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The effect of ignoring the sample support on the global and local mean grade estimates, mineral resource classification and project valuation of variable width Merensky and UG2 Reef orebodies

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The application of geostatistics to exploration data to derive estimates of the global and/or local means of metal contents and to assist in the classification of the mineral resources is well documented and established. It is also well documented and established that the regionalized variable employed in geostatistical analysis needs to be additive, i.e. of equal support. When dealing with shallow dipping planar orebodies, a two-dimensional geostatistical approach is appropriate, however, at least the intersection widths should be used to provide equal support to the intersection grades; the accumulation methodology. It is thus surprising that it has become fashionable in some sectors of the platinum industry to ignore the intersection widths and apply geostatistical analysis to intersection grade data directly for block grade estimates; the grade methodology. Two Merensky Reef and two UG2 Reef case studies have been employed to understand the magnitude of the differences [(grade – accumulation)/accumulation] associated with the estimation of metal grade by the grade methodology. (This convention provides positive differences for overestimation and negative differences for underestimation of the grade methodology.)

The case studies show that the global mean metal grades can have differences of between -8% and 2% whereas the average local (block) mean differences are generally lower, between -6% and 2%. The assumption that the downstream applications on block models created by the grade methodology will have similarly low estimation differences is naïve and incorrect. Individual block grade differences range from -34% to 60%, thus removing confidence in the local block grades estimated by the grade methodology.

The difference associated with the classification of the Mineral Resources is measured on the contained PGE metal ounces in the Measured and Indicated Mineral Resource categories. The classification in the case studies is standardized on various levels of kriging efficiency. The differences in the contained PGE ounces of the Measured and Indicated Mineral Resources vary from -12% to 100%. Also the percentage of the Measured and Indicated Mineral Resources to the Total Mineral Resources can provide a measure of the project's ability to attract investment and based on a 50% hurdle, the Case 1 Merensky and UG2 Reef project would obtain investment based on the accumulation estimation whereas only the Case 1 Merensky Reef would obtain funding based on the grade estimation. Valuation based on US$ per contained PGE ounce has differences of between -9% and 100%.

The differences associated with the local means prompted scrutiny of what differences may be associated within a mining schedule and discounted cash flow. A synthetic mine schedule that assumes mining from the highest PGE block grade to the lowest over time was derived for the grade estimation blocks. The corresponding accumulation estimation block grade was also employed in a parallel schedule as the 'true' block grades. In this manner, the differences in metal production can be modelled as well as a measure of the difference in the before tax net present value for each project. The differences in the net present value ranged between -15% and 31%.

Introduction

It is the norm in the platinum industry of South Africa to evaluate the generally shallow dipping Merensky Reef and UG2 Reef projects on either the platinum group elements (PGE) individually, or on a combined Pt, Pd, Rh and Au (PGE (4)) evaluation cut (intersection) value, from vertically oriented diamond drilled core samples. The intersection value is normally averaged on a length-weighted basis but can also be weighted on a length and density-basis as described by Boufassa (1989) and Young (2006) of the core samples. Thus a database of at least PGE intersection gram per ton grade (g/t) and width (m) are created for the point intersection data and in some instances the orebody density.

It would appear that the fashion in recent years by various evaluation practitioners within the platinum industry, when evaluating a project or mine, is to employ the intersection PGE (g/t) and width (m) as the variables. This is termed the grade methodology. Estimation based on the PGE metal accumulation (metre gram per ton (mg/t) in the case of the length-weighted basis and gram per square metre (g/m^2) in the case of the length and density-weighted basis) of the intersection data is termed the accumulation methodology. The accumulation methodology is rejected by certain practitioners on the basis of the g/t versus m relationships of the intersection data.

The arguments put forward by the proponents of the grade methodology generally refer to scrutiny of the scattergrams of the intersection widths versus the grades. Some proponents argue that if there is no obvious correlation between the grade and the width then it is better to use the grade methodology and not the accumulation methodology. Conversely, other proponents of the grade methodology argue that if there is a relationship between the intersection width and grade, then the grade methodology should be employed and not the accumulation methodology. Their arguments are thus contradictory for acceptance of the grade methodology and rejection of the accumulation methodology. The author thus sets out to understand what biases could exist in a grade methodology mineral resource estimate by comparing it with a mineral resource estimate based on the generally accepted accumulation methodology.

Confusion as to what constitutes a regionalized variable can occur for the inexperienced evaluation practitioner as there are abundant technical papers dealing with various aspect of geostatistics that make mention of 'metal grades and/or values' for the variables under consideration. Examples of this can be found in Wainstein (1975), Hekkila and Koistinen (1984) and Krige (2003) where it is not always apparent what they mean. However, on scrutiny of other technical papers such as Journel (1976), Dowd (1982), Lantuejoul (1988) and Zhang *et al* (1990) it soon becomes obvious that the regionalized variables are associated with a specific volume (support). Hence, in this age and country of well-entrenched geostatistical knowledge, it is surprising that the grade methodology is applied to variable width Merensky and UG2 Reef intersection data, and that the grade (g/t) is employed as a regionalized variable by some practitioners.

Geostatistics, the study of regionalized variables, require that the variables being employed should be additive, i.e. of equal support size as defined by Journel and Huijbregts (1978) and the overall procedure is described in detail by Parker (1991). Recently Lambert (2004) provided an indication of the error associated with the grade methodology and compared simulations that enabled her to conclude that the accumulation methodology is simpler and less prone to error. Krige (1981) summed up the situation nearly three decades ago when he recognized that many people were being mislead with their interpretations of what constitutes a regionalized variable and were incorrectly assuming that the intersection grade (g/t) and width (cm) were the variables to use in geostatistical estimation. He asserts that the only two variables to use are width (m) and accumulation (mg/t) if no significant variations in density occur.

It is conceded that in many instances a standard mining width, hangingwall or footwall cut is evaluated, thus the support is constant. In these cases the use, of the associated grade variable is applicable as the cut is of equal support, but it would not be applicable if the density varied significantly. In the situations where virtually unchanging grade occurs, i.e. the chromium grade of the LG6 Layer, or the iron/vanadium/titanium content of the Main Magnetite Layer, only the width may need to be geostatistically estimated to evaluate the tonnage and contained metal of the project.

The SAMREC Code (2007) (Table I: Checklist and Guideline of Reporting and Assessment Criteria, Section T4.2 Estimating and Modelling Techniques) requires that a description is made of the assumptions and justification of correlations made between variables. The interpretation the author makes of this clause is that it cannot be invoked for incorrect assumptions as what constitutes a regionalized variable.

Two data sets of Merensky and UG2 Reef have been used as a case study to analyse the differences in the global and local mean grades, classification of the Mineral Resources and valuations of the project by comparing the results of the accumulation and grade methodologies. This paper contains the results of this study.

Data

Two data sets from exploration projects evaluating both the Merensky and UG2 Reefs have been accessed from the public domain and employed in this case study comparison. The exploration projects are not revealed in this comparison as the relative difference in the methodologies is the focus and not the absolute estimates of tonnage, metal contents, classification of Mineral Resources and valuation. Also, significant differences exist between the published project statistics and this study's results due to the data sets footprints being employed instead of license and structural boundaries. Also, no in-depth evaluation based on differing facies type has been employed.

The relationship between the g/t and m for each dataset were scrutinized and noted to have no obvious relationship except for the Case 1 UG2 Reef where a narrow grade spread about the 5 g/t level for all widths occurs, whereas the Case 2 UG2 Reef would appear at first glance to be bimodal with high and low grade facies. The scattergrams are contained in Figure 1.

Case 1 had detailed density data reported for each intersection, thus the accumulation methodology could be based on the g/m^2, t/m^2 and m variables, whereas Case 2's reporting was restricted to the cmg/t and m variables.

Case 1 had many deflection data per borehole whereas Case 2 had mainly one intersection per borehole and very few deflections. Thus the Case 1 data was declustered by averaging the deflection data on a length and density weighting basis to remove any screening effects (Deutsch and Journel, 1998), particularly as the coordinates of the reef intersection data are not well known, only the borehole collars.

