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The Role of Computer-aided Sedimentological Synthesis in Strategic Mine Planning at Blyvooruitzicht Gold Mining Company, Limited

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In recent years, rapid depletion of the higher grade reserves, allied to decreases in paylimits, has led to the exploitation of secondary, erratically mineralized placer horizons on various marginal and low grade gold mines. On Blyvooruitzicht Mine, the rich Carbon Leader Reef has limited reserves, necessitating exploration of the lower grade Middelvlei Reef. This placer has always presented evaluation and exploration problems, to such an extent that it was, at one stage, considered uneconomic. Despite an extensive underground drilling programme no ore reserve targets of reasonable size were apparent. However, when a certain degree of parallelism between sedimentological trends in the Middelvlei Reef and the underlying Carbon Leader was recognized, a meaningful exploration model could be developed.

Firstly, all historical sampling records for the Carbon Leader were entered into a computerized system; the database comprised in excess of 340 000 data points. Variables captured consisted of gold value, uranium value, conglomerate thickness and total reef thickness. The raw data were then averaged into blocks, and plots of different variables were computer-generated for further analysis. This enabled the Carbon Leader to be modelled sedimentologically and, thereby, exploration targets for the Middelvlei Reef were generated, based on the Carbon Leader facies trends.

Geostatistical analysis of sampling data in exposed areas of the Middelvlei Reef underground has confirmed the sedimentological breakdown of the placer into distinct facies areas. A facies model relating value distribution patterns to depositional trends, both for the Carbon Leader and the Middelvlei Reef, has thus been incorporated into a mine planning strategy.

Introduction

The continuing depletion of the high grade reefs in the Witwatersrand Basin, as well as decreases in pay limits due to the high gold price, have focused attention on the possibility of mining less important, often erratically mineralized reef placers on many gold mines. By selectively mining and blending these lower grade ores with the remaining higher grade 'sweetener', the projected lifespan of many gold mines has been extended well into the future. The mines of the Orange Free State, exploiting the Basal and Leader Reefs, are good examples of this.

Blyvooruitzicht Gold Mine was originally established on the high grade Carbon Leader reef. The orebody has displayed a high degree of consistency in terms of the distribution of payable ore and has presented little in the way of evaluation problems. Mining of the entire reef

horizon from one end of the lease area to the other is constrained only by the need to leave stabilizing pillars.

The limited reserves of Carbon Leader still available has necessitated the exploration of the lower grade Middelvlei Reef, which had for many years been considered uneconomic. No coherent exploration strategy had been developed during that time and evaluation of the available data, consisting mainly of borehole values, had indicated no ore reserve targets of reasonable size.

In the Main Conglomerate Formation in the northern portion of the Witwatersrand Basin, there appears to be a concordance between distributional trends in one reef and those above or below it both on a regional scale [1] and more locally on a mine scale [2]. An analysis of limited data on Blyvooruitzicht Gold Mine indicated a similar coincidence in trends [3]. The following critical assumptions were therefore adopted in the formulation of an exploration strategy on the mine:

1) The dispersal patterns of major channel systems in the three reef horizons comprising the Main Reef Conglomerate Formation at Blyvooruitzicht were controlled, primarily, by reactivation of pre-existing structural phenomena, in particular low amplitude folding. Footwall control would, theoretically, have caused a spatial distribution of certain facies types in one reef which could be repeated in the other reefs on the mine.
2) A general observation can be made that thin, sheet-like and kerogen dominated reefs tend to have higher gold concentrations and be less variable in the pattern of economic mineralization on a mine scale than the more channelized, banket reefs. While the distribution of gold, therefore, differs in some respects between a kerogen (carbon) dominated, seam-type reef (e.g. Carbon Leader) and a more discretely channelized, banket-type reef (e.g. Middelvlei Reef) it could, nevertheless, be predicted that the dominant depositional and value distribution trends in the Carbon Leader will reflect similar, but obviously not identical, patterns in the overlying Middelvlei Reef.

