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Breakeven extraction factors for the Merensky Reef using stope width and market price simulation

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The Merensky Reef zone, as developed on Impala Platinum's Rustenburg Operations, displays a gradational mineralized zone, with grades decreasing from the Merensky Pegmatoid Unit into the footwall and hangingwall. A system of identifying a manageable method of defining the mining cut is introduced, termed the grade profile attenuation cut-off grade.

Although horizontal grade selectivity is not applied in the mining of the Merensky Reef zone, low extraction of the orebody, due to manageable and non-manageable factors, can contribute to a reduction in revenue, even losses, due to fixed cost contributions in the mining and beneficiation of the ore. A model is proposed that integrates all variables affecting the revenue of the mining operation, including the grade profile attenuation cut-off grade, the extraction factors, commodity prices and exchange rates, utilizing numerical simulation techniques in a PC-based environment. A breakeven extraction factor for a specific cut-off grade is delivered for a range of market conditions.

The breakeven extraction factor is a useful guide when designing mining layouts in structurally complex and low metal content areas. Incorporating distribution functions for individual commodity prices and exchange rates into the model provides mineral resource managers with a risk profile for individual mining areas. Shaft areas have varying grade profiles and each area should have individual models run, to prevent generalizations being made about acceptable risk levels on mining areas.

Introduction

The modelling of the breakeven extraction factor at various stoping widths was undertaken by the application and adjustment of a cut-off grade technique employed on Impala, specific to the Merensky Reef, termed here the grade profile attenuation cut-off grade. This technique is well suited to the gradual decrease in mineralization and accompanying grade from the Merensky pegmatoid unit into the hangingwall and footwall. The modelling of the factors affecting the income derived from the beneficiated commodity, namely commodity price and exchange rate, was achieved using Latin Hypercube spreadsheet simulation.

Cut-off grades

Various authors have presented types of cut-off grades and methods to calculate them over the years. Wood (1997) provides an excellent synopsis of the various cut-off grades available in the mining industry and applies them to the platinum industry. Apart from the geological cut-off grade, described by Pasieka and Sotirow (1985) as 'cut-off grades that truncate a frequency distribution of *in situ* ore grades, or to separate mineralized material into grades fractions', most other definitions of cut-off grades in their various forms refer to the cost contributions and breakeven values in their calculations.

The Merensky Reef is a thin tabular deposit with a gradational mineralized zone in the vertical dimension. As such, Lambert (2003) notes that the use of reef accumulation and thickness does not apply well to the Merensky Reef, as opposed to deposits characterized by a sharp distinction between ore and waste.

The method employed of channel width and channel grade determination on Impala involves the application of a modified geological cut-off grade and is applied solely in the vertical dimension. This method of 'fractionating' the reef zone into ore and waste has historically been termed the application of a marginal cut-off grade, on Impala specifically. This differs from marginal cut-off grade in scientific literature. Thus the term 'grade profile attenuation' (GPA) cut-off grade is proposed and is an attempt to describe the gradual grade decrease in the reef profile, coupled with the grade index that is applied to the profile.

An example of applying a varying GPA cut-off grade to a grade profile is displayed in Figure 1. In this figure an estimated grade profile for a 40 x 40 m stope block is displayed. The outline shows an exaggerated grade profile. The highlighted portions represent the portion of the hangingwall and footwall to be included in the channel width determination. The pegmatoid unit is deemed to be mined in its entirety. The stepped nature of the profile has the effect that in some instances dropping or raising the GPA Cut-off grade will have no effect on the channel determination. Looking at a GPA cut-off grade of 1.6 g/t a 22 cm hangingwall (LMRPX) and 55.9 cm footwall (LFW1) is allocated to the channel segment, with a 2.1 cm pegmatoid contribution, for this specific stope example.

