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A logical approach to the evaluation of a stacked multi-reef Witwatersrand gold deposit

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This paper gives an account of the development of a technique whereby the vertical limits of geological horizons may be identified by the use of vertical variograms on the mineral of economic interest. This information may supplement or guide the correct subdivision of the individual horizons into meaning full data sets by diligent geological observation.

This process then improves the quality of the variance modelling of the gold distribution in the plane of the individual layers and therefore enables better estimates to be made into the grids or blocks of the mine model.

The technique is explained by an account of the development work, which was performed, on duplicate superimposed reef horizons in the Kimberley formations.

The paper then shows how the correct approach was developed to evaluate the mineralized layers in a multiple stacked conglomerate layer sequence in the Elsburg reefs of the Witwatersrand Rand System at the Target deposit. The method of categorization of resources according to confidence in the estimate is also explained.

The feasibility processes carried out on the three-dimensional model, in accordance with the SAMREC code are also described. An example of the development of a reconciliation process utilizing chip sampling is also explained.

The rationale behind the methodology used in the evaluation of thick multi-reef deposits

The author, W.D. Northrop performed research work in the late 80s and early 90s[1] on the deleterious effects to correct estimation of having mixed populations of reef horizons in databases that were to be used in geostatistical processes.

David first noticed this phenomenon[2] which he called the zonal effect as regards to variography in the early 1960s.

This is demonstrated in Figure 1 with an explanation of the origin in Figure 2.

He attributed it to the presence of mixed populations in the database, which produces an experimental variogram, which is very difficult to model and may require other kriging techniques to evaluate[3]. This situation can typically occur in multiple channel fluvial systems such as found in the Kimberley reefs. A diagrammatical representation of this situation is shown in Figure 3[4,5], where two conglomerate placer horizons are occurring so close in the succession that they may be mistaken for one single horizon. During research into the properties of calculating variograms of the gold values at right-angles to the plane of deposition of the placer deposits within which the mineralized zones occurred, Northrop found that this phenomenon could be utilized to recognize whether a data set was in fact homogeneous or not[1]. He discovered that a good idea of the thickness of the thinnest horizon present could be read from the lag distance at which the slope of the experimental variogram either increased or decreased rapidly. Such a case is demonstrated in Figure 4.

The situation in which this can be studied and an explanation for the reason for the changes in the slope of the variogram at certain lag distances are explained by the rapid increase in the number of contributing pairs from the two different horizons at a certain lag distance[1].

At this stage the data are split at this vertical interval. If a geological log is also available, the splitting can be achieved by the recognition of some geological feature at this point. Further vertical variograms on the individual data sets may then be plotted to prove that the data have been split at the correct point. An example is given in Figure 5. The normal variography on the composites of the individual horizons in the horizontal plane then become easier to model due to the fact that mixed directions of major anisotropy have been eliminated. This is demonstrated by Figure 6. This is extremely important because the weights to be assigned to the samples within the search radius when estimating a value into a block or point are determined by these models. This process enabled several puzzling data sets on the Kimberley reefs of the Central Rand to be unravelled and enabled the optimum pay ability to be exploited. A mine-wide example of the result of utilizing this methodology is shown in Figures 7 and 8. The characteristic channelization of the Kimberley reefs has been described by Pretorius, D.A.[6].

Methodology developed to produce the database in the stacked Elsburg reefs at Target

It became quite evident that due to the three-dimensional distribution of values in the Elsburg reefs that a fully three-dimensional software package was necessary. Datamine was identified as being a package with these capabilities.

The problem was different in that we were not dealing with two or three reefs in a package, but as much as a