In order to reconstruct the sedimentary and gold distribution patterns in the mined-out areas of the Carbon Leader, and to use these trends to predict areas of exploration potential in the Middelvlei Reef, a comprehensive analysis of all the Carbon Leader chip-sampling data was initiated.

Methodology

Data capture

The following parameters were extracted from historical sampling records and entered into the computer database:

1) thickness of each conglomerate layer,
2) thickness of internal quartzite,
3) gold concentration in each conglomerate and internal quartzite layer (g/t),
4) uranium concentration in each conglomerate and internal quartzite layer (kg/t).

Initially, only stope sampling data were captured, but in areas that had not been stoped extensively these were supplemented with development data. In order to coordinate these sample data points two methods were used. For stope sampling the top and bottom corners of each stope face were digitized on a quarterly basis. The

date of the sampling being known, the program logic would then interpolate between the quarterly positions and assign a monthly face position to the date of sampling. Each individual sample section would then be assigned co-ordinates. In the case of the development sampling, co-ordinates were assigned on the basis of the distance of the samples from survey pegs. Sections were also coded depending on whether there was full exposure or only partial exposure of the reef. (All of the data capture programs as well as the analytical programs were developed in-house). Eventually the database comprised in excess of 340 000 co-ordinated data points representing more than forty years of mining.

Data analysis

Witwatersrand gold reefs are subject to seemingly random fluctuations in many of their grade distribution and sedimentological parameters on a small scale. In order to obviate this problem, the raw data were regularized into square blocks. The size of grid could be chosen to suit the scale of analysis; in this study the size of blocks varied from 25 m x 25 m to 100 m x 100 m depending on the level of detail required. All data points within a block were arithmetically averaged and this value assigned to the centre of the block. In order to filter the data even further an option to smooth the values by an inverse distance weighting function was also available.

Trend pattern plots of the different variables were then computer-generated for further analysis. In spite of the limited sedimentological data recorded in the historical sampling records, plots of the following variables were compiled from which facies areas were reconstructed:

1. Total reef thickness (cm).
2. Conglomerate thickness (cm).
3. Internal waste quartzite thickness (cm).
4. Gold concentration in reef (g/t).
5. Uranium (oxide) concentration in reef (kg/t).
6. Gold accumulation in reef (cmg/t).
7. Uranium (oxide) accumulation in reef (cmkg/t).
8. Gold variance (g^2/t^2).
9. Slope of reef thickness, (i.e. the rate of change in reef thickness between adjacent blocks. In this way a measure of the degree of footwall scouring is obtained).
10. Correlation plot of reef thickness versus grade, (i.e. a relative measure of the association between reef thickness and gold concentration).

Simplified contour plans of the total reef thickness and gold concentration drawn from the computer plots are shown in Figure 1.

Data interpretation

An investigation of reef morphological trends and gold concentration and variance patterns in the Carbon Leader showed that the reef could be divided into at least two basic depositional areas representing two placer-forming systems on the mine:-

a) A western distributary system dominated by a prominent linear zone of relatively thick reef (greater than 30cm) probably representing an axis of fluvial channelization, and
b) an eastern system dominated by areas of thin reef (less than 30cm) and relatively shallow scouring probably representing interchannel environments of placer deposition associated with algal (kerogen) development.

