin chromite layers. The lower chromite layer is generally more prominent and can typically be up to 5 cm thick. The upper chromitite layer is very thin (<<1cm thick). The pegmatoidal feldspathic pyroxenite contains interstitial subhedral pyrrhotite and chalcopyrite blebs. The pegmatoid consists of cumulus bronzite crystals, typically 10–20 mm in diameter, with interstitial plagioclase feldspar. The pegmatoidal facies typically occurs on top of a full stratigraphic sequence. The optimal mining cut is 40 cm above the bottom reef contact and 60 cm into the footwall (Figure 5).

Contact facies

The contact Merensky Reef facies is present where the pegmatoidal feldspathic pyroxenite is absent and only the lower chromite is developed (>5 mm thick). The immediate hangingwall is a feldspathic pyroxenite (bronzite) typically 1–2.25 m thick, which grades upwards into a norite. Phenocysts of diopside (±20 mm) are present within the feldspathic pyroxenite. The Merensky hangingwall pyroxenite typically contains sulphides (pyrrhotite and chalcopyrite) for some 50 cm from its basal contact with the Merensky Reef, and sulphide mineralization also extends down into the footwall. The contact facies occurs on a full stratigraphic sequence and should not be confused with pothole edges which can also have chromitite developed on them. The mining cut is characteristically a footwall cut (Figure 6).

Pothole facies

The pothole Merensky Reef facies consists of a pegmatoidal feldspathic pyroxenite bounded by two chromitite layers. The upper chromitite layer is more prominent and up to 5 cm thick, while the lower chromitite is either absent or poorly developed. The pegmatoidal feldspathic pyroxenite may be up to 180 cm thick, but the average is between 60–80 cm. This facies is further characterized as being at a slightly lower elevation (up to 2 m) than the facies previously mentioned.

The grade profile is concentrated around the pegmatoidal feldspathic pyroxenite, with the highest PGE concentration associated with the chromitites. The immediate hangingwall is a feldspathic pyroxenite typically 1–2.25 m thick, which grades upwards into a norite. The footwall lithology is defined by the degree to which the pothole has transgressed its footwall. Accordingly, the pothole facies has been subdivided into FW 1 pothole facies, FW 3 pothole facies, FW 6 pothole facies and FW 7 pothole facies.

FW1 pothole facies

The FW1 pothole facies has all the characteristics described above but in general has the least developed pegmatoid. It is classified by its stratigraphic location and overlays either footwall FW1b or FW2. The mineralization is concentrated below the top reef contact (Figure 7). As a result, the optimal mining cut is defined above the 30 cm above the bottom reef contact and 70 cm into the footwall (Figure 7).

FW3 pothole facies

As per the FW1 pothole facies, the FW3 pothole facies is classified by its location within the stratigraphy and overlies either footwall FW3 or FW4. The FW3 pothole facies typically has the lowest grades at BRPM, with a unique grade profile and values confined to the pegmatoid only (Figure 8). Because of the narrow width of mineralization the mining cut of this facies type has high dilution.

FW6 pothole facies

The FW6 pothole facies is the best developed of the pothole facies types, and can reach a thickness in excess of 1 m. The grade is confined to the pegmatoidal unit and has a characteristic bimodal nature (Figure 9). Sporadic grades occur in the harzburgitic footwall. The harzburgite is associated with all the pothole facies types, but is better developed in the FW6 pothole facies types.