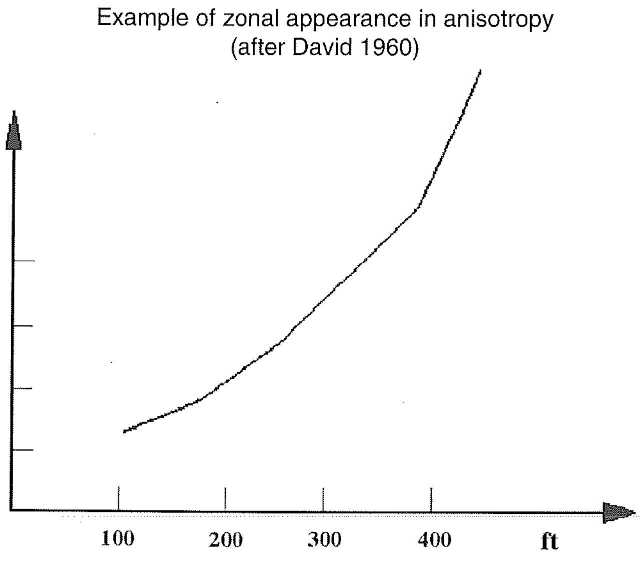

Figure 1. An example of the 'parabolic' effect of the drift on a variogram in a lead-zinc mine (lead trend)

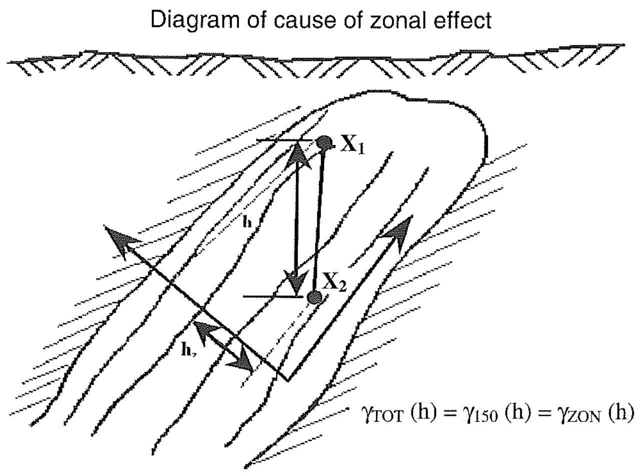

Figure 2. Within a single layer, variations are low. There are maximum perpendicular to the layering and total variations are due to real distance *h* between points and h_z distance

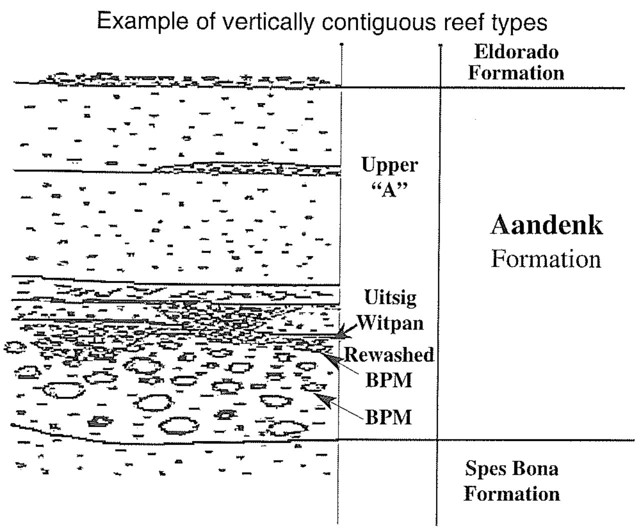

Figure 3. Schematic sections of the Aandenk reefs

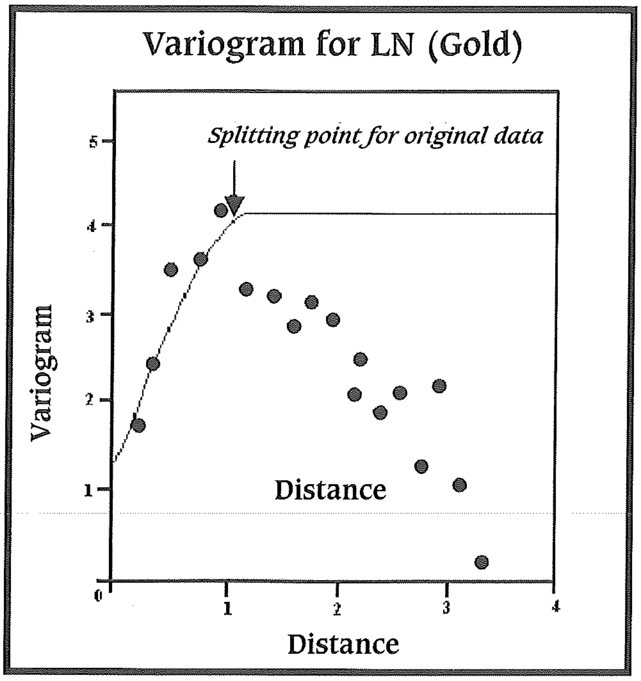

Figure 4. Example of the splitting point of the 9A-9B package of the kimberleys on the Central Rand