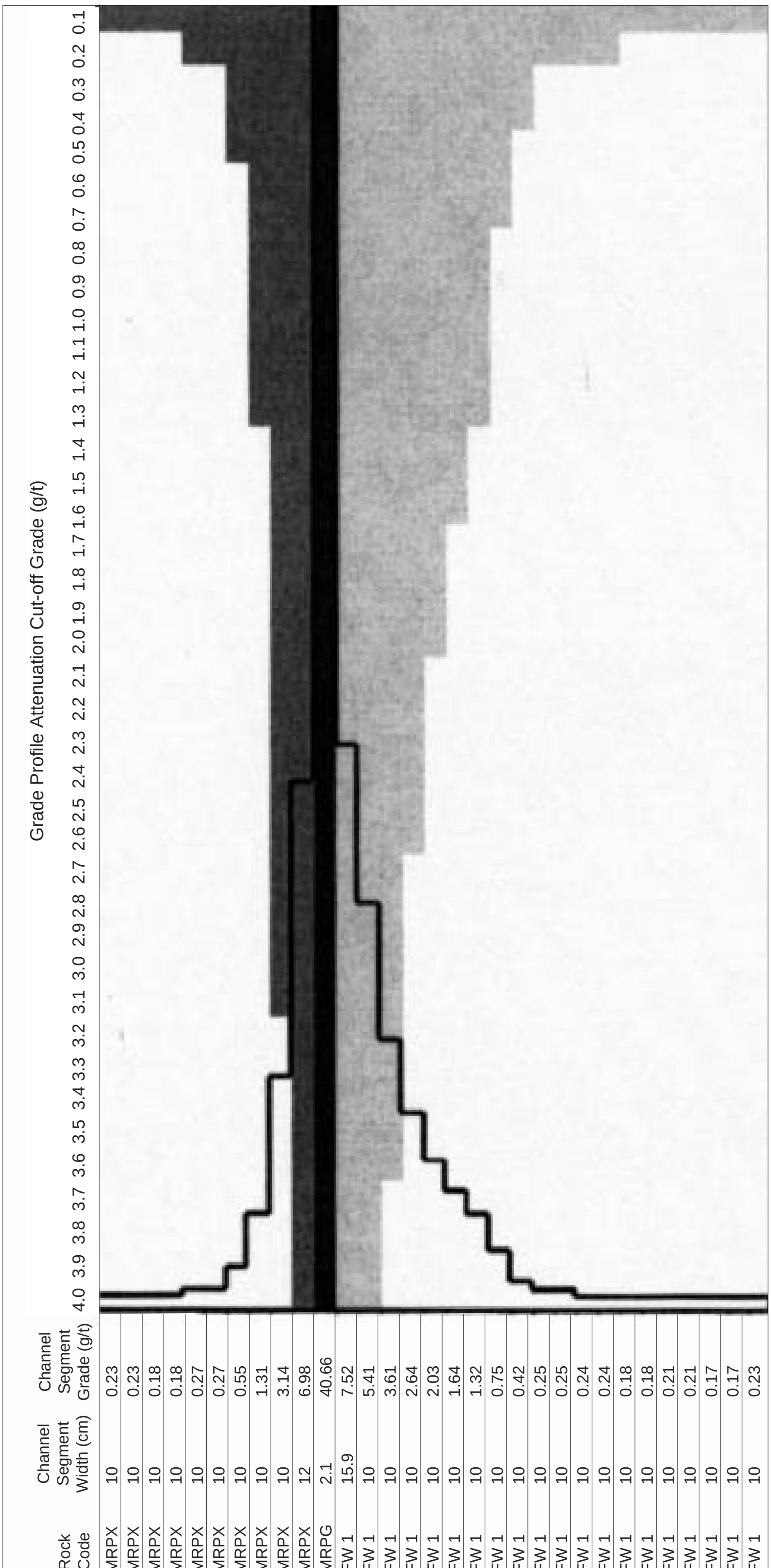

Figure 1. Exaggerated mean grade profile for Merensky 'A' Reef, showing the effect of applying an incremental grade profile attenuation index or 'cut-off' grade

Impala employs a minimum mining height of 80 cm on its conventional mining areas, with a maximum height of 150 cm. Areas with a channel width of lower than 80 cm are increased to the minimum by an allowable overbreak parameter. Where the channel is in excess of 150 cm at a specific GPA cut-off grade, the channel parameters are reduced by an allowable underbreak factor. In all cases, the Merensky pegmatoid unit is assumed to be mined in its entirety.

Mining, beneficiation and extraction factors

Mining method

Close to 98% of Merensky Reef areas are mined conventionally, on an up-dip breast mining method. Drives are developed in the footwall with a drive to reef middling averaging 25 m. Level spacings are in the order of 45–50 m across the property, which results in back-lengths of approximately 310 m, given a reef dip of 9°. Raise line spacings are in the order of 120 m, and advance strike gullies are developed from the raise at an angle of approximately 15° above strike.

Extraction factor

The extraction factor, or sometimes called erroneously, the extraction rate, is a lesser publicized figure which has enormous consequences for activities such as cost analysis and resource classifications. It is defined by Golenya (2002) as 'that factor applied to an area of ground on a Half-Level and to individual blocks to estimate the mineable area after losses attributed to geological features, mining design and the ground control districts pillar configuration. The extraction factor is expressed as a percentage of what is estimated to be recoverable.'

In terms of mining a reef or reef zone in the case of the Merensky Reef, the extraction factor should be by all accounts divided into vertical extraction and horizontal extraction factors, since a three-dimensional block of ore is being removed. The vertical extraction factor presents a particular problem in definition on the Merensky Reef, since the channel estimates based on a specific GPA cut-off grade intrinsically defines the reef zone. A measure of the overbreaks and underbreaks relative to issued parameters, resulting in a percentage channel dilution, is probably a better method to quantify extraction in the vertical sense.

Stope design and the associated in-stope pillars consistently play a role in quantifying the (horizontal) extraction factor for a stope area, shaft, or project area. Pillar designs on conventional layouts rarely account for more than 10% of the total area in question (L.G. Gardener, personal communication). Mechanized mining layouts, requiring higher stope widths, will alter this percentage, since larger spans would have to be supported, with a larger pillar design with depth a reasonable possibility.