The distribution graphs for each variable per case were scrutinized; the plots being contained in Appendix 1. From these distribution graphs it can be seen that Case 2 has positively skewed distributions for all variables (cmg/t, m, g/t) for both the Merensky and UG2 Reefs. A bimodal distribution of the g/t and m variables exist for the UG2 Reef of this case that would prompt separate geostatistical evaluation of the data below and above various thresholds. However, scrutiny of the variables spatial distributions indicated that the higher values are intimately mixed with the lower value intersections which would require a complex boundary definition to evaluate separately. As this

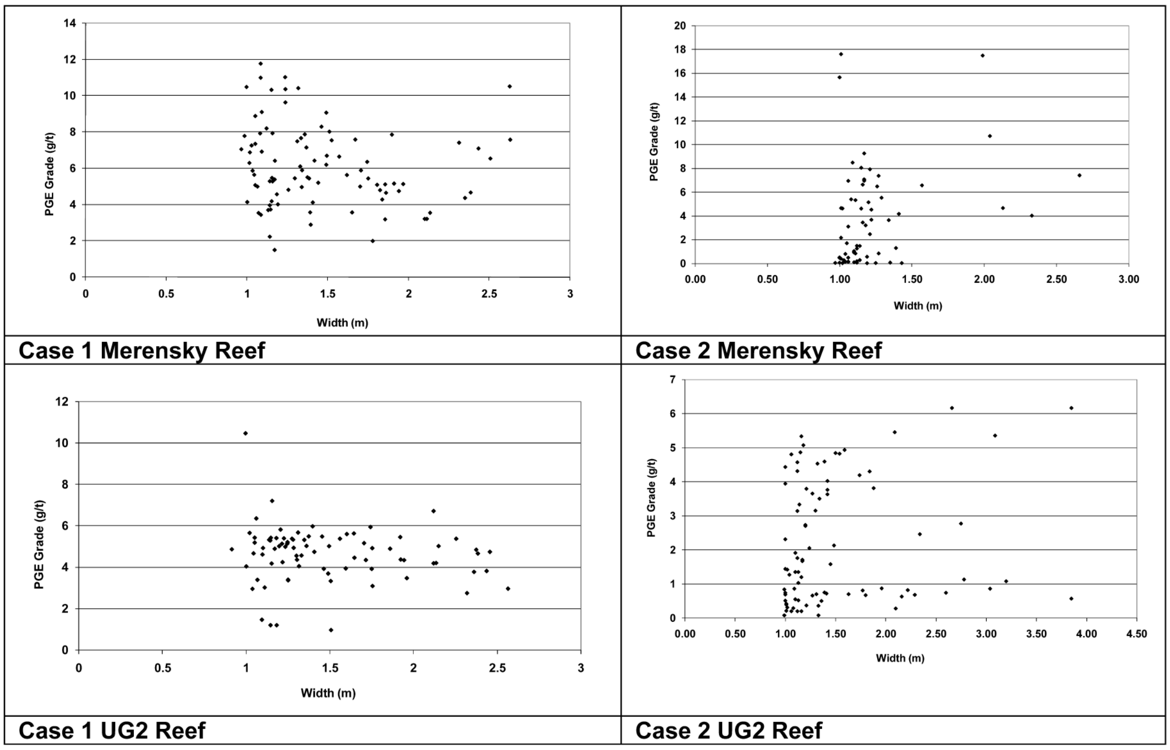

Figure 1. Grade versus width relationships for the four cases investigated

is only a comparative study and not a definitive mineral resource estimate, grouping of both populations is not identified as a material flaw in the estimation procedure.

The Case 1 Merensky and UG2 Reef t/m^2 and m variables are the only positively skewed variables, the others having central tendencies. The statistical data for each case and reef are contained in Table I.

From the plots depicted in Figure 1 it can be seen that no evaluation cuts have been based on a width of less than 1.0 m which correlates with the reporting that indicates minimum mining widths of 1.0 m were considered in the mineral resource statements. An independent review of the analytical quality assurance and control was not possible on the data provided and does not form part of the scope of this study, however, regression analysis of the Pt/Pd and Rh/Au for the intersections was completed. Figure 2 is an example of this methodology which can assist in identifying analytical outliers; none were identified in this study.

To understand if the data contained significant outliers for the different variables an analysis of the ascending variable value versus the ascending variable coefficient of

Table I
Statistical results for each case and reef type

Statistic	Case 1 Merensky Reef	Case 2 Merensky Reef	Case 1 UG2 Reef	Case 2 UG2 Reef
Average (g/m^2)	27.93	N/A	25.99	N/A
Std dev (g/m^2)	12.03	N/A	8.92	N/A
Coefficient of variation (g/m^2)	0.431	N/A	0.343	N/A
Number (g/m^2)	91		80	
Average (mg/t)	N/A	4.91	N/A	3.21
Std dev (mg/t)	N/A	6.22	N/A	3.21
Coefficient of variation (mg/t)	N/A	1.267	N/A	1.001
Number (mg/t)		66		83
Average (t/m^2)	4.64	N/A	5.62	N/A
Std dev (t/m^2)	1.30	N/A	1.52	N/A
Coefficient of variation (t/m^2)	0.281	N/A	0.271	N/A
Number (t/m^2)	91		80	
Average (m)	1.46	1.22	1.49	1.49
Std dev (m)	0.42	0.32	0.43	0.61
Coefficient of variation (m)	0.288	0.260	0.285	0.407
Number (m)	91	66	80	83
Average (g/t)	6.12	3.68	4.64	2.13
Std dev (g/t)	2.21	4.08	1.33	1.75
Coefficient of variation (g/t)	0.361	1.111	0.288	0.82
Number (g/t)	91	66	80	83

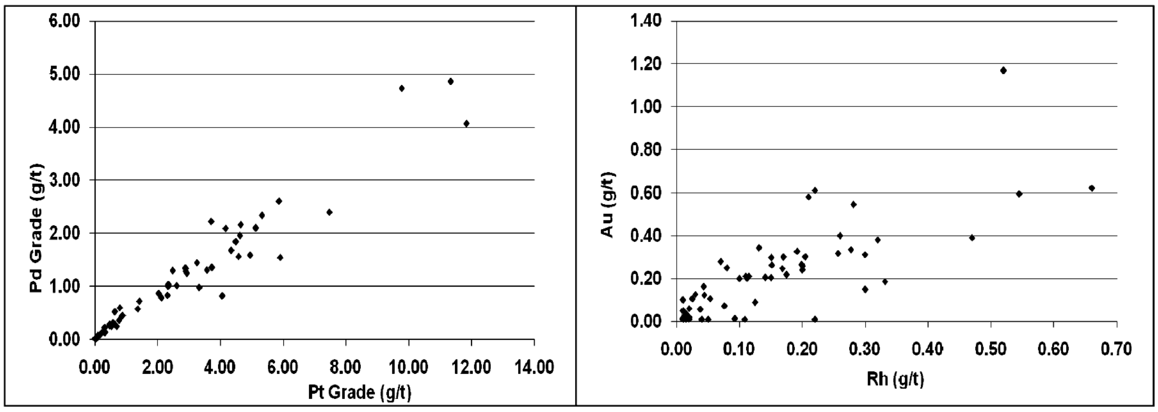

Figure 2. Regression of Pt versus Pd (left) and Rh versus Au (right) for Case 2 Merensky Reef