It is evident from the pattern of

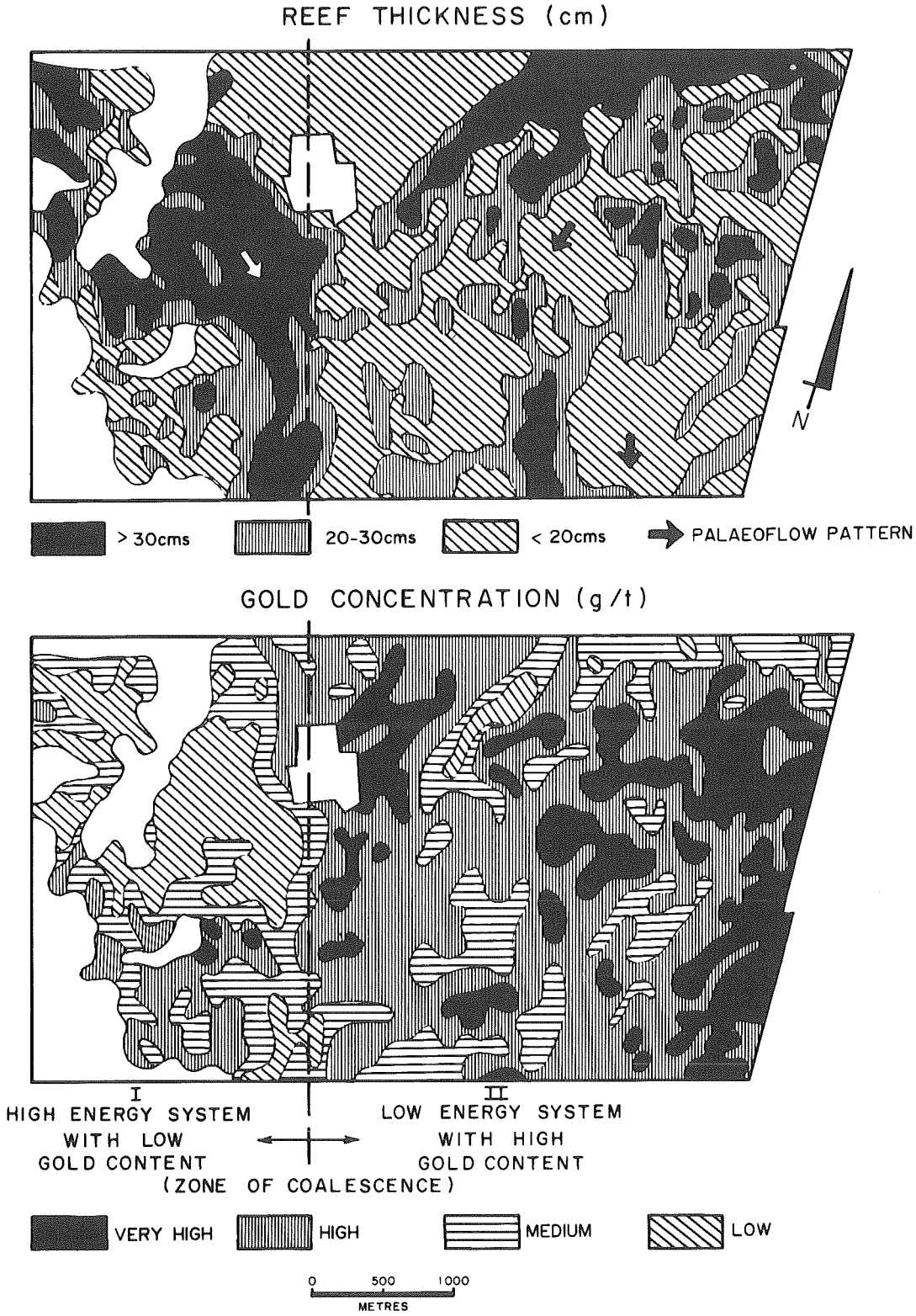


FIGURE 1. Relationship between reef thickness trends and gold concentration patterns which define major depositional systems in the Carbon Leader at Blyvooruitzicht Mine

shallow channelization that the streams depositing the Carbon Leader flowed in a general southerly direction. However, there is also a distinct variation in the palaeoflow pattern and size of the channels on either side of a north-south line running through the western half of the mine. This suggests a coalescence of two different braided systems, one being of a higher energy than the other. This interpretation is borne out by the significant difference in the tenor of gold distribution in the two systems. The more uniform distribution of higher gold concentrations occur in the eastern, lower energy system and, in most cases, the highest accumulations are associated with the interchannel areas.