Geological features that contribute to losses or a decrease in the extraction factor, with the possible creation of white: areas, include the following:

- *Faults and shear zones*—these structural features cause either reef losses through vertical displacement of the reef, or create situations where large-scale collapses of the mining area occur. Such events, termed 'falls of ground', contribute negatively to earnings since rehabilitation costs are extremely high and conditions unsafe.
- *Dykes*—two types of dykes occur across the property. Dolerite dykes can create losses due to the intrusion and associated horizontal displacement of the reef. Lamprophyre dykes are generally thinner than the dolerites encountered, being in the order of tens of centimetres versus the metre-wide dolerite dykes, but can create severe ground control problems. Lamprophyre dykes exhibit extreme deterioration on exposure to water and air, and beam stability problems result when these dykes advance in the direction of mining.
- *Potholes*—the abrupt termination of available stope face due to potholing causes losses of available ground. Depending of the size of the pothole, either redevelopment is required, or complete abandonment of the stope or stopes. Pothole percentages vary across the property, and areas with high pothole frequencies in the order of 30 per cent of available ground are encountered.
- *Replacement pegmatoid zones*—these zones are generally associated with large-scale faulting and are believed to be related to the intrusion of late stage alteration fluids. The platinum content of the stope is generally unaffected, while the peak platinum marker tends to move marginally lower in the stratigraphy. Extraction rates can be negatively affected due to the apparent lack of exposed reef, which would cause abandonment of stoping operations where replacement pegmatoid is encountered. Dilution percentages are also generally highest in these areas as a result of excessive overbreak and underbreak, relative to the stoping parameters.
- *Sills*—if sills are developed sufficiently high in the hangingwall, stoping may continue under certain parameter restrictions. However, massive stope, collapses have occurred in the past due to dead weight failure of insufficiently supported sills.
- *White areas*—these are areas created by the voluntary or involuntary abandonment of mining in a specific area. These white areas are in the most part being re-investigated and opened up for mining again, albeit at a much higher cost than the initial mining operation would have cost. It is the percentage of ground that is left behind that makes the biggest impact on the profitability of mining operations

Costs

Various costs are involved in the extraction and beneficiation of platinum group elements. These can be broadly classified into mining costs, processing costs, services costs, refineries costs, and selling and admin costs. Since this paper is not focused on a specific shaft or business unit within Impala, certain global assumptions about costs have been made.

The costs used in the simulation model were based on projected costs for the current financial year (2003–2004), which in turn are summaries for both the Merensky and UG2. Tonnages are normalized to the target of achieving 1.9 million ounces of PGEs.

As with many industries, the cost of an operation or activity can be split into fixed and variable costs. Fixed costs are those costs that do not vary with an increase in production, and variable costs are those that do vary with an increase in production. Various classical economics textbooks refer to the fact that in the long term, there are no fixed costs (Varian, 1992). Since the production projected

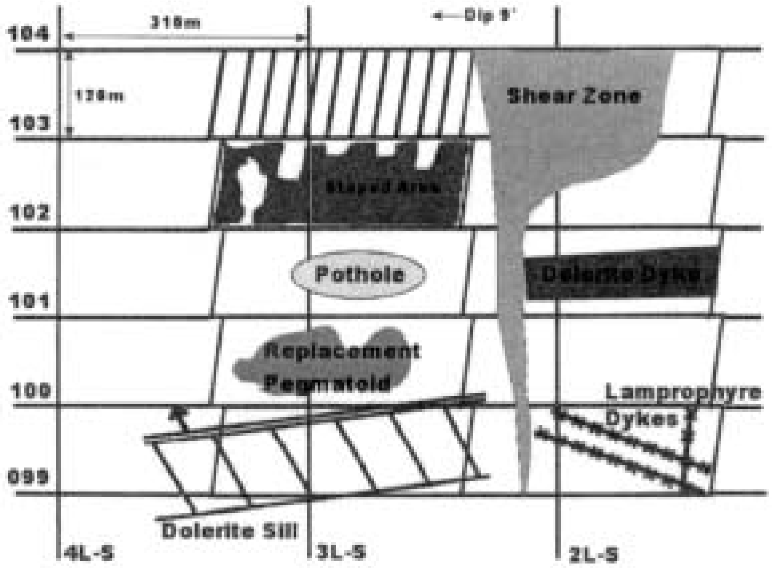

Figure 2. Layout of a typical Merensky mining layout with examples of structural features that affect the extraction factor

in the model is based on an annual figure, the fixed costs are indeed fixed. Sunk costs are assumed to be those costs that have already been committed and cannot be recovered. However, confusion about the definition of what is fixed and sunk arises in a few economics texts (Baumol and Blinder, 1997). There is no distinction between these two types of costs in this paper, and for matters of simplicity only fixed and variable costs are included. Avoidable costs, which do exist, are for all intents and purposes included in portions of fixed and variable costs, from historical projections of efficiencies.

The total cost contribution to an activity is the sum of all the fixed and variable costs of all activities. Where this total cost is greater than the income generated from the sales of the platinum group metals, a loss is experienced. Conversely, a profit is yielded when the income generated exceeds the total cost of producing these metals.

Breakeven extraction factor determination

The method of determining the breakeven extraction factor for a specific GPA cut-off grade involved two different models drawing on the same grade profiles, basic assumptions regarding metal splits, recoveries as well as modifying factors applied to the conversion of channel to mill widths and grades.

The first method involved the construction of a profit-loss matrix, with static input variables, while the second method involved the dynamic modelling or simulation of the variables, which provided a range of revenue outcomes, essentially reflecting best and worst case economic scenarios. Both methods are described in this report. A flowchart describing the steps common to both models, with the exception of the simulation of variables, is portrayed in Figure 3.