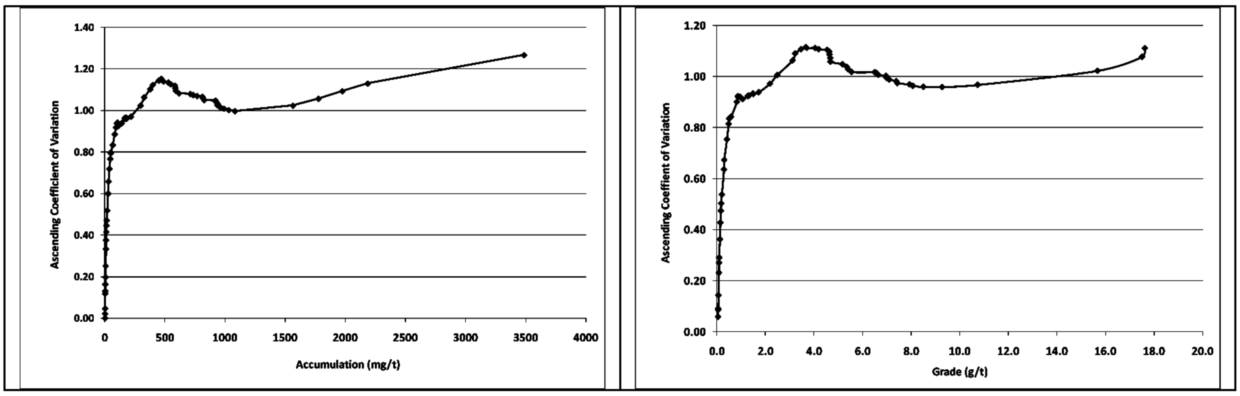

Figure 3. Case 2 Merensky Reef analysis of ascending variable value versus coefficient of variation (mg/t left and g/t right)

variation was completed (Figure 3). Plots depicting similar shapes would suggest similar overall distributions. The need for capping of high values or elevating of low values for a particular variable was then judged in the context of this comparative study. No adjustments were made to the variables in this study.

Estimation of mineral resources

Ordinary kriging was performed on the variables utilizing mostly the GSLIB software. Blocks of size 500 × 500 m were selected as the data distribution is approximately on a 250 × 250 m grid (Appendix 2) in both cases, thus blocks will be well informed for both cases and depict the local data values.

The variography of the Case 1 data was performed in three passes. The first pass was on the individual intersection data to establish the nugget effect (N_1) from deflection data. The second pass was to establish the isotropic variogram based on the declustered data by employing an amended nugget effect (N_2) from the first pass as described by Rendu (1978). (The nugget effect can be considered approximately inversely proportional to the size of the sample. The de-clustered data are approximately 2.6 times larger than the individual intersections as there are on average 2.6 deflections per declustered borehole, thus $N_2 \approx N_1/2.6$.) The third pass was to test for anisotropy by firstly scrutinizing spatial distribution plots of the variable for the various cases. Scrutiny of these plots was then used to assist in directional variography to test for anisotropy. The isotropic variograms interpreted in the second pass for all of the variables are contained in the figures, Appendix 3. The second pass isotropic variogram models are contained in Table II and Table III contains the anisotropic data relating to the direction and range models where required.

Variography of the Case 2 data was completed by conducting only the second and third passes as described above, as no deflection data was available.

Ordinary normal kriging was completed with the following parameters set for all variables and for both cases:

Block size	500 × 500 m
Minimum no. of samples	5
Maximum no. of samples	16
Search distance	Two and one half times the variogram range
Block discretization	8 × 8

The differing variogram ranges and hence search radii or ellipse will impact on the block evaluation footprint. In the comparative study only the estimated blocks that had a common footprint were employed. Table IV contains the evaluated block data comparisons.

Comparative results

The outputs from GSLIB (Z-Estimate and Z-Kriging Variance) were built into an Excel spreadsheet for each reef and case so that the block data were aligned. The results could thus be compared and processed for the different methodologies under consideration. Poorly informed blocks with no results or having less than the minimum number of samples were erased throughout, thus permitting comparison of only moderately to well-informed blocks that had a common variable footprint per case were employed.

Table II
Isotropic spherical variogram models

Parameter	Variable	Case 1 Merensky Reef (Semivariance)*	Case 2 Merensky Reef (Semivariance)*	Case 1 UG2 Reef (Semivariance)*	Case 2 UG2 Reef (Semivariance)*
Nugget	g/m2	77.02	N/A	32.193	N/A
Co + C	g/m2	146.50	N/A	80.500	N/A
Range	g/m2	1200 m	N/A	600 m	N/A
Nugget	mg/t	N/A	50 000	N/A	0
Co + C	mg/t	N/A	390 600	N/A	104 000
Range	mg/t	N/A	500 m	N/A	150 m
Nugget	t/m2	0.2019	N/A	0.22	N/A
Co + C	t/m2	1.7150	N/A	2.35	N/A
Range	t/m2	650 m	N/A	625 m	N/A
Nugget	m	0.0198	0.019	0.0147	0.06
Co + C	m	0.1785	0.103	0.1830	0.37
Range	m	675 m	900 m	550 m	350 m
Nugget	g/t	3.00	4.0	0.56	0
Co + C	g/t	4.95	17.0	1.80	3.075
Range	g/t	775 m	500 m	575 m	200 m

* Where applicable

Table III
Anisotropic directions and ranges—spherical models

Case	Reef	Variable	Principle direction	Major range (m)	Minor range (m)
Case 1	Merensky	g/m2	045°	1 200	750
Case 1	UG2	g/m2	030°	650	550
Case 1	UG2	m	020°	650	400
Case 1	UG2	g/t	030°	500	350
Case 2	Merensky	g/t	050°	500	350
Case 2	UG2	m	120°	350	150

Table IV
Evaluation block data

Case	Reef	Variable	Number of blocks estimated	Number of blocks compared
Case 1	Merensky Reef	g/m2	89	74
Case 1	Merensky Reef	t/m2	75	74
Case 1	Merensky Reef	m	77	74
Case 1	Merensky Reef	g/t	83	74
Case 1	UG2 Reef	g/m2	71	65
Case 1	UG2 Reef	t/m2	69	65
Case 1	UG2 Reef	m	71	65
Case 1	UG2 Reef	g/t	77	65
Case 2	Merensky Reef	mg/t	58	58
Case 2	Merensky Reef	m	72	58
Case 2	Merensky Reef	g/t	58	58
Case 2	UG2 Reef	mg/t	16	16
Case 2	UG2 Reef	m	49	16
Case 2	UG2 Reef	g/t	27	16

Global grade estimates

The global grade estimates for the four comparisons are contained in Table V. In this method, only the average grade and contained PGE (4) metal of the common estimation footprint is calculated.

Local block grade estimates

The disparity in grade for each block has been analysed to understand the difference on a local scale that can be associated with employing the grade methodology. Table VI contains the average estimation % difference results and range of estimation differences.

Classification of resources

The classification of the mineral resources is based on three methods as documented by Mwasinga (2001). The first is based on the block estimate estimation error at the 90% confidence limits as defined by:

$$Est_{Error} = {}^{(1.645 \times \text{Krig Std Dev})}/_{Z_{Est}}$$

Where estimation errors are less than 10% the block is classified as measured; between 10% and 25% the block is classified as Indicated and when >25% the block is classified as Inferred.

The second classification method is based on the value of the kriging variance divided by the block variance. Where

Table V
Case 1 and 2 Merensky and UG2 Reef comparison

Case	Reef	Attribute	Accumulation	Grade	Difference %
1	Merensky	Ave Block Grade PGE (4)	5.96	6.07	1.91%
1	Merensky	Data Ave Grade PGE (4)	6.02	6.12	1.66%
1	Merensky	Contained PGE (4) Moz	12.372	12.671	2.42%
1	UG2	Ave Block Grade PGE (4)	4.61	4.56	-0.91%
1	UG2	Data Ave Grade PGE (4)	4.62	4.64	0.43%
1	UG2	Contained PGE (4) Moz	9.991	9.958	-0.33%
2	Merensky	Ave Block Grade PGE (4)	4.33	3.97	-8.32%
2	Merensky	Data Ave Grade PGE (4)	4.07	3.68	-9.58%
2	Merensky	Contained PGE (4) Moz	5.572	5.109	-8.32
2	UG2	Ave Block Grade PGE (4)	2.17	2.15	-0.54%
2	UG2	Data Ave Grade PGE (4)	2.15	2.13	-0.93%
2	UG2	Contained PGE (4) Moz	0.970	0.965	-0.54%

Table VI
Average block data estimation difference and range of difference

Case	Reef	Average (%)	Minimum (%)	Maximum (%)
Case 1	Merensky	1.75	-11.38	23.11
Case 1	UG2	-1.08	-20.27	16.87
Case 2	Merensky	-5.52	-33.96	60.07
Case 2	UG2	0.25	-25.12	19.79
Averages	All	-1.15	-22.68	29.96

this is <0.5 the block is classified as Measured, where it is <1.0 it is classified as Indicated and Inferred when it it >1.0.