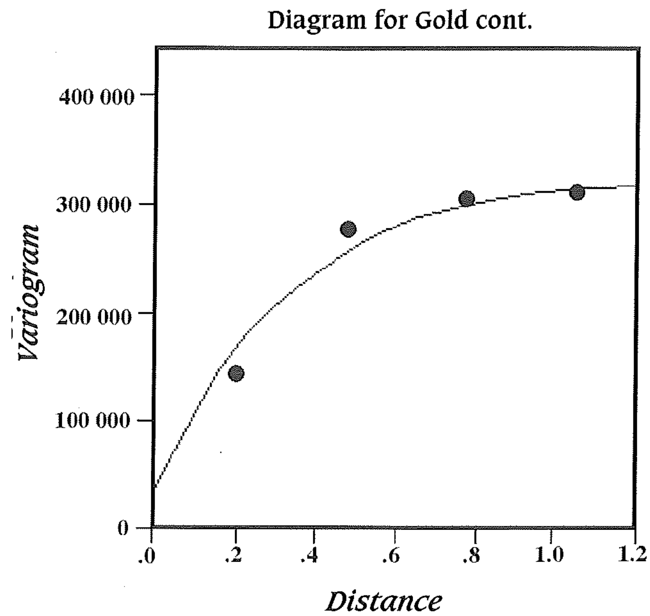

Figure 5. Vertical variogram to check that bottom reef has been split out correctly

sequence of 50 different reef types with intervening waste horizons.

The first split was done by utilizing the intermittent occurrence in geological time of quartzwacke horizons, which by virtue of their negligible gold tenor, and radically different composition, were thought to have originated from a different source area, to the more durable mature conglomerates and quartzites. The advent of a quartzwacke obviously heralded completely different depositional conditions, and therefore was the first natural break as far as splitting the whole package up into homogeneous layers

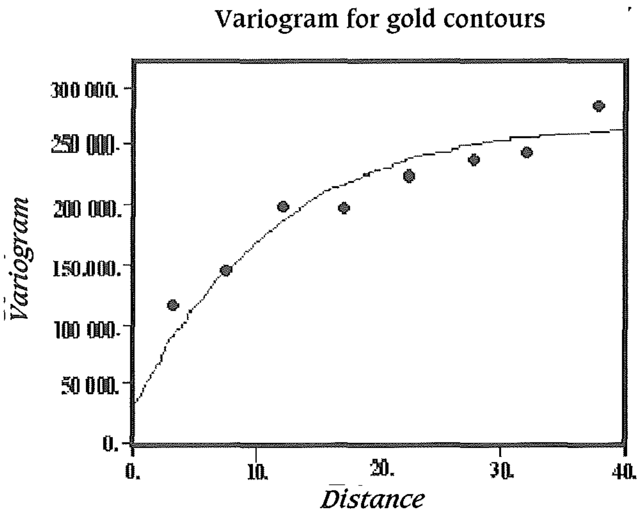

Figure 6. Diagram to show how variogram in plane of bottom reef has improved after splitting of data

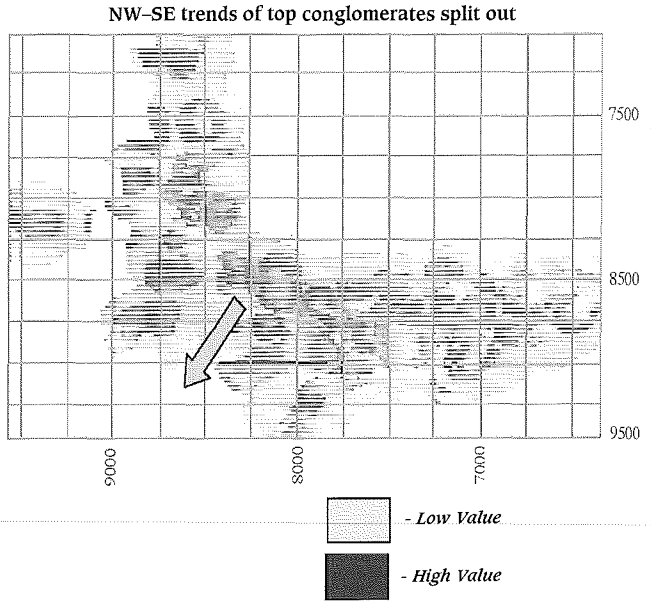

Figure 8. Kriged gold values of the 9 top band of the kimberley reefs at Central Rand