This scale of facies modelling using plots of different variables and combinations or ratios of variables has provided a means of demarcating the major different areas of gold variance in the reef. Furthermore, detailed analysis which combined underground sedimentological observations with trend pattern interpretation of the variable plots has led to a more accurate definition of the facies areas for the purposes of mine valuation [4]. When the regression areas used in traditional valuation techniques at Blyvooruitzicht G.M., which have been determined independently of sedimentology, are superimposed on the facies area plan (Figure 2), the correspondence is clear, indicating that regression areas are merely a reflection of the different facies areas.

This accurate facies delineation has enabled meaningful variograms to be modelled for the separate reef populations. Kriged ore reserve estimates could then be compiled for the Carbon Leader.

The exploration model

The basis of the model is the perceived facies repetition on a broad scale throughout the Main Conglomerate Formation. Major channel flow trends as well as ore distribution trends in the Middelvlei Reef would therefore parallel those in the lower reefs as a result of the reactivation of

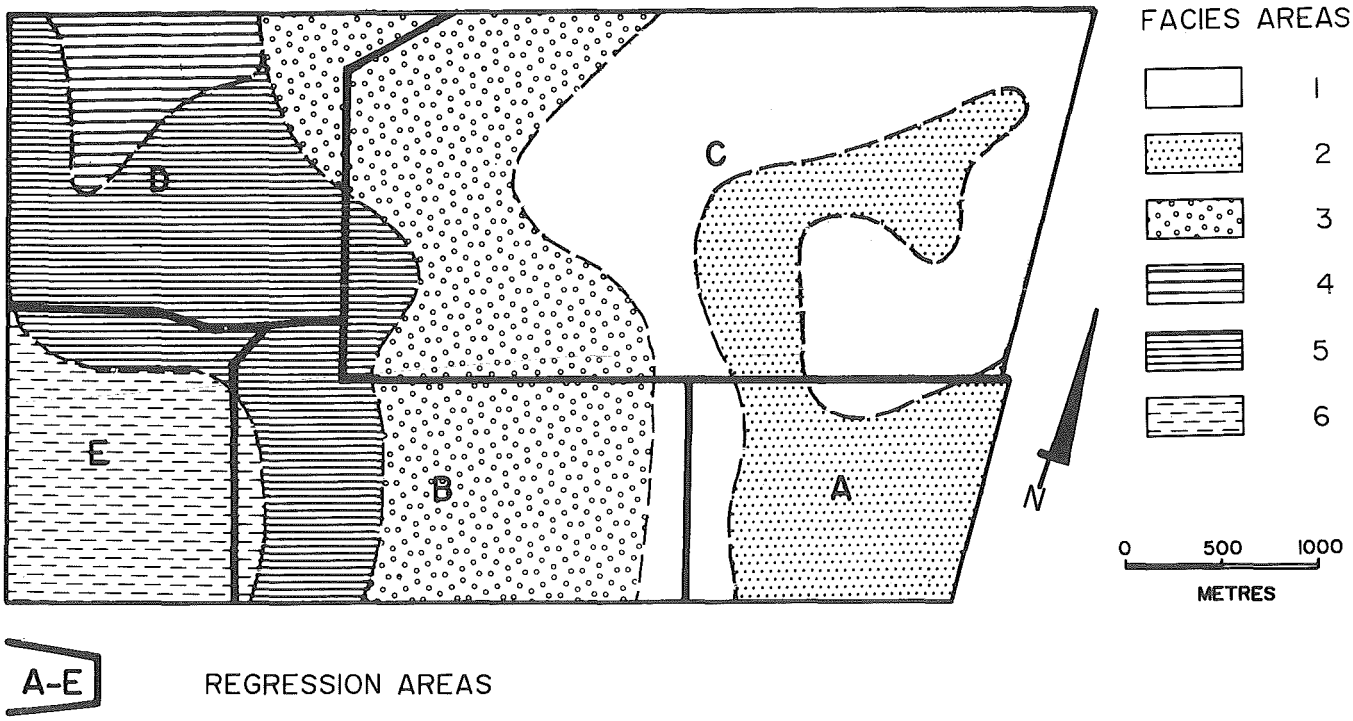


FIGURE 2. Location of Carbon Leader facies areas

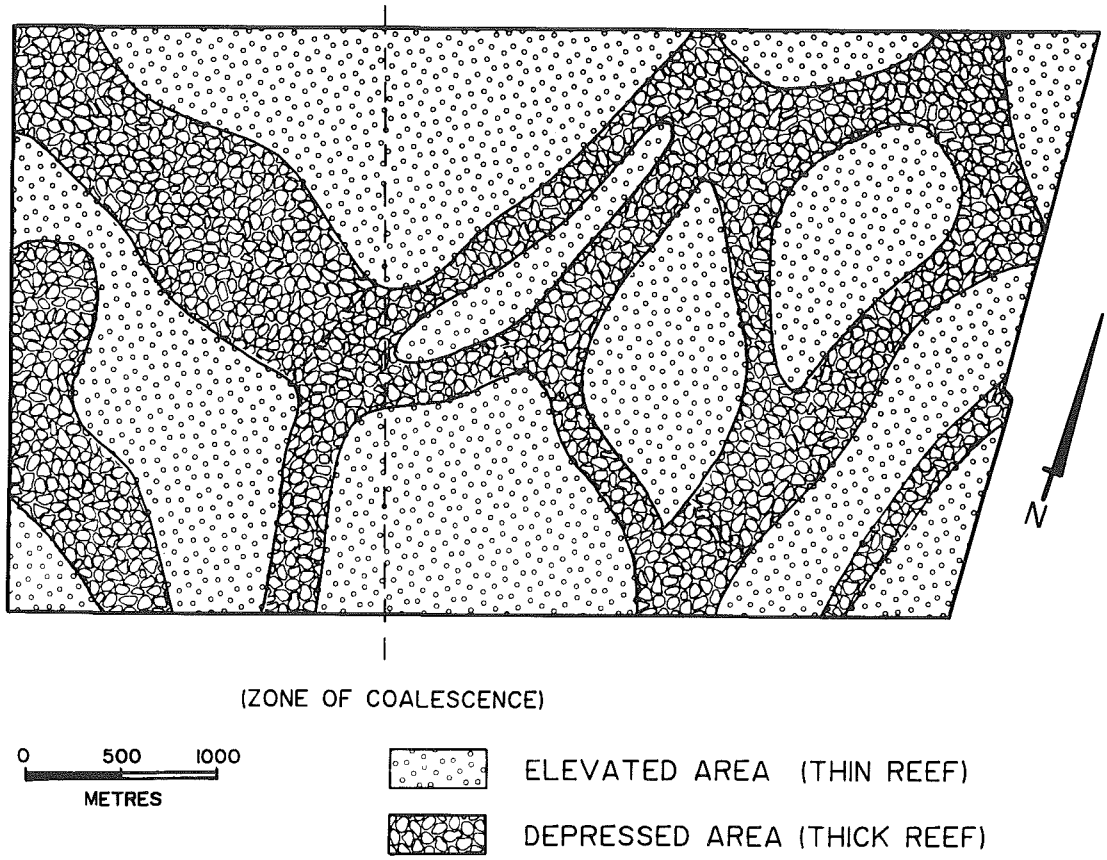


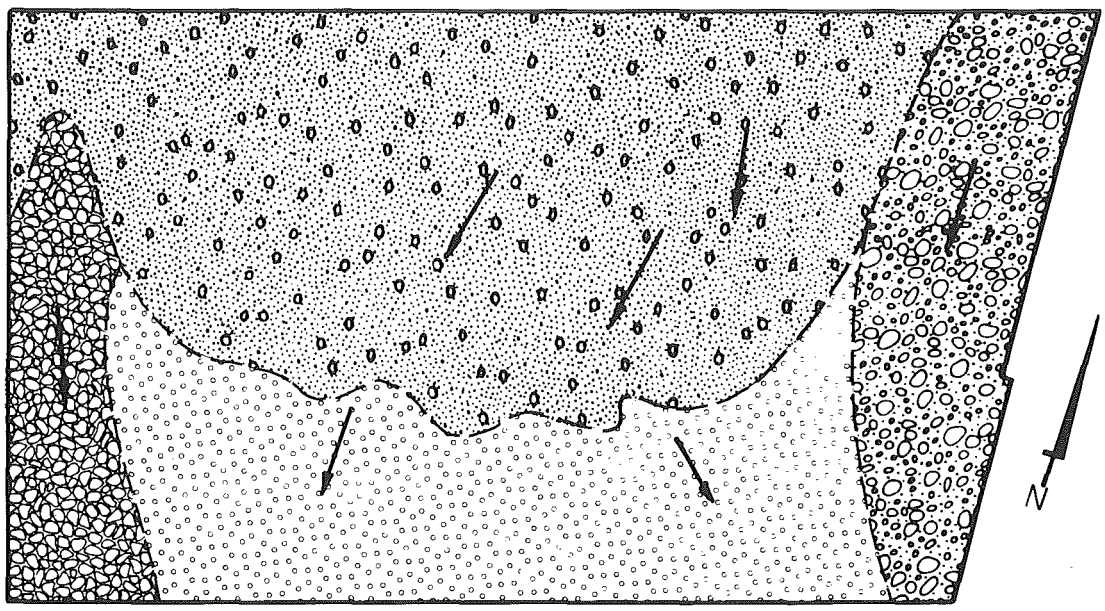
FIGURE 3. Predicted areas of elevation (thin reef) and depression (thick reef) in the Middelvlei as modelled from Carbon Leader morphological trends

footwall structures. The hypothesis would therefore imply that over most of the mine the Middelvlei Reef would consist of thin, small pebble conglomerates or grits (Figure 3). Narrow discrete pay zones would be present in this area, but only in the west and east would thicker, channelized and better mineralized conglomerates be present. Target areas were then assigned priorities for development based on this reasoning combined with the little information then available on the value distribution within the Middelvlei Reef.

After two years of exploration development had been completed, the model was reassessed in the light of the information obtained from the selective exposures.