The third classification method is based on the kriging efficiency defined as:

Kriging Efficiency (K_e) = $^{\text{(Block Variance – Kriging Variance)}}/_{\text{Block Variance}}$

For values of K_e >0.5 the block is classified as Measured; as Indicated for values of K_e between 0.3 and 0.5 and Inferred when it is <0.3. The results of these classifications of the contained PGE (4) metal for the different cases and methodologies are contained in Figure 4.

Geostatistical classification of a mineral resource is often based on the various 'errors' associated with the kriging results. The data in Figure 4 indicates that the most

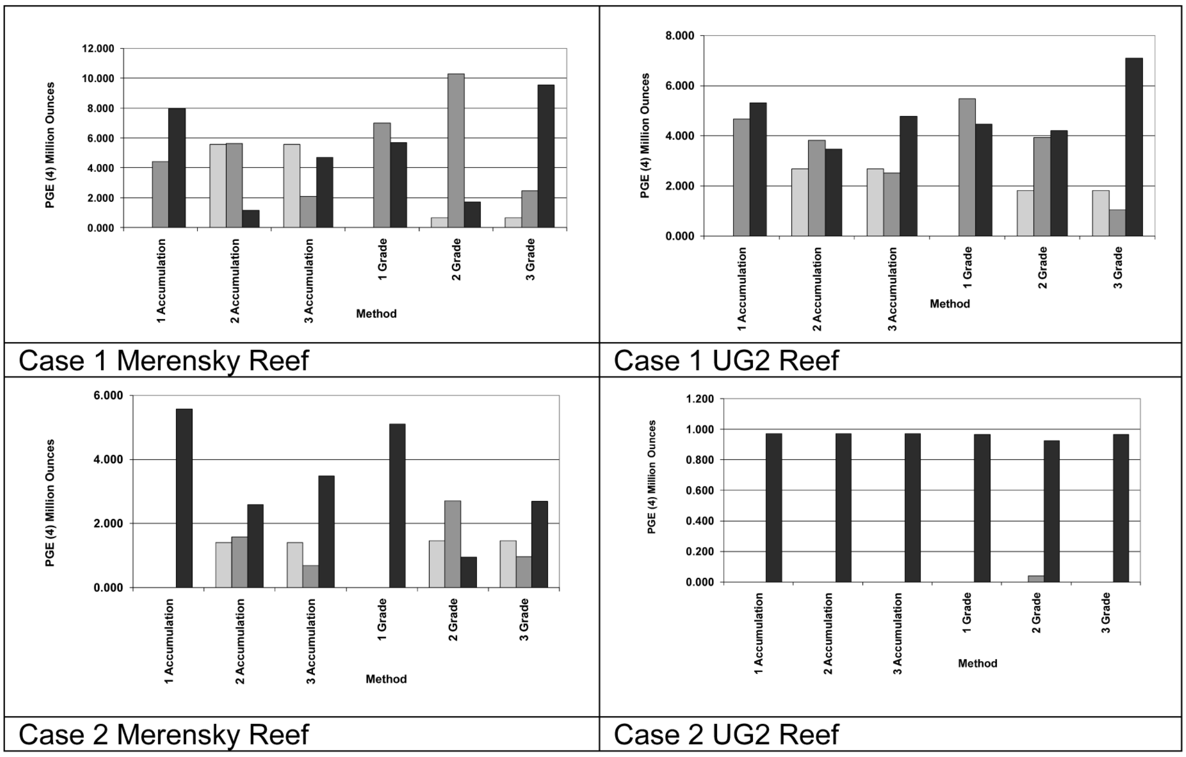

Figure 4. Classification results of the two cases for each reef based on the contained PGE (4) metal. (Classification methods: 1 = confidence limit, 2 = kriging variance to block variance ratio and 3 = kriging efficiency. Mineral Resource classification: Inferred = black, Indicated = medium gray and Measured = light gray)

conservative classification is the 90% confidence limits error and the most liberal the kriging variance to block variance ratio with the kriging efficiency in-between. This applies to all cases and reefs. The Figure 4 data is summed up simplistically in the matrix contained in Table VII where the % difference between the grade and accumulation methodologies is presented per classification system.

An important consideration when competing for investment capital is the ratio of Measured and Indicated Mineral Resources compared to either the total project area or 'payback area'. Thus an evaluation methodology and classification scheme that overly depresses this ratio is adding to the hurdle for investment. Based on a requirement that at least 50% of the total Mineral Resources are required to be in the Measured and Indicated class, the Case 1 Merensky and UG2 Reefs evaluated by the accumulation methodology (Table VIII) would attract investment, whereas only the Case 1 Merensky Reef would attract investment.

Table VII
Differences associated with grade and accumulation estimation methodologies

Case	Reef	Class	Error (CL)	Error (Kv/Bv)	Error (Ke)
1	MR	Meas	N/A	-88.03%	-88.03%
1	UG2	Meas	N/A	-32.59%	-32.59%
2	MR	Meas	N/A	4.45%	4.45%
2	UG2	Meas	N/A	N/A	N/A
1	MR	Ind	58.79%	82.40%	17.97%
1	UG2	Ind	17.40%	2.93%	-58.44%
2	MR	Ind	N/A	71.08%	38.94%
2	UG2	Ind	N/A	N/A	N/A
1	MR	Inf	-28.75%	48.64%	102.75%
1	UG2	Inf	-15.88%	21.12%	48.35%
2	MR	Inf	-8.32%	-63.58%	-22.82%
2	UG2	Inf	-0.54%	-4.88%	-0.54%

Valuation of mineral resources

Two methods of valuation have been employed. One is based solely on the *in situ* PGE (4) ounces at a suitable PGE (4) metal price and the other is based on a very rudimentary conceptual mine schedule and discounted cash flow. The results are discussed in the following commentary.

In situ valuation

The *in situ* contained PGE (4) ounces have been derived for both cases and both reefs, thus four average valuations for each methodology result. The classification of the Mineral Resources plays an important part in this valuation, i.e. the Measured and Indicated Mineral Resources are valued at a premium to the Inferred Mineral Resources. Van Der Merwe (2006) provides historical information on *in situ* platinum prices and an analysis of his presented data indicates that Inferred Mineral Resources trade at a 52% discount to Indicated and Measured Mineral Resources. A value of US$25 per ounce of PGE (4) for Measured and Indicated contained metal has been assumed and the discount factor has been applied to the valuations considered in Table IX.