An initial limiting factor on the model was that at each GPA cut-off grade, the kilograms produced must remain constant, at the maximum extraction factor applied. A decision was made not to maintain constant kilograms at all extractions, since (a) plant kilogram fluctuations do occur, mainly as a result of a lack of tonnage from the plant, and (b) the models are designed merely as an initial investigative step, with the capacity to add on components based on requirements of management should it be required. The model could be criticized for being oversimplified, but the point is to provide some feel for the character of the solutions and the sensitivity for various assumptions.

Variables involved

The following factors all play a pivotal rote in the commercial viability of the mining of a mineral resource:

- The grade of the ore being mined
- The percentage splits and recoveries of the metals to be recovered from the ore
- The cost of mining the ore
- The cost of milling the ore
- The cost of processing the milled ore
- The cost of refining the metal recovered from the processed matte
- The cost of marketing and selling the products
- The prevailing and long-term prospects of the commodity prices
- The prevailing and medium-term prospects of the exchange rate, if the metal price is based on a foreign currency.

These factors as well as the correction factors applied to convert from channel to mill, and the kilogram to ounce conversion factor were built into a spreadsheet model. For every GPA cut-off grade and extraction factor combination, a total cost and turnover figure was calculated, with the resultant revenue generated. Positive revenues reflect a profitable scenario, whereas negative revenues for a particular cut-off grade and extraction factor combination reflect a loss.

Static model

The static model involved the specific commodity prices and exchange rates at each extraction factor and cut-off grade combination. Results of the each run were reflected in a summary profit-loss matrix, where a conditional indicator 'PROFIT' was returned for revenues greater than zero, and 'LOSS' returned for revenue less than zero. A random selection of three profit-loss matrixes is shown in Table I.

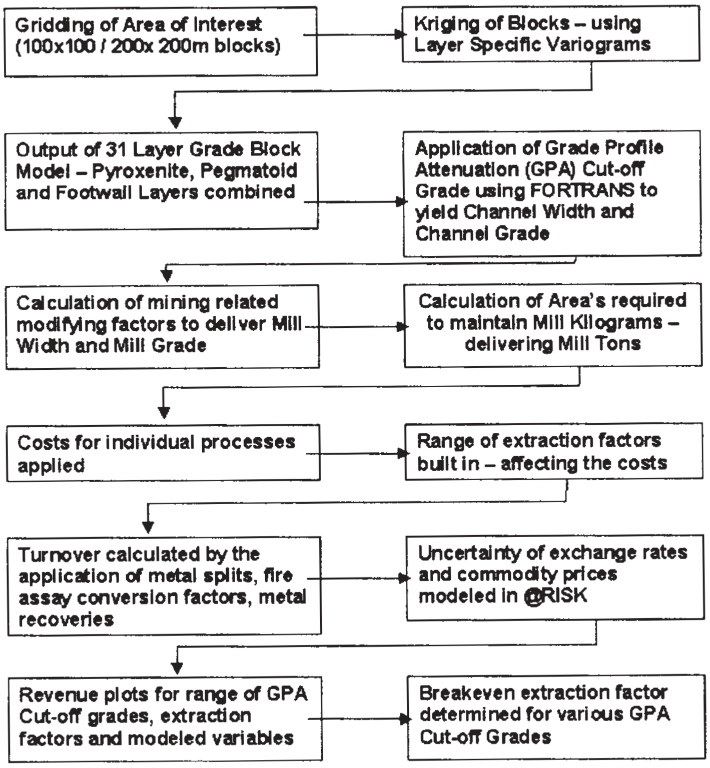

Figure 3. Flowchart outlining the basic steps involved in the determination of the breakeven extraction factor at varying GPA cut-off grades

The profit-loss matrix portrayed in Table I, shows a 'boundary' between the two indicator categories, which moves from the top leftmost quadrant in an apparent wave, to the bottom rightmost quadrant, as market conditions improve.

The profit-loss matrices work well as a motivational tool for resources managers trying to improve the extraction factor and optimization of an orebody. However, the detail behind the model is cumbersome, the various iterations necessary with the volatility of the market make long-term range assessment difficult, and the output is qualitative but indicator filtered, with no hint of relative highs or lows.

Risk analysis and simulation

A need to quantify the ranges in revenue due to market fluctuations, as well as to identify the contributors to the greatest variation in revenue, was identified. Risk management or analysis software is one method to this achieve this goal. Palisade Corporation's risk analysis suite, @RISK 4.5, was used due to the fact that the base model used in the static case analysis could be incorporated without modification.

The word risk relates to uncertainty in the outcome of an event or decision, and in the case of the revenue calculation model, relates to the variability to the variables involved in the calculation of the revenue at varying cut-off grades and extraction factors. The range of outcomes or results is associated with probability levels. The type of risk involved in the model creation is subjective risk with the best estimate being gained from personal knowledge and filtered information gathering techniques

The technique used by @RISK is quantitative, usually referred to as simulation. Simulation is the term used where a model, such as the Revenue model developed in Excel, is calculated many times, with changing variable values, with the aim of getting a complete representation of all the possible combinations of cut-off grades and extraction factors.

Distribution sampling

Latin Hypercube is a relatively recent development in sampling techniques and was first proposed by McKay *et al.* (1979). It is a stratified sampling technique with a random selection of each stratum within the sampled distribution. With Latin Hypercube sampling, sample values are randomly shuffled among different variables. As sampling is forced to represent values in each interval, it is forced to recreate the input probability distribution. A representation of the stratification system employed by Latin Hypercube sampling is shown in Figure 4. Latin Hypercube sampling does not resample values already sampled, and the number of stratifications is equal to the number of iterations. Thus, if a distribution with 200 discreet values is sampled, with 1 000 iterations, some values may be sampled more than once, depending on the probability attached to the value.