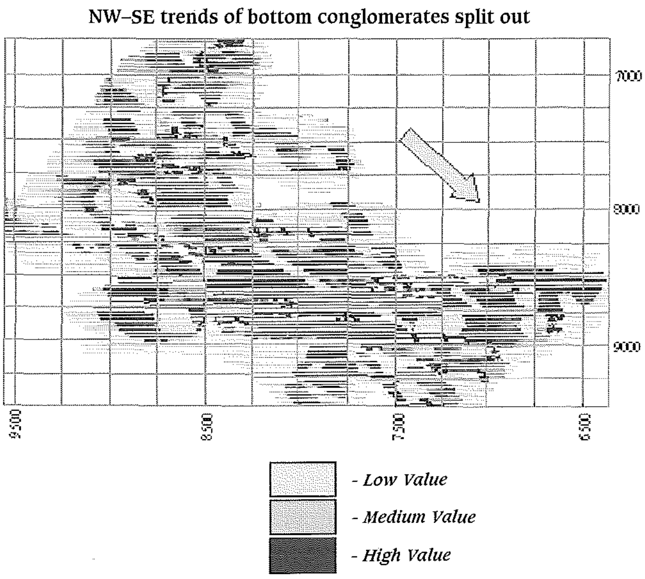

Figure 7. Kriged gold values on the 9 bottom reef horizon of the kimberleys on the Central Rand

Table I
Example of a part of the succession in the Elsburgs at Target

Standardized nomenclature and colour chart for stratigraphic units in the Elsburg and Dreyerskuil Formation			
Local stratigraphic units	SABLE stratigraphic codes	Datamine modelled horizons (Zone codes)	
		14X–18A	18A–21X
EA8 top quartzite	8TQ	8TQ	8TQ
EA8 top reef	8TC		
EA8 middle quartzite	8MQ	8MC	
EA8 middle reef	8MC		
EA8 bottom quartzite No. 2	8B2Q	8BQ	8BC
EA8 bottom reef No. 2	8B2C		
EA8 bottom quartzite No. 1	8B1Q	8BC	
EA8 bottom reef No. 1	8B1C		
EA8 FW quartzite	8Q	A8A	A8A
EA8 quartzwacke	8QW		
EA7b top quartzite	7bTQ	A7T	A7T
EA7b top reef	7bTC	A7S	A7S
EA7b middle quartzite No. 3	7bM3Q	7BTQ	7BMQ
EA7b middle reef No. 3	7bM3C		
EA7b middle quartzite No. 2	7bM2Q	7BMH	
EA7b middle reef No. 2	7bM2C		
EA7b middle quartzite No. 1	7bM1Q		7BMC
EA7b middle reef No. 1	7bM1C		
EA7b bottom quartzite	7bBQ	7BMC	
EA7b bottom reef	7bBC		
EA7b FW quartzite	7bQ	A7J	A7J
EA7b quartzwacke	7bQW	7BQW	7BQW
EA7a top quartzite No. 3	7aT3Q	7ATQ	7ATQ
EA7a top reef No. 3	7aT3C		
EA7a top quartzite No. 2	7aT2Q	7ATC	7ATC

with respect to the distribution of gold values. The zones between the quartzwackes were numbered EA 1 to 15. An abbreviated example of the stratigraphy with the quartzwackes highlighted is shown in Table I.

Distributions showed a clear break at about one g/t and an example is given in Figure 9. This grade division was identified for each major subdivision (EA1 to EA15). At this point the database was divided into reef and waste, zone by zone for the purpose of modelling. Distributions of both waste (or inter-reef) and reef were found to be log normal.

Drill hole sections with histograms of individual sample values were used to select the geo zones on the basis of gold value, but at the same time maintaining meaningful thickness of zones down dip and along strike. This is demonstrated by Figure 10. It is logical to select the geozones in this manner because the mineralization closely follows, and for the most part is constrained by the upper and lower contacts of the sediments[7].