Discounted cash flow valuation

A simplistic mining schedule has been erected for each case and reef where it has been assumed that mining of the 500 × 500 m evaluation blocks from highest grade to lowest can be achieved. The metal contents derived from the sorted grade methodology blocks can be directly compared to the corresponding accumulation blocks. Only the

Table VIII
Comparison of the Measured and Indicated Mineral Resource contained PGE (4) metal via the two estimation methodologies

Case	Reef	Accumulation methodology* (% Measured and Indicated)	Grade methodology* (% Measured and Indicated)	% Difference
Case 1	Merensky	62.76%	55.47%	-11.61%
Case 1	UG2	54.70%	47.18%	-13.74%
Case 2	Merensky	30.32%	42.97%	41.70%
Case 2	UG2	0%	1.45%	100%

* Average of the three classification methods employed

Table IX
***In situ* PGE (4) valuations in US$ millions**

			90% C L		Kv/Bv		Ke		Averages	
Case	Reef	Class *	Acc	g/t	Acc	g/t	Acc	g/t	Acc	g/t
1	MR	M+Id	$110	$175	$290	$274	$191	$79	$194	$176
1	MR	Inf	$100	$71	$14	$21	$59	$119	$58	$70
1	MR	All	$210	$246	$294	$295	$250	$198	$252	$246
2	MR	M+Id	$0	$0	$74	$105	$52	$61	$42	$55
2	MR	Inf	$70	$64	$32	$12	$44	$34	$49	$37
2	MR	All	$70	$64	$106	$117	$96	$95	$91	$92
1	UG2	M+Id	$117	$137	$163	$142	$130	$71	$137	$117
1	UG2	Inf	$67	$56	$43	$53	$56	$89	$55	$66
1	UG2	All	$184	$193	$206	$196	$186	$160	$192	$183
2	UG2	M+Id	$0	$0	$0	$1	$0	$0	$0	$0
2	UG2	Inf	$12	$12	$12	$12	$12	$12	$12	$12
2	UG2	All	$12	$12	$12	$12	$12	$12	$12	$12

(* M+Id refers to Measured and Indicated Mineral Resources and Inf refers to Inferred Mineral Resources)

EBITDA real terms cash flow has been modelled without consideration of capital expenditure as it was considered that this would be introducing an unnecessary subjective variable.

The parameters employed in all cases are as follows:

Extraction	85% of mineral resource tonnage
Head grade	75% of mineral resource grade
Recovery of metal into concentrate	85%
Pt metal price	$1 200
Pd metal price	$500
Rh metal price	$4 500
Au metal price	$800
Rand/dollar exchange rate	7.75
Concentrate sale value	80% of contained metal
Operating costs	R500 per ton

The net present value at a 10% discount has thus been modelled for each case and reef for the grade and accumulation methodologies, the results being contained in Table X.

The PGE (4) ounce conceptual production schedules are depicted in the graphs contained in Figure 5.

Discussion of results

The global grade estimates have a low estimation difference (less than 2%) between the two methodologies for three of the comparisons. However, in the Case 2 Merensky Reef a difference of -8.32% is noted (Table V) which indicates that the global mean can have a significant difference when the grade methodology is employed. A similar result is yielded in the overall contained PGE (4) metal and the Case 2 Merensky Reef comparison has a -8.32% difference.

On a local scale the maximum underestimation potential of grade by the grade methodology for all cases would be at approximately 23%, however, it would appear that the maximum overestimation potential is somewhat directly related to the magnitude of the average global estimation difference, irrespective of whether it is positive or negative (Table VI).

The geostatistical classification scheme employed to classify mineral resources can produce highly variable results thus the average difference associated with all three, methods is scrutinised. As Mineral Reserves are drawn from the Measured and Indicated Mineral Resources, the results of these classes are employed to ascertain the methodology differences. Table XI contains the results of the average Measured and Indicated Mineral Resources in terms of contained PGE (4) metal for the differing methodologies.

From Table XI it would appear that the grade method has a propensity to provide large differences in the Measured and Indicated Mineral Resources in terms of contained PGE (4) metal.

The valuation based on the total *in situ* Mineral Resources has generally material differences based on the

Table X
NPV results for the differing estimation methodologies and the associated differences

Case	Reef	NPV – Accumulation Methodology (RM)	NPV – Grade Methodology (RM)	% Difference
Case 1	Merensky	6 454	6 816	5.6%
Case 1	UG2	6 345	6 505	2.5%
Case 2	Merensky	3 498	2 718	-22.3%
Case 2	UG2	-86	23	126.7%

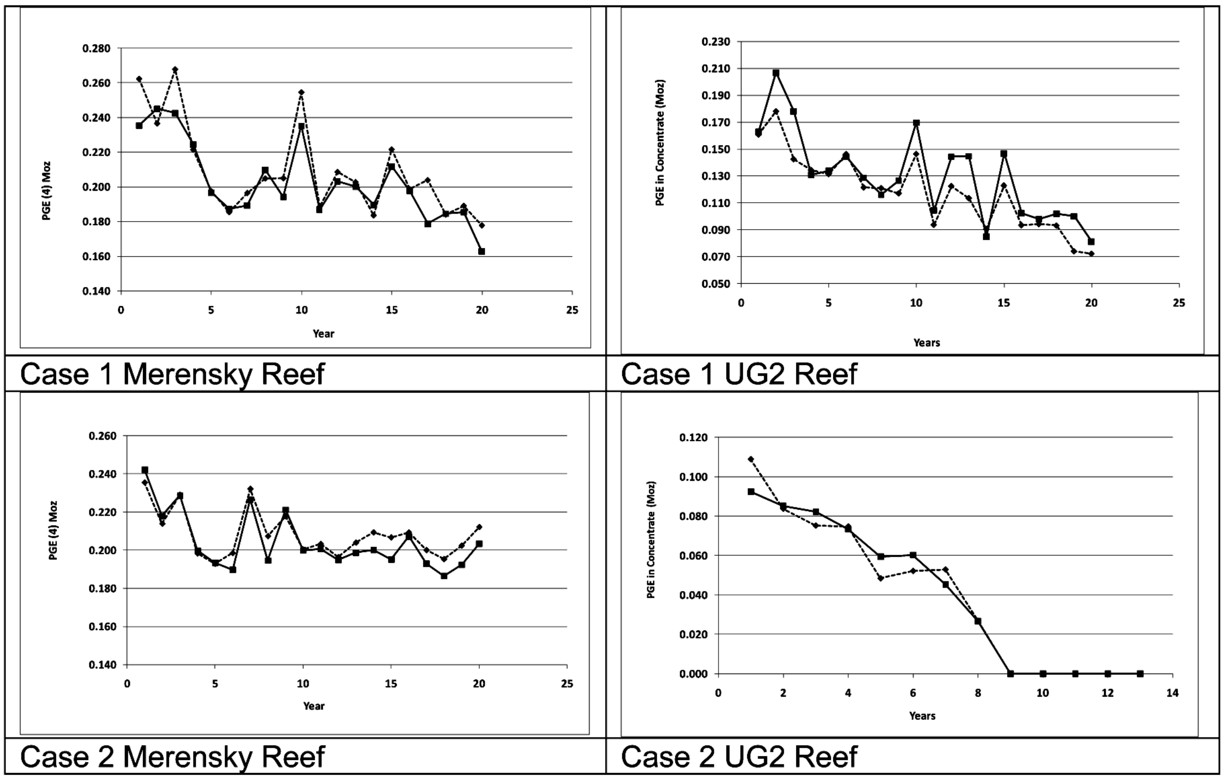

Figure 5. PGE (4) production into concentrate based on the grade methodology sorted block data and corresponding accumulation block data for each case and reef (solid lines = accumulation results, dotted lines = grade results.)

Table XI
Measured and Indicated Mineral Resources in terms of Contained Metal (PGE (4))

Case	Reef	Attribute	Accumulation methodology	Grade methodology	% Difference
1	Merensky	Contained PGE (4) Moz	7.764	7.029	-9.47%
1	UG2	Contained PGE (4) Moz	5.465	4.699	-14.03%
2	Merensky	Contained PGE (4) Moz	1.690	2.195	29.91%
2	UG2	Contained PGE (4) Moz	0	0.014	100%

Table XII
***In situ* valuations for all Measured and Indicated Mineral Resource classes**

Case	Reef	Value ($M) – Accumulation methodology	Value ($M) – Grade methodology	% Difference
Case 1	Merensky	194	176	-9.3%
Case 1	UG2	137	117	-14.6%
Case 2	Merensky	42	55	30.9%
Case 2	UG2	0	0	0%

Table XIII
Comparative estimation differences for the different comparisons and cases

Case	Global mean difference	Contained PGE (4) difference	Local mean average difference	Local mean difference range	Total measured and indicated difference	Measured and indicated *in situ* value	NPV difference
Case 1 MR	0.91%	2.42%	1.75%	34.5%	-11.61	-9.47%	-9.28%
Case 1 UG2	-0.91%	-0.35%	-1.08%	37.14%	-13.74	-14.03%	-14.6%
Case 2 MR	-8.32%	-8.32%	-5.52%	94.03%	41.70%	29.9%	30.9%
Case 2 UG2	-0.54%	-0.54%	0.52%	44.91%	100%	100%	N/A

two different estimation methodologies, i.e. between 0% and 30.9% as can be seen from Table XII.