Each variable chosen in the model is considered to be independent, and modelled accordingly, preventing any unnecessary, and potentially confusing correlation between variables. With sufficient iterations, situations where variable are indeed correlated might in fact be sampled as such, without defined correlation. Low probability variables are catered for in the sampling process by the implicit stratification across the entire distribution.

Distribution sampling occurs in @RISK through the allocation of a distribution descriptor function in the model. Two types of distribution functions were used in the model, viz. RiskHistogrm and RiskUniform.

Table I
Profit loss matrix for various GPS cut-off grades and extraction factors at a Pt price of $865/oz, Pd price of $239/oz, Rh price of $520/oz, Ru price of $42/oz, Ir price of $85/oz, Au price of $409/oz and exchange rate of R7.16$

GPA Cut-off	Extraction factor									
grade (g/t)	100%	90%	80%	70%	60%	50%	40%	30%	20%	10%
4.0	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss
3.9	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss
3.8	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss
3.7	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss
3.6	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss
3.5	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss
3.4	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss
3.3	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss
3.2	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss
3.1	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss
3.0	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss
2.9	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss
2.8	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss
2.7	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss
2.6	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss
2.5	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss
2.4	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss
2.3	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss
2.2	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss
2.1	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss
2.0	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss
1.9	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss	Loss
1.8	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss	Loss
1.7	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss	Loss
1.6	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss	Loss
1.5	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss	Loss
1.4	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss	Loss
1.3	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss	Loss
1.2	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss	Loss
1.1	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss	Loss
1.0	Profit	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss	Loss
0.9	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss	Loss	Loss
0.8	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss	Loss	Loss
0.7	Profit	Profit	Profit	Profit	Profit	Profit	Loss	Loss	Loss	Loss
0.6	Profit	Profit	Profit	Profit	Profit	Loss	Loss	Loss	Loss	Loss
0.5	Profit	Profit	Profit	Profit	Profit	Loss	Loss	Loss	Loss	Loss
0.4	Profit	Profit	Profit	Profit	Profit	Loss	Loss	Loss	Loss	Loss
0.3	Profit	Profit	Profit	Loss	Loss	Loss	Loss	Loss	Loss	Loss
0.2	Loss	Loss	Loss	Loss	Loss	Loss	Loss	Loss	Loss	Loss
0.1	Loss	Loss	Loss	Loss	Loss	Loss	Loss	Loss	Loss	Loss

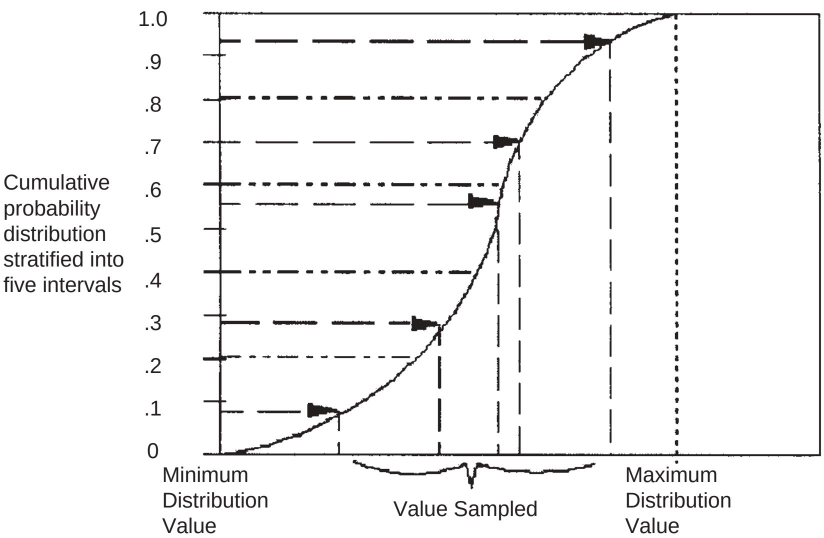

Figure 4. Sampling of a cumulative distribution curve using Latin Hypercube sampling (modified from Palisade Software users, manual, 2003)

The form of the RiskHistogrm function is:

= *RiskHistogrm (minimum,maximum,{p.1,p.2,...,p.n})*

which describes a histogram distribution with a range defined by the minimum and maximum values, divided into *n* classes, each class having a weighting *p*. Each weight is relative, thus weightings do not have to add up 100% with the normalizing achieved by summing all individual weights and dividing each weight by this summation.

The RiskUniform distribution function is described by:

= *RiskUniform (minimum,maximum)*

which specifies a uniform probability distribution with every value across the range having an equal likelihood of occurrence.