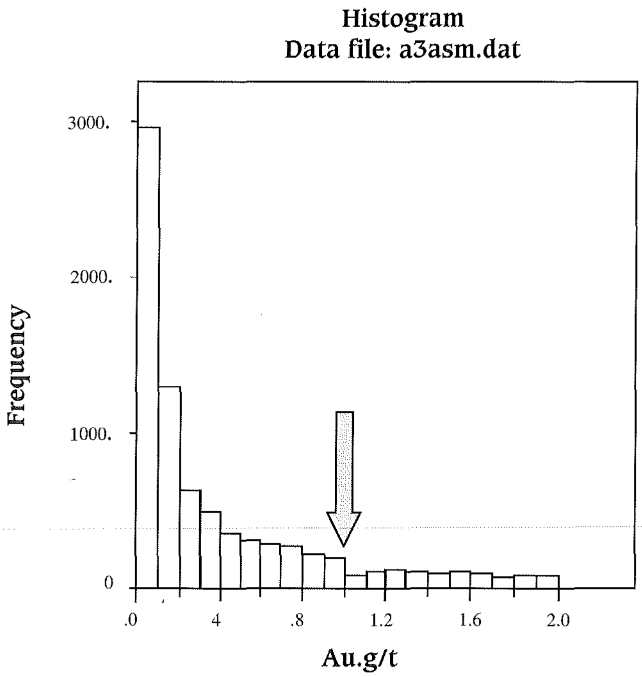

Figure 9. Histogram of individual gold values in 3s to show aprox. approximately 1.0 g/t break between waste and reef

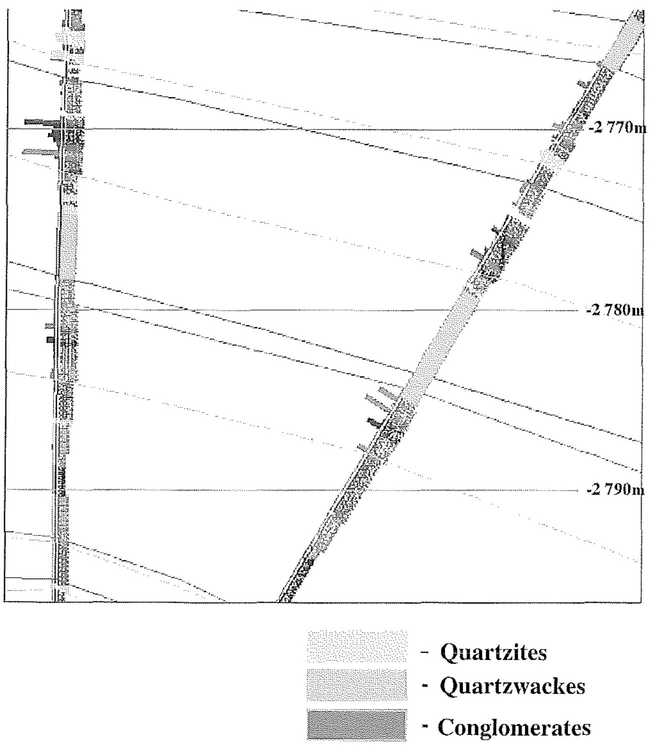

Figure 10. Datamine section through a drill line to show down hole distribution of gold values

Therefore modelling was done observing the upper and lower limits of the sediments unless the continuity of the mineralization depicted otherwise. The achievement of homogeneity of sample populations in each horizon was verified by performing vertical variography as described in the earlier part of this paper. Figure 11 shows the complete combined model of all the geo-economic horizons. The waste zones left behind were modelled separately from the base of each quartzwacke up to the uppermost quartzite and the areas occupied by the reef zones were subtracted by a Datamine process when formulating the block model.

The composites database for the geostats was made utilizing the compositing facility in Datamine.

The use of one-metre composites instead of reef composites was avoided due to the bias in number of composites that would be introduced by low angle boreholes.

A sensitivity study was performed between the two methodologies and it was found that irrelevant variance over and above the population variance was introduced into the system by using 1-metre composites. However, for the thicker low grade waste zones (< 1g/t) there was no other option but to utilize one metre composites.