The valuation based on a synthetic NPV estimation also provides a significant comparison as it attaches a monetary value to the estimation difference associated with the grade methodology. The Case 1 Merensky Reef comparison has an estimation difference of less than 10%, whereas the Case 1 UG2 and Case 2 Merensky Reef comparisons have material differences in the NPV (Table XIII): one overestimated and one underestimated. These trends can be seen from Figure 5 where the underestimated cases depict generally lower PGE (4) ounces for the grade methodology and vice versa for the accumulation methodology.

In terms of the differences of the global mean and total contained PGE (4) metal, three of the four comparisons yield differences of less than 2% with one comparison (Case 2 Merensky Reef) having substantial differences, but less than 10% (Table XIII).

The local mean difference range is purely the maximum to minimum local mean % difference to provide a measure of the comparative spread of the % difference. It would appear from Table XIII that the classification in terms of the total Measured and Indicated contained PGE (4) metal, Measured and Indicated *in situ* value and NPV yield the highest and consistent % differences when employing the grade methodology.

The Case 1 UG2 Reef data that has a relatively constant grade independent of width (Figure 1) would intuitively be considered to have the lowest differences in all comparisons. This is not the case as can be seen from Table XIII (compare Case 1 Merensky Reef to the Case 1 UG2 Reef).

Conclusions

Data sets with varying grade to width relationships have been employed to estimate block grades by ordinary normal kriging. The variables employed in this estimation are a mixture of g/m^2, mg/t, t/m^2, m and g/t, thus a comparison between the accumulation and grade methodologies can be made. The conclusions of this study are as follows:

1. The global means of grade, contained PGE (4) metal, and average local mean differences apart from one case, have estimation differences that are insignificant. The anomalous case is bordering on materiality which does indicate the grade methodology is not unequivocally acceptable for Mineral Resource estimation.
2. Specific local means can have significant differences of estimation of between -34% and 60%. This range would not be identified by comparison of the global mean estimate and average of the local mean differences.
3. The most conservative geostatistical classification methodology is the 90% confidence limits whereas the most liberal is the kriging variance to block variance ratio.
4. The most significant difference in employing the grade methodology would appear to be in the classification of the Mineral Resources. In seven of the eight comparisons relating to the Measured and Indicated Mineral Resources, the differences are greater than 10% and in four cases they are essentially greater than 30%.
5. Valuation based on the *in situ* approach has material differences between the grade and accumulation methodologies and the valuation based on the discounted cash flow approach, has significant to material differences.

6. Mineral Resource statements, classification of Mineral Resources, Mineral Reserves, metal production schedules and valuations that have been estimated via the grade methodology are recommended to be re-estimated by an appropriate accumulation methodology.
7. Due to the material differences that have been identified with the grade methodology, it brings into question whether such estimated Mineral Resources are compliant with the SAMREC Code (2007).

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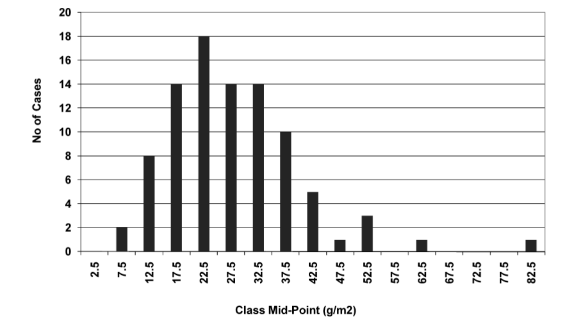
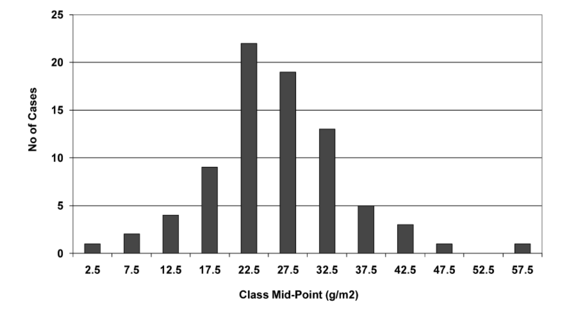
1979-1998	JCI group of Companies: mining geology, mineral resource estimation and valuation of Witwatersrand and Archean age gold and platinum projects.
1998 to Present	Director of The Mineral Corporation; evaluation and valuation of projects worldwide for gold, platinum, base metals, industrial minerals and diamonds.

Appendix 1



Case 1 Merensky Reef g/m^2



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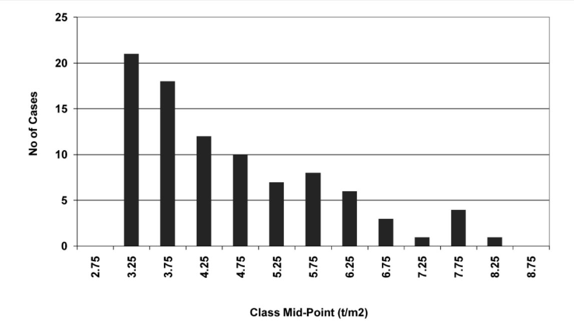

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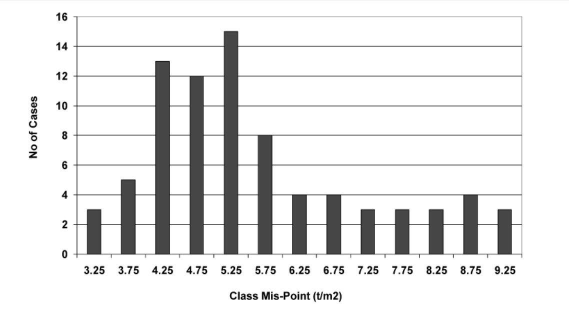

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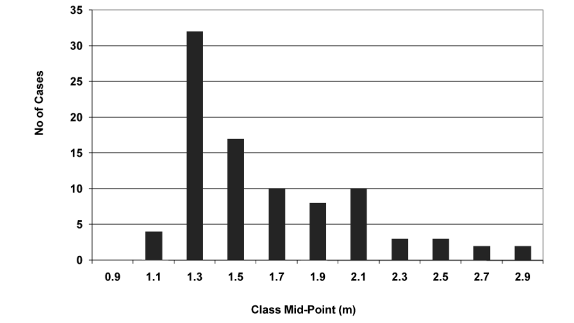

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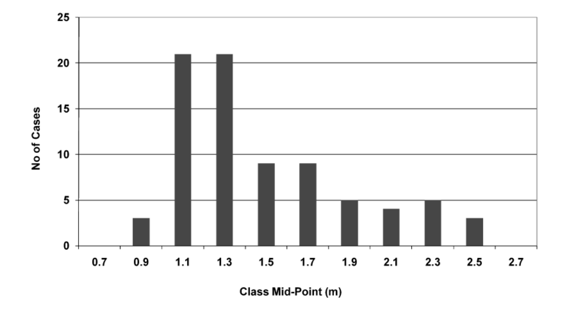

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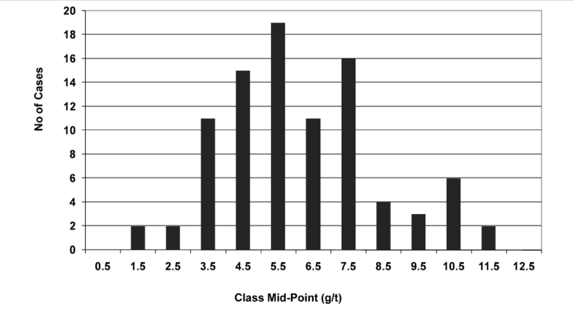