[5] Palaeocurrent directions obtained from scour orientations and cross-bedding in the Middelvlei Reef indicated flow patterns trending from north to south on the eastern side of the mine and approximately north-west to south-east on the western side of the mine. These directions match those predicted for the target areas and serve to confirm the footwall control postulated for the deposition of the Middelvlei Reef.

Sedimentological facies analysis of the reef coupled with statistical analysis of the value distributions has, however, led to a major modification of the exploration model. Four facies areas have been defined (Figure 4).

Facies Areas 1 and 2 in the western and eastern parts of the mine, respectively, have been shown to contain reef that is generally thicker, channelized and better mineralized than in the other areas. In this respect the model has held. However the narrow discrete pay zones predicted



FACIES AREAS		DOMINANT CHARACTERISTICS
	1	THICK, SINGLE OR DOUBLE 'BAND' CONGLOMERATE, (30-50cm) IN SHALLOW CHANNELS. Mpc - Lpc.
	2	THICK MULTIPLE 'BAND' CONGLOMERATE, (>50cm), OFTEN DEEPLY SCOURED CHANNELS. Lpc,
	3	THIN SINGLE PEBBLE LAG (< 5cm). ISOLATED PATCHES OF CARBON. Spc - Mpc.
	4	THIN SINGLE 'BAND' CONGLOMERATE, (5-30cm), THICKENING IN LINEAR DEPRESSIONS, OFTEN ASSOCIATED WITH CARBON Spc - Mpc.