The RiskHistogrm function used for the above variables is as follows:

USdol2Rand	RiskHistogrm (6,12.5,(0, 17, 34, 71, 173, 125, 49, 41, 50, 81, 49, 57, 26, 8))
Ptdoloz	RiskHistogrm (400, 910, (0, 0.8, 16, 23, 19, 22, 24, 24, 8, 7, 9, 18, 34, 22, 24, 45, 22, 27, 36, 51, 37, 30, 18, 17, 13, 11, 25, 24, 23, 29, 18, 8, 9, 6, 4, 10, 11, 3.1, 2, 2.1, 3, 0, 0, 0, 0, 0, 0, 0, 0))
Audoloz	RiskHistogrm (200, 430, (0, 0, 0, 0, 0, 0, 18, 111, 97, 39, 49, 38, 97, 56, 22, 42, 56, 34, 36, 24, 13, 12, 0, 0))
Rhdoloz	RiskUniform (400, 500)
Pddoloz	RiskHistogrm (150, 1075, (4, 54, 84, 45, 42, 41, 8, 92, 61, 72, 34, 13, 25, 27, 3, 2, 2, 6, 7, 14, 14, 13, 8, 7, 4, 9, 7, 4, 2, 2, 1, 0, 1, 7, 4, 2, 8, 13, 2))

Note that the rhodium price uses a RiskUniform Function, with minimum and maximum values of 400 and 500 US Dollars per ounce. Ruthenium and iredium were included in the model at static prices of $41/oz and $87/oz repectively

Breakeven analysis

Each combination of extraction rate and GPA cut-off grade was simulated in @RISK, with the variables. Considering that the model was constrained between GPA cut-off grades of 2.0 and 0.1 g/t, 200 discreet revenue distributions were produced, an example of which is contained in Figure 5. Revenue is expressed in R millions.

The shape of the probability distribution has a slight positive skewness, due to the effect of the distribution shape of the commodity prices and exchange rates. This is expected to be the norm of most revenue distribution plots, as Cashin *et al.* (1999) points out, 'price slumps last longer than price booms'.

The process of determining the breakeven extraction factor at a GPA cut-off grade analysing the revenue at varying extraction factors, while keeping the GPA cut-off grade constant. Since a range of probable revenue values is produced for each combination, the mean, 95th and 5th percentile as well as one standard deviation from the mean were chosen to regress and determine the breakeven extraction factor, or likewise the breakeven cut-off grade for a specific extraction factor.

Ranges of revenue based on specific combinations of cut-off grade and extraction factor are shown in Figures 6(a)-(b)* and 7†. All charts showing the revenue at a specific cut-off grade show a negative slope, or more specifically a decrease in revenue with a decrease in extraction factor. The situation changes radically at a cut-off grade of 0.3 to 0.1 g/t, where the range of revenue values from the 5th percentile to 1 standard deviation of the mean show positive slopes, with a decrease in the extraction rate. This means that less loss is made if less is mined, when market conditions are unfavourable.

*(Constant GPA cut-off grade) †(Constant extraction factor)

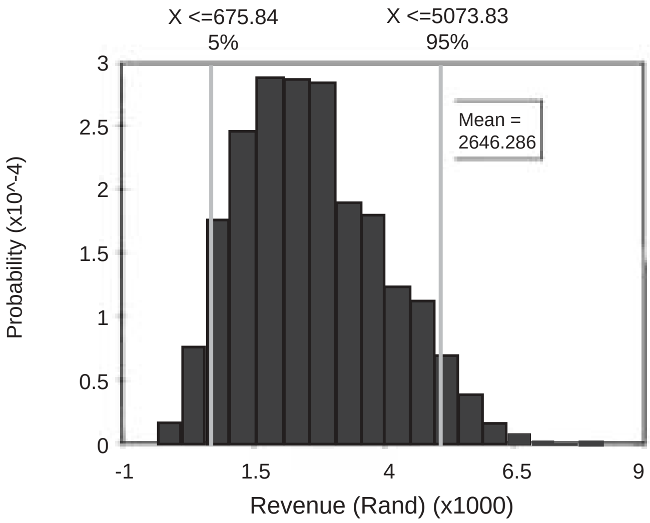

Figure 5. Revenue distribution for a GPA cut-off grade of 1.5 g/t at 100% extraction

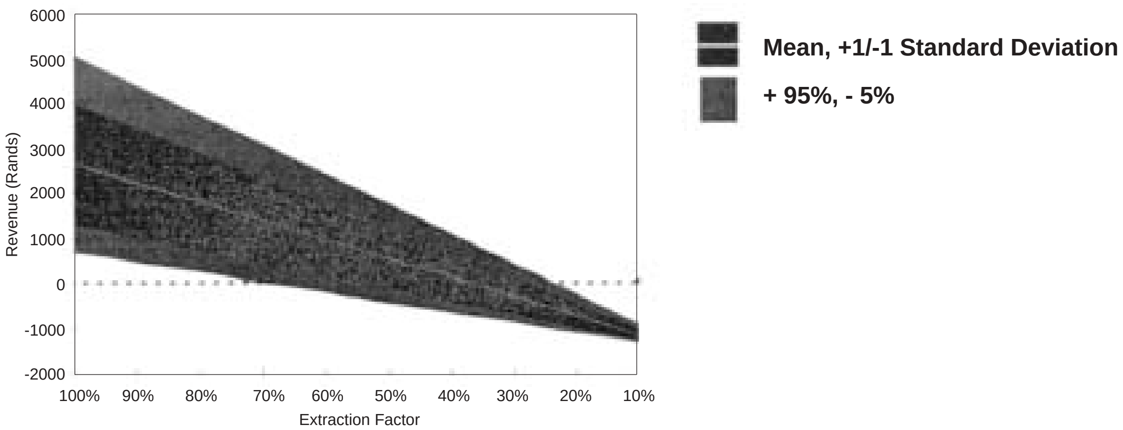

Figure 6(a). Range of revenue values at varying commodity prices and exchange rates at 1.5 g/t GPA cut-off grade