Plane of orientation used to perform the geostatistical work

The best plane in which to do geostats will always be the one in which the samples utilized are spatially distributed similarly to the position they were in at the time of formation of the orebody. In the case of a deposit of placer origin this will be very close to a flat plane. It is evident from the model that the Target orebody is an asymmetrically folded plunging syncline cut by several major north-south striking faults that have a finite down throw to the west. Fortunately these faults trend to the north north east in a northerly direction and do not greatly affect the major part of the orebody. Nevertheless although Datamine offer a unfold facility; the time involved to utilize the system was not warranted in view of the fact that the orebody is not tightly folded. This was verified by a sensitivity study.

It was therefore decided to perform the geostats in a plane, which represented the best overall strike, dip and plunge of the orebody as we see it today. Variogram models were done in Datamine in local or world directions. This is a very useful feature when it is necessary to compare these directions with other software during auditing processes. A good agreement was obtained between log variogram and variogram models[8].

The variability of the variogram parameters throughout the package clearly demonstrates the necessity of splitting up the sequence into homogeneous layers. This is recorded in Table II.

Kriging of the individual horizons and categorization of resources

Ordinary block kriging was found to produce the most realistic results of grade into each modelled horizon.

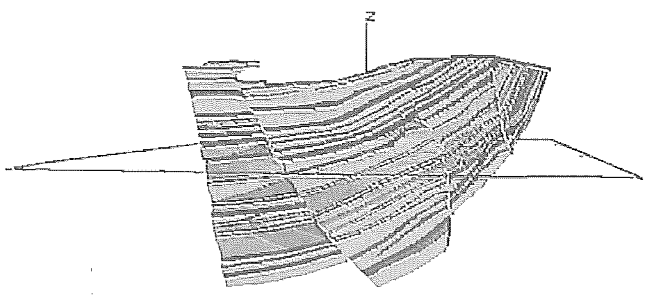

Figure 11. The multiple stacked reef package at Target Mine

Table II
Variogram parameters Eldorado Fan

Variogram parameters in the Eldorado fan of targer										
Reef	Sill	Nug	Maj. Dir. deg.	Min. Dir. deg.	Maj. Ran m	Min Ran m	Min Ran 2m	DM Az. eg	Az. dir. deg	Dip dir. deg
13CC	1.60	0.43	30	120	141	108	221	91.6	1.6	4.5
13AC	1.80	0.66	15	105	184	46	216	74.8	345	9.6
12C	0.90	0.1	30	120	212	120	223	91.6	1.6	15.0
11C	1.96	0.63	30	120	155	95	219	94.4	4.4	12.7
10C	2.14	0.57	45	135	200	63	222	107	17	12.7
9BC	2.01	0.44	30	120	267	144	270	93.4	3.4	12.7
8BC	1.34	0.30	30	120	205	124	222	93.6	3.6	12.2
7BMC	2.19	0.58	120	30	143	95	220	104	13.9	12.6
7ATC	2.54	1.50	30	120	157	46	220	199	109	13.6
5TC	1.37	0.47	30	120	182	119	221	93.9	4.0	14.9
5BC	1.72	0.52	165	75	207	147	221	290	200	6.9
3CC	1.90	0.60	60	150	155	114	221	132	42	13.4
3BTC	1.59	0.47	60	150	103	70.6	110	132	41.6	28.1
3BMC	1.83	0.75	60	150	107	36.6	220	132	42	28.1
3BBC	1.95	0.62	30	120	237	96	223	101	11	18.4
3AC	1.90	0.66	30	120	191	87	222	101	11	3.7
2TC	1.32	0.23	60	130	238	152	221	132	42	18.6
2BC	1.24	0.59	30	120	165	50	222	101	11	1.6
1TC	1.08	0.11	120	30	298	233	223	101	11	5.4
1MC	1.38	0.21	75	165	259	191	221	151	61	5.4
1BC	0.59	0.13	60	150	275	202	221	133	43	31.5
BCD1AX	3.44	1.09	45	135	165	109	220	45.4	315	-10
D1XC	5.70	1.81	30	120	163	66.1	224	113	23	0
D1BC	2.11	0.63	105	15	183	94	221	78.4	348	9.7
D1CC	1.8	0.59	135	45	124	61	218	102	12	2.2
D1DC	2.81	0.46	135	45.0	204	43.0	220	116	26	5.8
D1EC	2.17	0.12	135	45	182	130	220	84.0	354	11.2
D4AC/BC	1.82	0.44	30	120	153	98	223	104	14	1.4
D4CC/DC	0.86	0.28	165	90	159	98	204	149	59	0.6
D6C	3.61	1.33	75	165	157	94	219	181	91	-10