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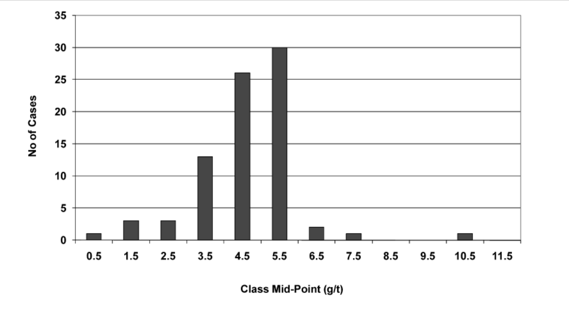

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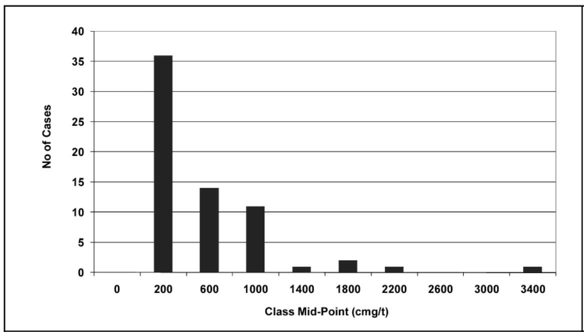

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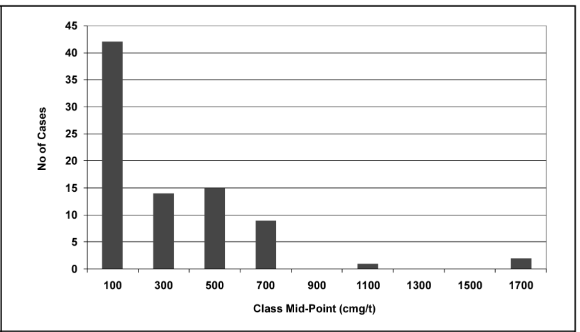

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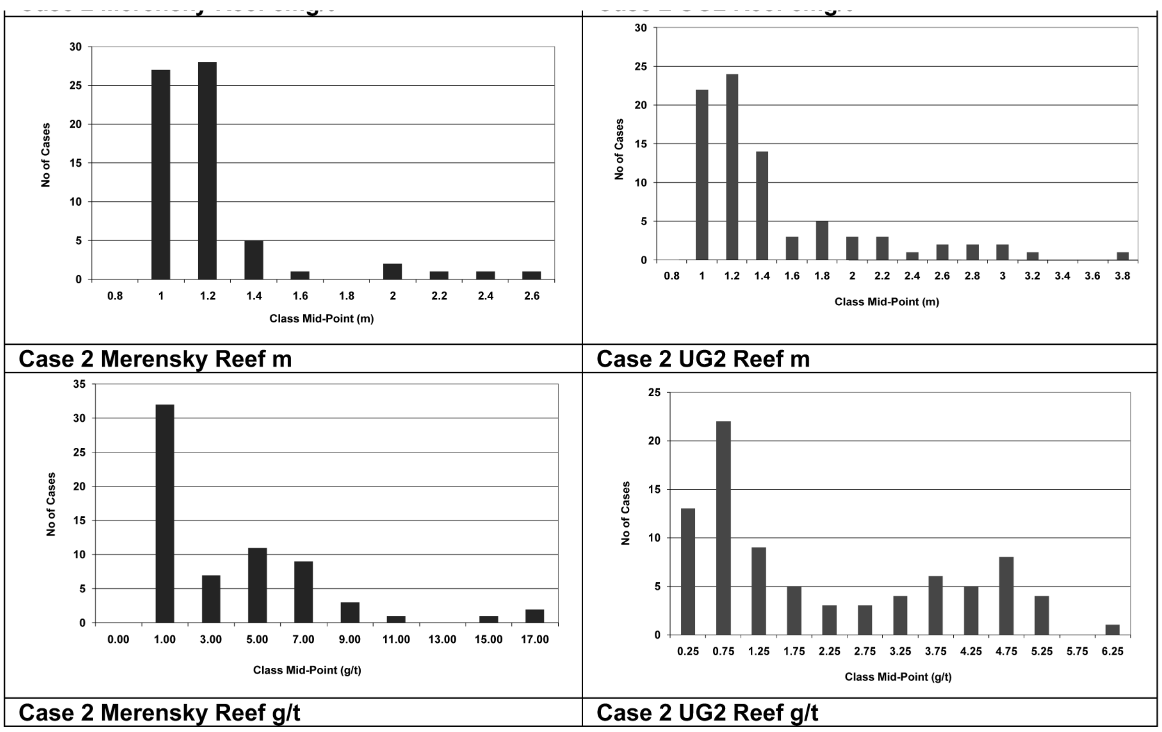


Figure 6. Distributions of the variables for each case and reef type

Appendix 2

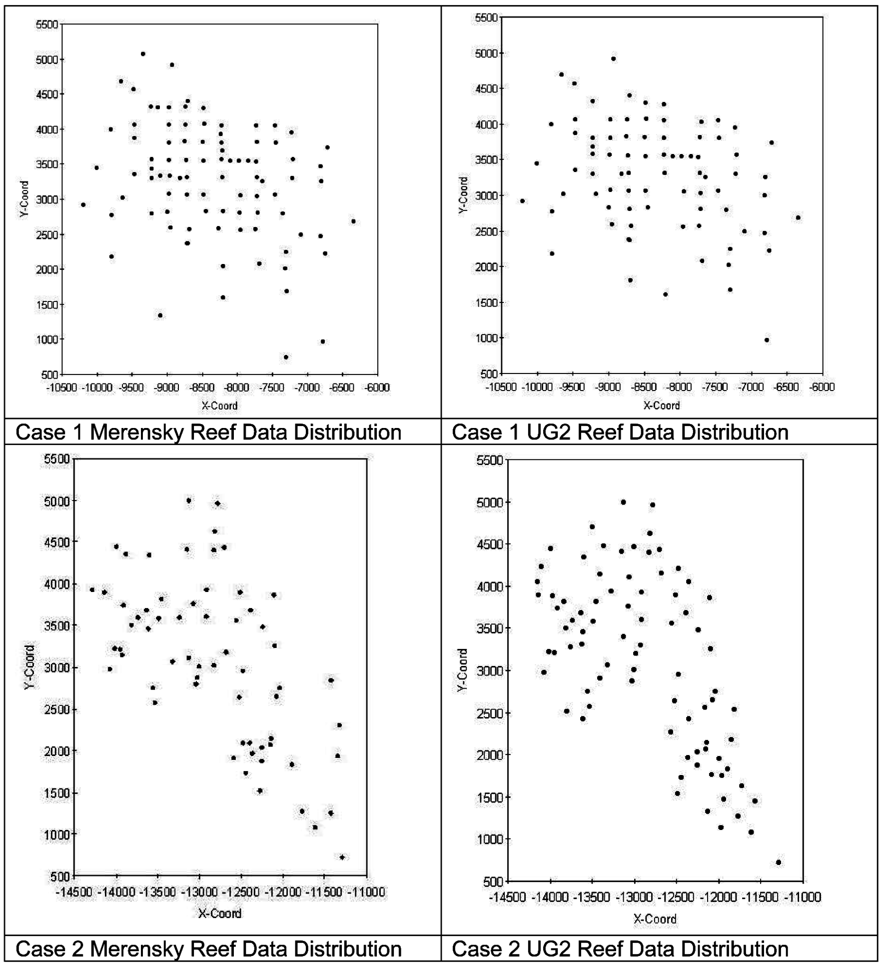
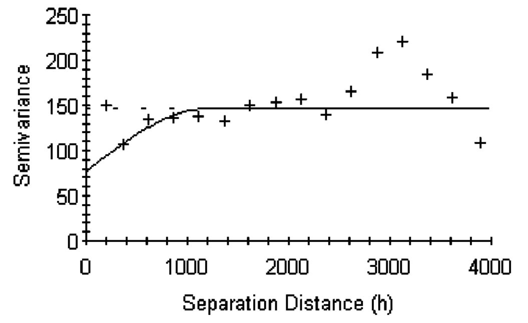