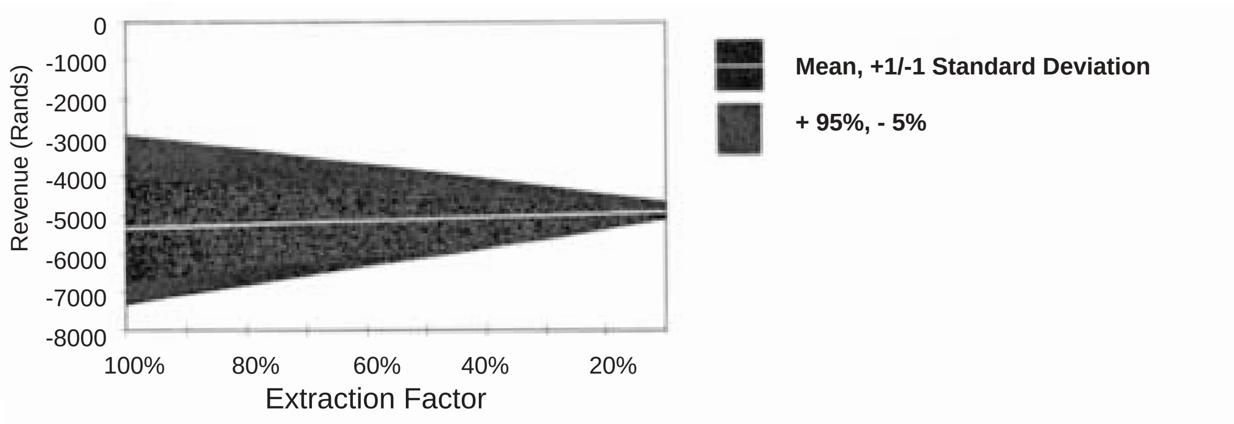

Figure 6(b). Range of revenue values at varying commodity prices and exchange rates at 0.1 g/t GPA cut-off grade

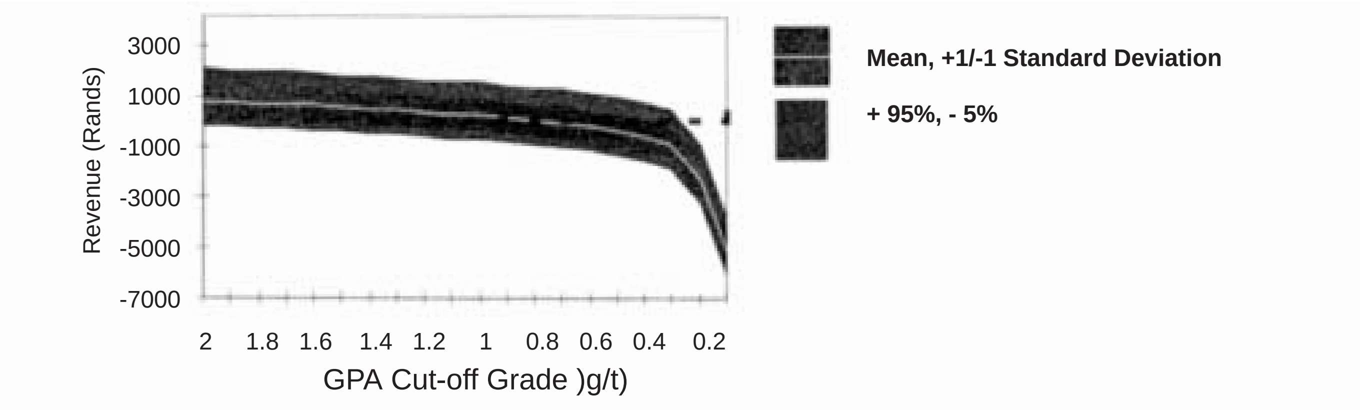

Figure 7. Range of revenue values at a 50% extraction factor with varying commodity prices and exchange rates

A point of inflection is evidenced in Figure 7 depicting the range of revenues based on a specific GPA cut-off grade, due to a marked increase in defined channel width when decreasing the cut-off grade.

Consolidation of results

Regression and analysis of the data from the simulations enabled an extraction factor to be determined for revenue return of zero. This is taken to be the breakeven extraction factor for a specific GPA cut-off grade. Results from this analysis are contained in Table II, and graphed in Figure 8. Due to the combination of high stoping heights and high associated costs, along with simulated market conditions, certain of the combinations regression return breakeven extraction factors in excess of 100%. These are removed from the results, since these situations will always be mined at a comparative loss. It must be noted that the denotation of the -5% and -25% does not refer to negative per cent extraction factors, but the percentiles with unfavourable economic conditions, i.e. low exchange rates and low commodity prices.

Under all market conditions, a decrease in the breakeven extraction factor occurs with an increase in the GPA cut-off grade. The variance in the breakeven extraction factor at varying market conditions (-5th percentile represent the worst case scenario while the 95th percentile the best case scenario) decreases with an increase in the GPA cut-off grade.