Categorization of the resources was done according to kriging variance, number of samples in the search radius and range of influence of variograms. This was found to be the best way in which resources could be categorized for the purpose of complying with the SAMREC code. Figures 12 and 13 are examples of plot outs of kriging variance values and number of samples in the search radius respectively. The search radius limits were set at the variogram range and less for indicated resources and the range at two thirds of the population variance for measured resources[9]. Blocks informed by a minimum of 3 samples but at a search radius greater than the range of the variogram are classified as inferred. This automatically places an acceptable number of samples in the search radius for indicated and measured resources.

Packages of reefs suitable to various types of mining were selected from indicated resource categories and higher. These were combined in one model for the purpose of delineating reserves.

Block factors

Block factor calculations of the Target deposit have been done by utilizing close spaced underground follow up chip sampling. This enables an accurate 'gold called for' figure to be calculated for the purpose of 'mine call factor' and 'block factor' calculations. Figure 14 is a contoured geological block factor plan of one of the reefs. Areas where high block factors have been recorded (1.2 or more) had been categorized as inferred resources in the original evaluation utilizing the drill hole data base. The resources were moved into a higher category in a Bayesian fashion by utilizing knowledge of typical down dip extension of grades in a similar alluvial fan to the south. These estimated grades were later found to be conservative subsequent to re-evaluating using supplementary infill drilling and chip sampling. Since the follow-up grades were higher one can only suppose that some gold was lost in the original drilling.

Delineation of reserves

This was done through the Datamine process 'stope optimizer', which identifies areas that can be mined economically by varying the input parameters such as cut - off grades and mining unit size. A wire frame of the stope design is produced. Figure 15 shows a grade value section through a package of reefs, which demonstrates the sort of resource information that is provided for feasibility studies. This Figure also demonstrates how a massive open stope design is derived from the individual reef models. The outline of the massive open stope design is shown superimposed in section.

Planning of blast holes

The long hole open stope blast holes have been designed by the use of the Datamine 'Rings' module, which utilizes the wire frame model of the stope design for the limits of the mining.