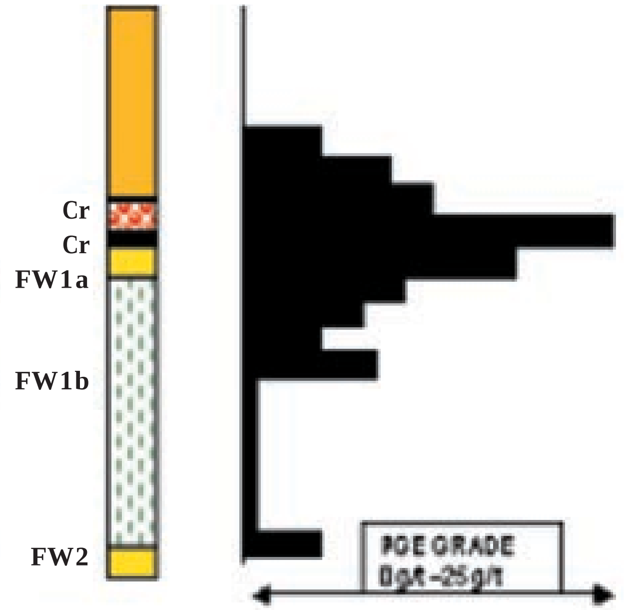

Figure 5—Grade profile of the permatoidal facies at 10cm intervals

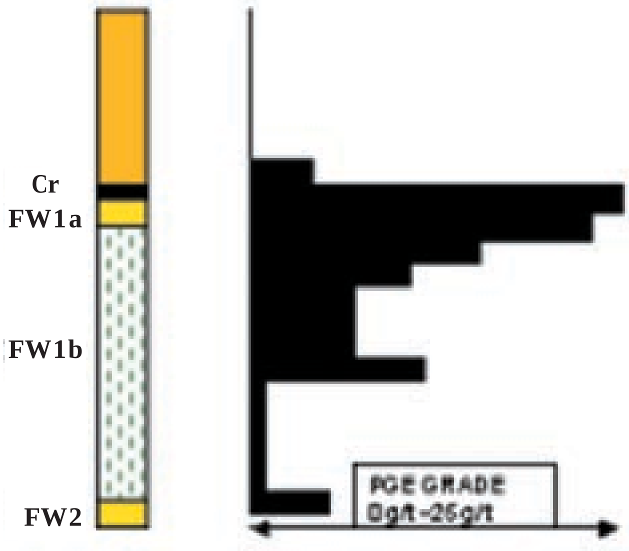

Figure 6—Grade profile of the contact facies at 10 cm intervals

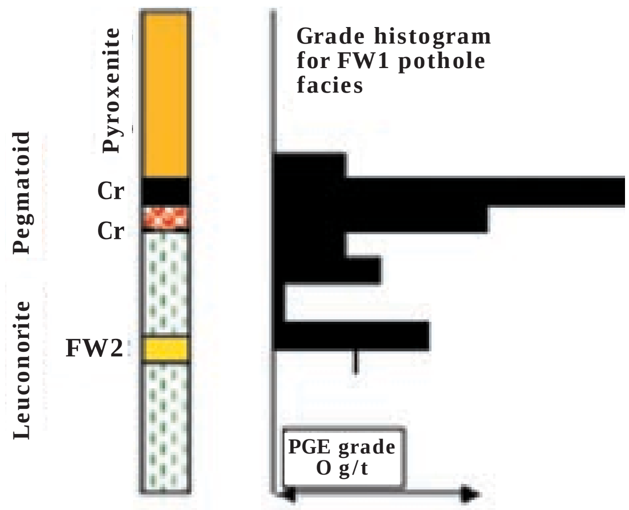

Figure 7—Grade profile of the FW1 pothole facies at 10 cm intervals

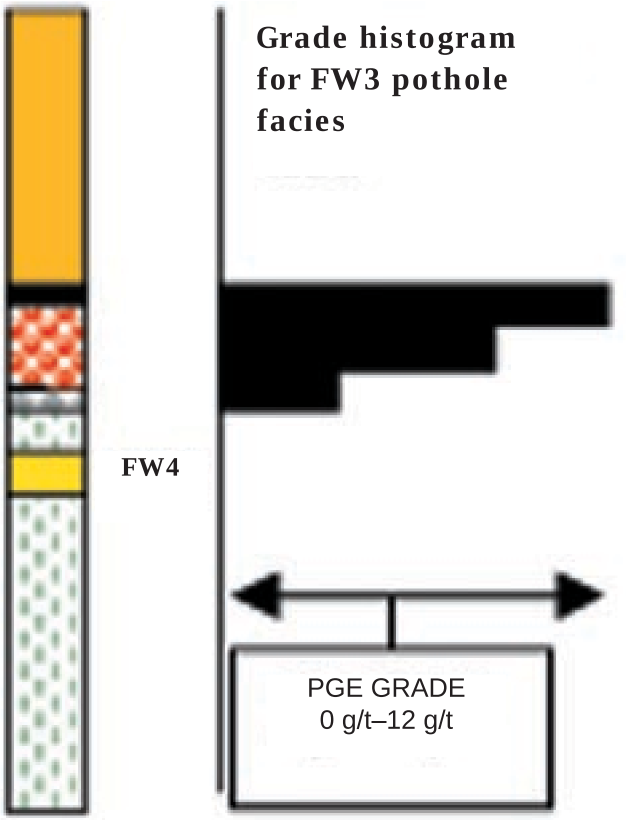

Figure 8—Grade profile of the FW3 pothole facies at 10 cm intervals

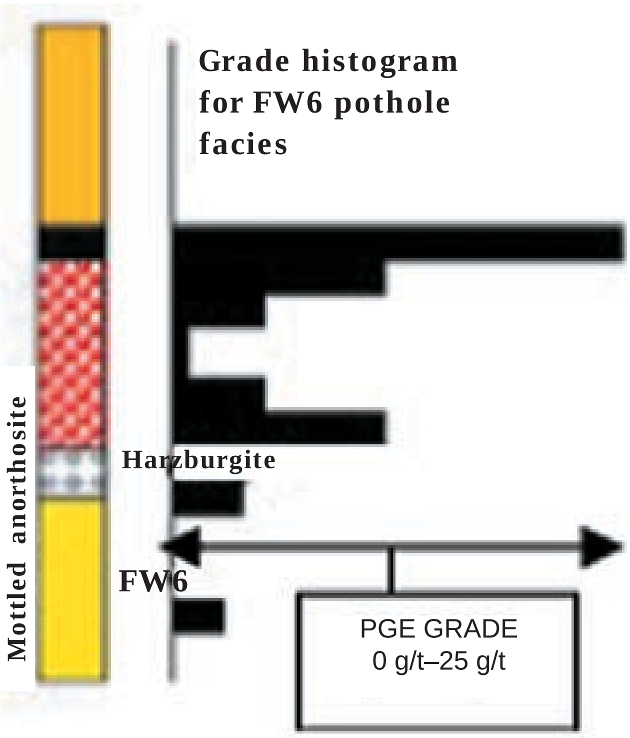

Figure 9—Grade profile of the FW6 pothole facies at 10 cm intervals

FW7 pothole facies

The FW7 potholes have not been modelled, but are more common in the southern portions of the lease area. They are typically developed deep into the footwall stratigraphy. Currently the evaluation has been limited to classical statistical analysis. The first attempts to mine this facies type started only in 2005. Historically, the FW7 potholes formed part of BRPM's geological losses.

Evaluation of the Merensky facies types

Data validation

In Anglo Platinum the validation of data utilized for evaluation receive the highest priority. The data undergo a series of rigorous tests and procedures to ensure that they are accurate and representative. Historically, contract geologists have been used to log and sample the exploration drill holes on BRPM. The mine exploration geologist is held accountable for validating the logging and sampling of the core. All logs are checked prior to sampling and input into the database. The mine exploration geologist ensures that the logging and sampling standards are in accordance with Anglo Platinum's standards. On transfer of the drill hole data into Datamine (the evaluation software utilized by Anglo Platinum), the data are checked and validated throughout the modelling process.

Compositing

BRPM produces a number of two-dimensional models. The data are divided into the facies groupings and composited into a series of mining cuts. Mining cuts are produced using the bottom contact of the Merensky Reef as a reference. The bottom contact is the most recognizable reef contact on BRPM. Cuts into the footwall are produced at 10 cm intervals. Hence a 10/100 cut would indicate a cut 10 cm into the footwall over a mining cut of 100 cm. A 20/100 cut indicates a cut 20 cm into the footwall over a 100 cm mining cut, and so on.

Determination of classic and spatial statistics

Classical statistics, histograms and cumulative probability plots are produced for individual mining cuts for each facies type. The objective is to evaluate all the cuts and determine the optimal mining cut.

The introduction of structural domains and facies classifications into the BRPM approach has resulted in an improvement in the spatial statistics.

Grade interpolation

All the facies types have been modelled within the constraints of their relevant structural blocks.

The modelling parameters applied per model cut conform with the kriging neighbourhood study completed prior to the interpolation of grades as far as practicable. Kriging neighbourhood studies run a series of iterations that determines critical inputs into the modelling parameters. Criteria that are investigated include block size, minimum and maximum number of samples, and search radii. Ordinary kriging has been used to interpolate the grades into the block model.