Figure 7. Area distribution of the data for each case and reef type

Appendix 3



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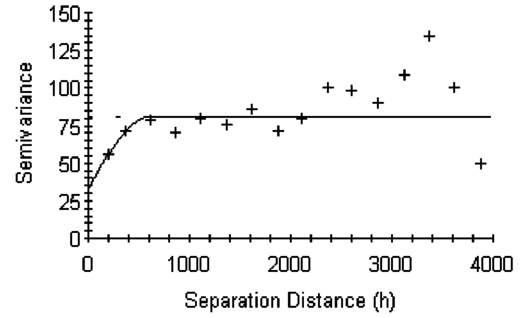

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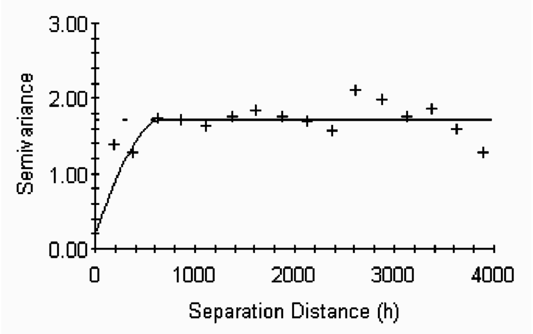

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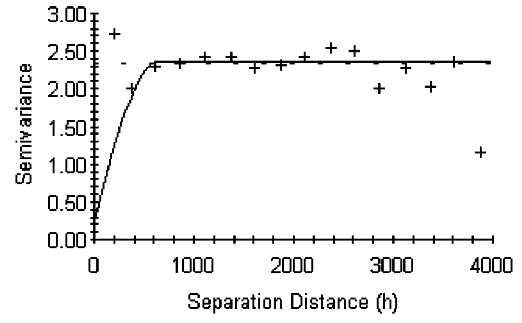

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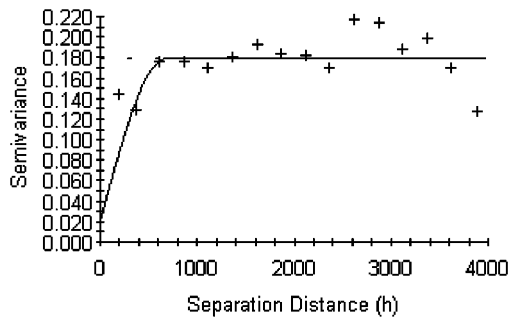

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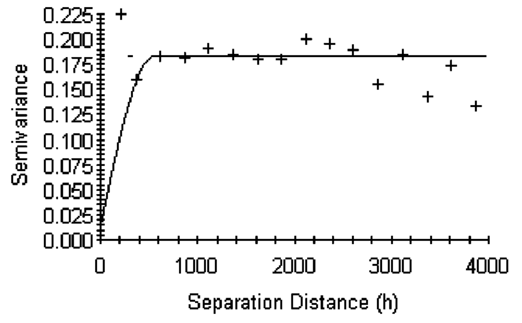

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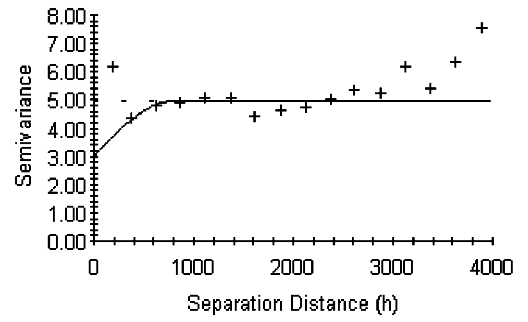

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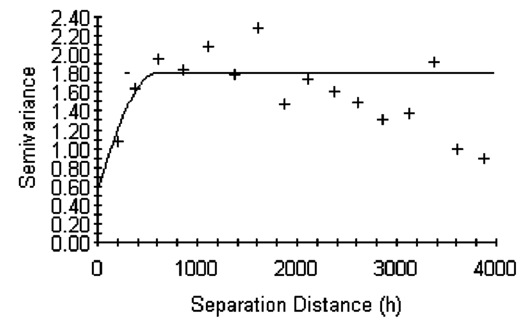

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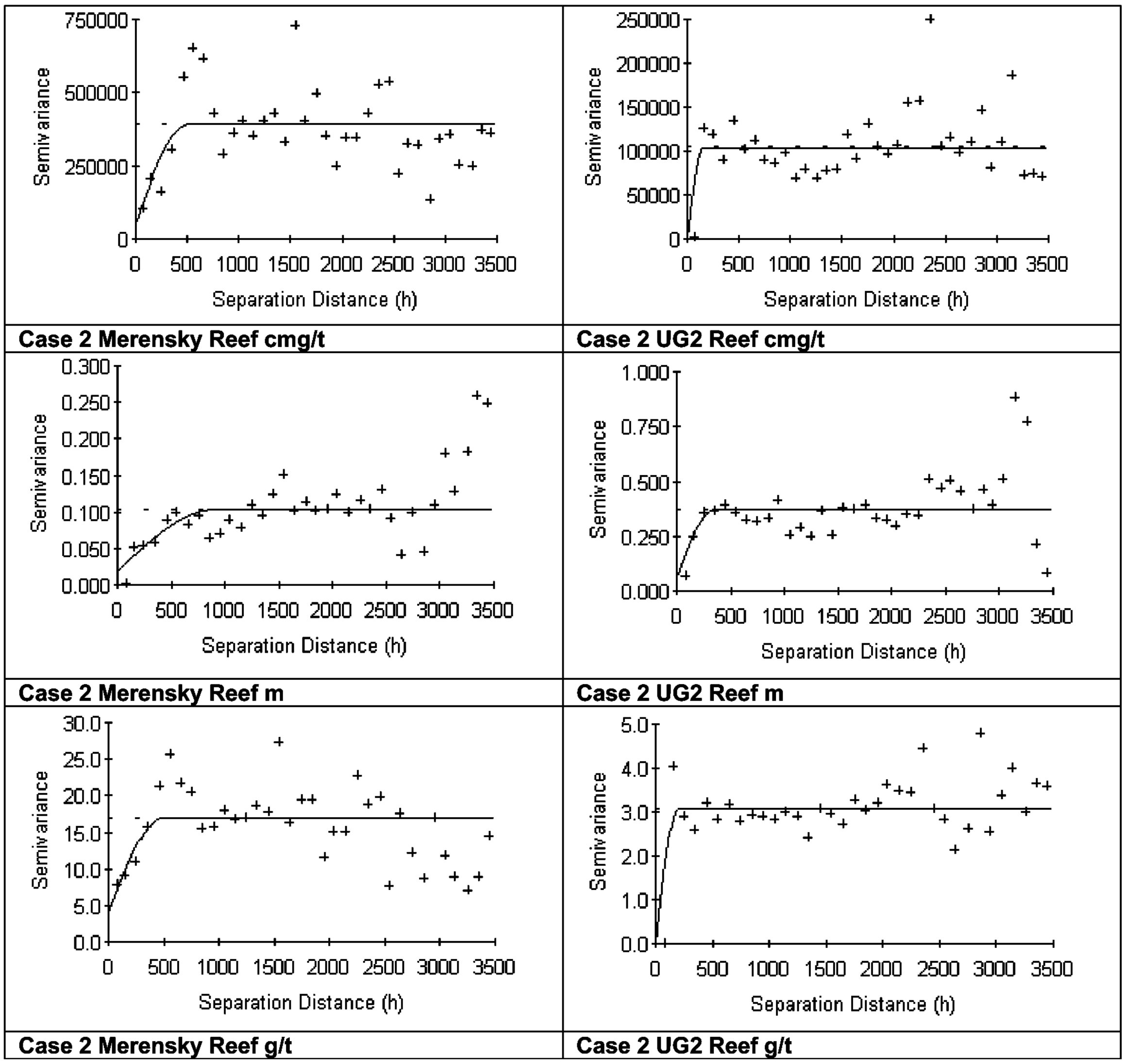

Figure 8. Variogram results of the four cases and all variables considered