Lpc LARGE PEBBLE CONGLOMERATE (16mm - 32mm)

Mpc MEDIUM PEBBLE CONGLOMERATE (8mm - 16mm)

Spc SMALL PEBBLE CONGLOMERATE (4mm-8mm)

PALAEOFLOW DIRECTION

0 500 1000
METRES

FIGURE 4. Location of Middelvlei Reef facies areas

for the central part of the mine are not as prominent as expected. It would appear that the effect of the palaeo-elevation of the north-central part of the mine was underestimated. This area effectively separated the drainage systems of Facies Areas 1 and 2 and because of its elevated nature only isolated, narrow scours would have occurred. Relatively small, linear areas of payability would, therefore, be expected; these could be associated with the local development of kerogen. In

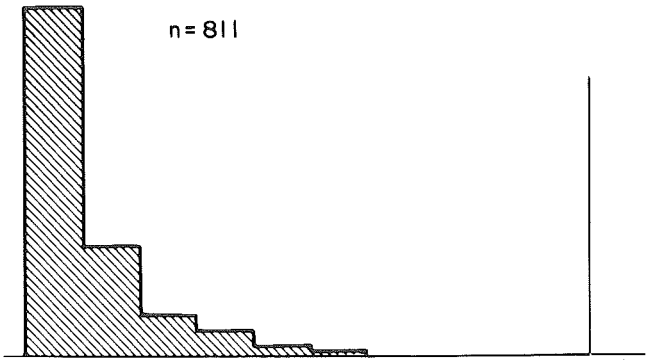


FIGURE 5.1 Histogram of untransformed grades, Middelvlei Reef

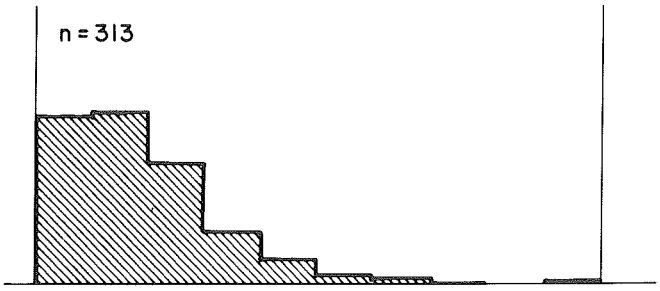


FIGURE 6.1 Histogram of untransformed grades, Middelvlei Reef, facies area

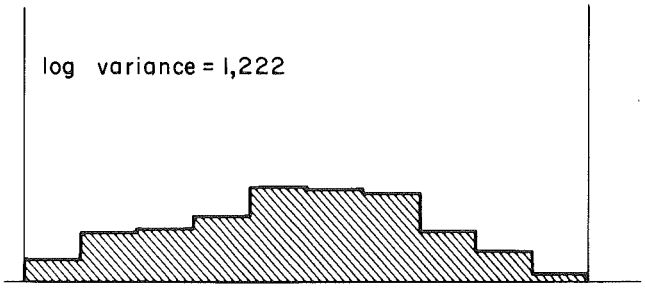


FIGURE 5.2 Histogram of log-transformed grades

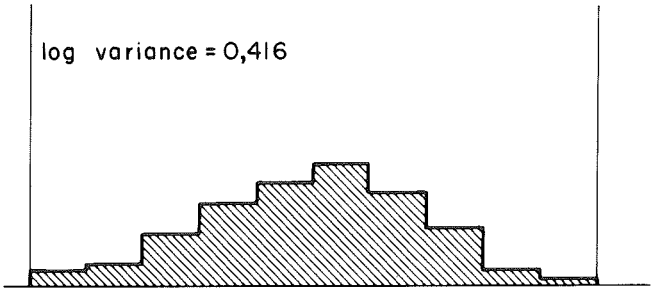


FIGURE 6.2 Histogram of log-transformed grades

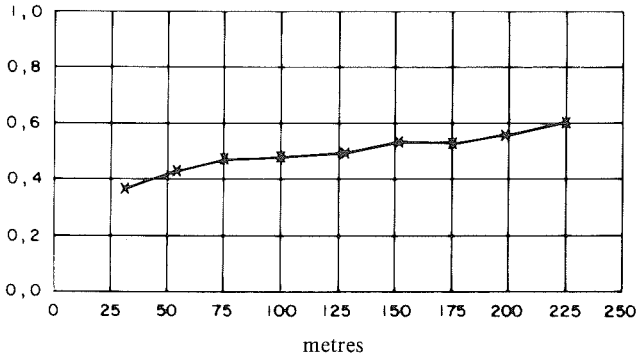


FIGURE 5.3 Normalized variogram

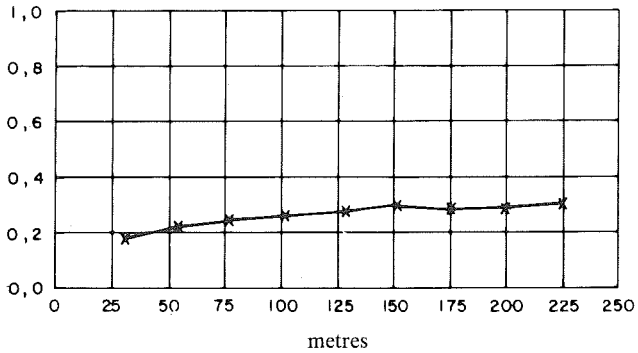


FIGURE 6.3 Normalized variogram

Facies Area 4, the development of small shallow channels has resulted in discrete, linear zones of payability.

In order to confirm that the facies area demarcation based on sedimentological observations is valid, statistical and geostatistical analysis of grades regularized into 25 m blocks was undertaken [6]. A histogram of the total mine area yielded the grade distribution seen in Figure 5.1. A log transformation was taken, producing a mixed population with high variance (Figure 5.2). Consequently, the semi-variogram, while showing some structure, has a high nugget effect (Figure 5.3). This analysis serves to confirm that the reef should be decomposed into separate facies areas and analysed separately. Analysis of Facies Area 2 validates the sedimentological breakdown, the histograms (Figures 6.1, 6.2) indicating that a single population of relatively low variance has been isolated yielding a semi-variogram with reasonable structure (Figure 6.3).