Table I

Example of weighting to determine *in situ* grades per mining cut (reconstructed 4E values)

Facies	PGE10100	PGE20100	PGE30100	PGE40100	PGE50100	PGE60100	PGE70100	PGE80100	PGE90100	WEIGHT
Pegmatoidal	3.53	3.84	4.52	4.84	5.01	5.76	6.16	6.06	5.91	0.6
Contact	3.60	4.42	4.50	5.81	6.00	6.40	6.35	5.50	5.21	0.21
FW1 Pothole	4.84	5.48	5.68	5.76	6.30	6.25	6.76	6.05	6.11	0.16
FW3 Pothole	5.75	5.90	5.71	5.42	4.78	4.68	4.25	3.55	3.20	0.02
FW6 Pothole	7.20	7.30	7.19	7.01	6.70	6.34	5.83	5.00	3.83	0.01
Average	3.84	4.30	4.75	5.22	5.44	5.96	6.25	5.88	5.72	

Once the models have been completed, they are validated against the drill hole data. Visual validations and comparisons of the classical statistics between the model and data are completed. A final reconciliation is made between the *in situ* grades achieved in previous years. The model is the final test to ensure that the interpolation of the grades has been successful.

Weighting of facies types

BRPM has a unique problem in that the facies variations are so extreme that it is not possible to fix hard boundaries for the facies types. Due to this extreme variability, an alternative approach has been considered.

The current approach involves a statistical analysis of the facies distributions. These predictions of the percentages of the facies expected are used to weight the facies models.

The determination of the facies splits is derived from two approaches:

- statistical analysis of the distribution of facies in the drill hole database per mining half levels
- analysis of the trends of facies distribution from underground mapping of areas for which there is relatively little information.

The benefit of this approach is that it allows the evaluation geologist the opportunity to apply local geological knowledge to the weighting procedure. If the local geological understanding of the area does not correspond with the statistical calculations, the local understanding of the geology is always given priority.

When the evaluation geologist is confident of the facies weightings, a final weighted model is produced. Polygons, representing all the grade models are received from the mine planners and evaluated. The five major facies types are weighted using the predicted facies distribution to calculate the optimal mining cut (Table I). The optimal mining cut is then applied for planning and mining instructions.

This approach has further benefits in that it allows the planning department the opportunity to adjust the mining cut in geotechnically complicated areas. If, for example, an area has been identified as having a parting in the hangingwall that cannot be supported by mining, it will not be possible to mine to the optimal cut. In a situation where these areas have been defined and signed off by the responsible rock engineer, a condoned cut will be chosen from the weighted grade sheet in Table I. If the parting was, for example, 70 cm above the bottom reef contact, the new grade used for planning would be the PGE30100 cut. Instead of planning on an optimal cut of 6.25 g/t, the new 4E grade used would be 4.75 g/t. The difference, which in this case exceeds 1 g/t, is a critical input into the planning process. In geotechnical areas the condoned grade is preferred to the optimal grade in the final model.

Conclusion

When evaluating any reef body it is absolutely critical that the evaluation geologist understands the local geology. At BRPM the distribution of the mineralization is globally erratic, but becomes more predictable when zoned into the appropriate facies types. The implications of not understanding the geology are numerous, not only from an evaluation point of view, but also when attempting to optimize the extraction of the ore.

Through an integrated team approach, BRPM has come a long way towards understanding the geological conditions that existed during the formation of the Merensky Reef. This has led to a dramatic improvement in its evaluation methods. The challenge is to take this information and apply it practically to the mining process to achieve the most significant impact.

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References

1. Leeb-du Toit, A. The Impala Platinum Mines., 1091–1106. In Anhauesser, CR and Maske, S. (eds)., *Mineral Deposits of Southern Africa*, vols. 1 and 2. Geol. Soc. Safr., Johannesburg.
2. Lomberg, K.G., Chunnett, G.K., Nel, J.J., Martin, E.S., Steenkamp. J.M.A., and Ruygrok, M. The Geology of the Bafokeng Rasimone Platinum Mine. Internal report.
3. Wagner, P.A. *The Platinum Deposits and Mines of South Africa*, 1929. 338 pp. Struik (Pty) Ltd. ◆