Conclusions

Even although the deposit is composed of many different

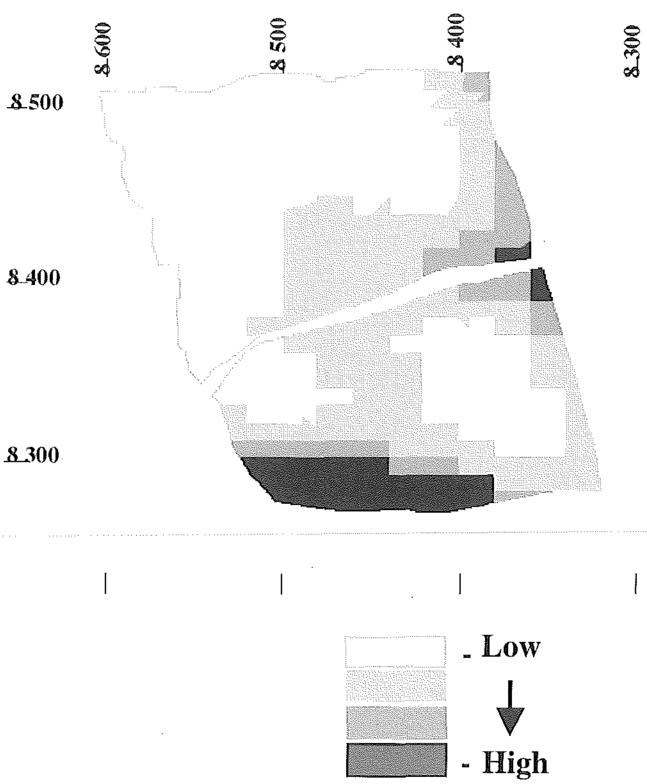

Figure 12. 7BMC krig variance

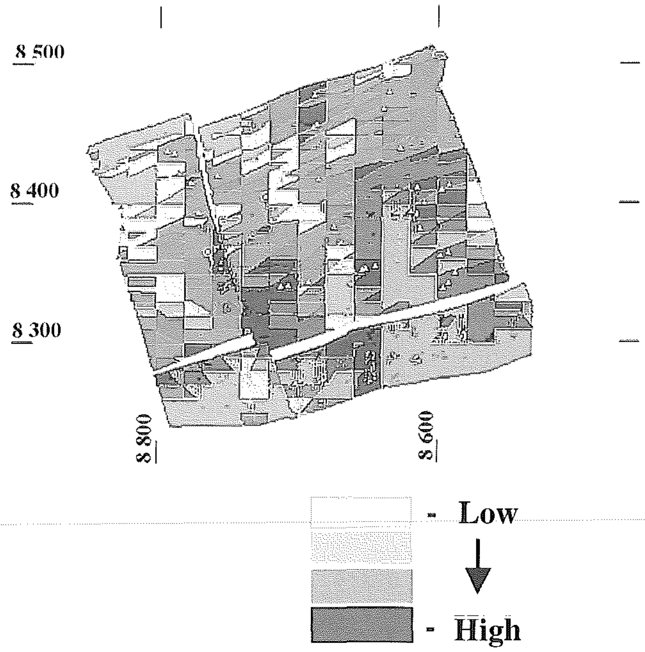

Figure 14. 7B s block factor plot out

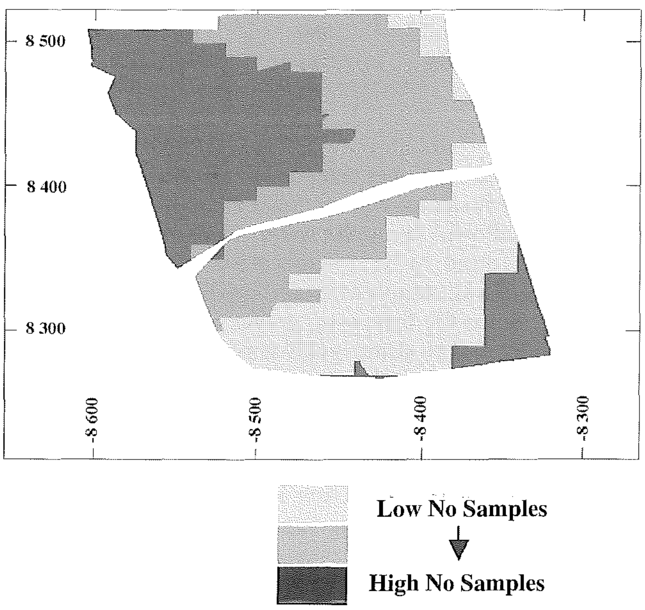

Figure 13. 7BMC no samples

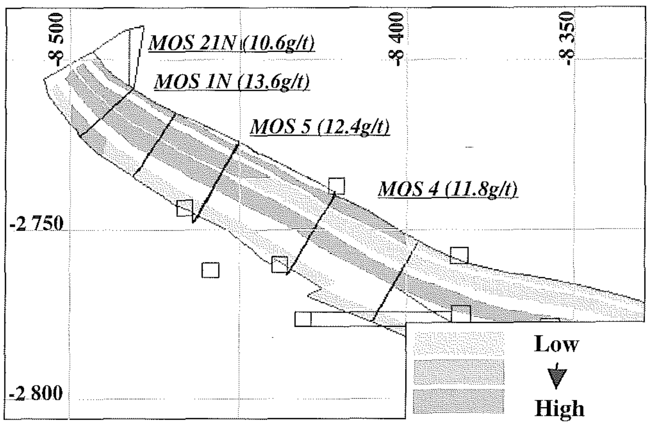

Figure 15. Cross-section E–W showing stope optimizer selection of wide open stope

geological horizons, all of which proved to contain sediments with mineralization that had been laid down under differing geological conditions, the evaluation has proved to be realistic, if a little conservative and the categorization of resources has been proved to be effective.

This is thought to be due to the rigorous division of the sample database into meaningful geological horizons, which resulted in the variogram models containing no 'zonal effect' and being true representations of the variance between pairs of samples.

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