Follow-up analysis of smaller grid sizes

(i.e. 12,5 m blocks) has led to better results due to the increased number of data points. Directional effects (anisotropy) have been noted and serve to further confirm the sedimentological interpretation of trends. Kriged grade estimates have been obtained and this has enabled the effectiveness of selective mining of differing block sizes to be assessed in terms of revenue and working costs.

Conclusion

The application of sedimentological and geostatistical analysis at Blyvooruitzicht Gold Mine led to the development of a meaningful model for the practical and cost-effective exploration of the Middelvlei Reef. The basis of this integrated analysis was the construction of a large computer database, incorporating all historical sampling records. This enabled rapid extraction and manipulation of data which could then be synthesized into a model for prediction and linked with underground observations.

The computer database further provides the basis for kriged ore reserves, the speed with which they may be produced and their accuracy being essential for maximizing returns through selective mining and blending.

It is too early to estimate the financial benefit of the computerized evaluation to the mine. Undoubtedly, the lifespan of the mine could be significantly increased as a direct result of this modelling exercise, and the incorporation of these sedimentological and geostatistical techniques into a mine production model will further optimize strategic planning and financial benefits. A generalized account of how these computerized techniques are used to predict grade on a routine basis for mine planning at different scales on all the gold mines of the Rand Mines Group has been published [7].

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