Variances between the mean value and the 95th percentile breakeven extraction factor are in the order of 20 to 10 per cent, while between that of the mean and the 5th percentile ranges from 65 to 35%.

Thus, at low commodity prices and a strong local currency to the US Dollar, revenue losses per mining area easily occur, should ground be abandoned due to ground conditions or bad mining practices. Given that the low-end members of the variables modelled have occurred in the past three years, and that no certainty in markets exists, loss-making stoping is a distinct possibility, with low extraction of ground, or low channel grades, or both.

Impala mines the Merensky Reef at an average extraction factor of 64% at a GPA cut-off grade of 1.5 g/t, which is above all breakeven extraction factors, except at the -5th percentile value, representing the most negative economic conditions. Losses might be incurred per stoping area if the extraction of ground drops below a mean value of 37%. If mining had to continue at the present extraction factor, profits could be achieved with an increase in the GPA cut-off grade, and the resultant dropping of channel width. The alternative is to maintain the stoping height and improve the extraction of ore.

Conclusions and recommendations

The cut-off grade philosophy introduced is unique in that no economics play a part in its construction, and it is coupled directly to the minimum and maximum stoping heights by overbreak and underbreak parameters.

Table II
Showing the breakeven extraction factor (in per cent) based on varying GPA cut-off grades

GPA cut-off (g/t)	-5% Perc extraction factor	-25% Perc extraction factor	Mean extraction factor	+75% Perc extraction factor	+95% Perc extraction factor
0.1					
0.2					74
0.3			80	55	44
0.4			67	48	38
0.5		98	60	44	35
0.6		92	56	41	33
0.7		80	52	38	31
0.8		76	50	37	30
0.9	94	72	47	35	28
1.0	86	66	44	33	27
1.1	82	65	43	32	26
1.2	80	63	42	31	26
1.3	77	59	39	30	25
1.4	75	58	39	30	25
1.5	70	55	37	28	24
1.6	66	52	36	27	22
1.7	64	50	35	27	22
1.8	63	51	35	26	22
1.9	59	48	33	25	21
2.0	57	46	32	25	21

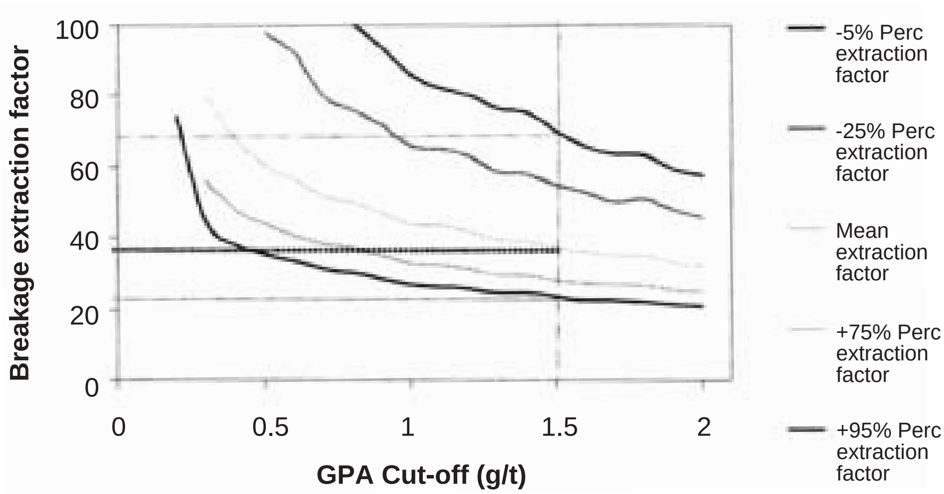

Figure 8. Summary of breakeven extraction factor at various GPA cut-off grades for varying market conditions

Increasing the stoping height has the indirect effect of a lowering of the GPA cut-off grade. This situation can result in losses should market conditions be unfavourable, or extraction of the ground in a stope be insufficient to cover the total fixed and variable costs associated with the mining and beneficiation of that ore.

Cost contributions and market prices form the overall basis of base case feasibilities. The ground able to be extracted from a project area must be able to cover the costs of extraction and beneficiation. Total optimization of a mine would involve achieving this aim with each and every stope.

Shaft mine areas have considerable amounts of data associated with geological structures and underground sampling. Mining layouts are generally decided upon far in advance. With the advent of unfavourable economic conditions, the temptation to increase tonnage output by widening the stoping height, or decreasing the GPA cut-off grade, should be resisted. Rather, mining more panels, at comparable mining parameters, should be implemented to increase tonnage with no negative effect on grade, and accordingly on the revenues.

The practice of leaving ground behind due to difficult mining, poor advances or stoping inefficiencies is manageable, and requires close monitoring. Returning to previously mining areas to remove scattered remnants of ground leads to costly re-equipping and removal of ore. Cost analyses must take all factors into consideration, including processing costs and other overheads, as well as prevailing market conditions. White area mining as practised on Impala would benefit from simulation modelling, albeit with tighter constraints on the variables, to determine the optimal mining cut based on cut-off grade models.

The breakeven extraction factor generated for various GPA cut-off grades must be viewed in relation to the mine design and its related pillar losses and structural domains. The generation of white areas creates short- to medium-term drops in the extraction factor. The reinvestigation and mining of these areas should be prompted by positive changes in the economic climate, and or changes to the GPA cut-off grade.

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