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Geostatistical modelling for realistic mine planning

Introduction

This paper is a brief discussion of problems which arose during the evaluation of a Zinc project in Southern Africa. Detailed geological interpretations were provided along with a substantial drillhole data base of assayed core values. The deposit had been sectioned by the resident geologist into (a) major fault block zones and (b) host rock characteristics.

Problems arose when a routine statistical analysis of borehole samples within the same fault zone and hosted in the same rock type were found to exhibit evidence of multiple populations. Narrowing down the study area failed to remove this behaviour.

Statistical Analysis

Extensive statistical analysis was carried out to pin down the complexities evident in the sample data. The data files were broken down by rock type and by fault block. Histograms were produced for all areas and all rock types. Where too few samples were available in a single rock type, a histogram was simply drawn for all fault blocks combined. Since the fault seem to produce only movement between the and do not (apparently) affect the mineralisation, this is a valid statistical (but not geostatistical) approach.

Representative histograms for all of the rock types and all faults were studied and the results are summarised here. It was apparent from all of the histograms that there were complexities in the mineralisation which had not been coded into the geological data. Histograms and probability plots suggest the presence of at least three major mineralisation phases – possibly three hydrothermal events.

In an attempt to make sense of the distribution of sample values, smaller and smaller blocks of ground were inspected within the major fault blocks. The histograms for all areas revealed two or three components in varying proportions. Blocks of ground were selected for detailed analysis to identify:

- how many components were actually present and
- the characteristics of those component distributions

Logarithmic (natural) values were used throughout the analyses. Only arkose samples were used, to avoid any further geological complexities.

All arkose samples in the central fault block were selected. The area was then divided into east/west strips 200m wide in the north/south direction. Histograms were constructed for each 200m strip. Multi-component lognormal models were fitted to the histograms.

It is clear from these histograms that there are at least three component. However, it is unclear whether the variations from strip to strip are due to geological changes or simply the differing coverage of the samples. For example, drilling is shallower at the north and south of the block and deepest in the middle.

Of the seven strips analysed, the centre strip was selected for further detailed analysis. This volume contains the deepest drilling and most complete coverage of.

To obtain enough samples to produce histograms, overlapping layers were taken at 40m intervals within this volume. Towards the surface more samples are available, so that the top 40m was split into separate 20m layers. Histograms were produced for each sub-volume and multi-component models fitted to these graphs.

This analysis showed the presence of two to four components in all layers. Manipulation of the components reveals the following pattern:

- A low grade, extremely variable, component exists at all levels. The percentage contribution of this component ranges from over 18% at depth up to 64% in the centre of the volume. The percentage then falls off to 9% in the upper 20m closest to surface.
- A medium grade, fairly consistent, component exists at all levels up to the top 20m. Above 520m the grade begins to drop sharply to non-economic at surface. The percentage of samples in this component is very high in the sub-volumes to 520m and drops sharply to below 20% above this level. It is quite possible that the component exists in the top 20m at such a low percentage that it has not been identified by the statistical analysis.
- A high grade component is seen when considering samples above 520m. Average grades at this depth are around very high at depth, dropping swiftly to moderately low in the top 20m of the deposit. The percentage of samples contributing to this component rises from 10% at depth to almost 80% close to the surface.
- A fourth component is only seen in the top 20m of this volume. This may be (for example) some sort of supergene enrichment in the oxide zone. With an extremely high average value, this component accounts for almost 30% of the samples.

The four components overlap one another to a great extent. It is difficult to pick "discriminator" values which would give reliable separation between the components from the histogram graphs. It is also not possible to use standard geostatistical methods in a deposit in which the character of the distributions varies so widely between volumes so close together.

Geostatistical Analysis

The statistical analysis reveals the presence of three --- or possibly four --- phases of mineralisation within the main body of the deposit. It is not possible to separate these component 'populations' statistically. However, there is a recognisable break point between the bulk of the 'background' low grade component and the rest of the values, which allows Ordinary Kriging to be used as a stable estimation technique. The estimation method proposed, therefore, was a three part approach:

1. An indicator kriging is used to evaluate the proportion of the block likely to be above or below the breakpoint value;
2. ordinary kriging is used to predict the likely value for the "low grade" mineral;
3. ordinary kriging is used to predict the likely value for the "high grade" mineral.

These three values are combined to produce an estimated grade for each block. There is no mathematically valid way to evaluate the "kriging standard error" for the final estimate. It is generally recommended that the standard error for the most variable of the three components be used as a conservative measure of reliability for the estimated value. This is most often the "high grade" component on value.

Three separate geostatistical analyses were carried out. The first exercise was to find indicator "break-points" which would separate the heterogeneous histograms into quasi-Normal components so that ordinary kriging could be used for block estimation.

After detailed investigation, it was deduced that the best "break-point" value was 2%Zn. around half of the "low grade" population lies above this value. However, the semi-variograms produced for this break-point show that there is a natural geological cutoff at around 2%Zn. This is borne out by the geological interpretation. The values above this cutoff consist of samples from three (possibly four) different components. Whilst the means of these components differ, the standard deviations tend to lie around 0.4 (in natural logarithms) for all of the components. It is the variable low grade component which complicates the geostatistical analysis, with its very high logarithmic variance. The data was then broken into two parts at 2%Zn. Semi-variograms were constructed on the two data sets, using natural logarithms. Models were fitted to all three sets of semi-variograms.

Semi-variograms were calculated and modelled for each of the component exercises.

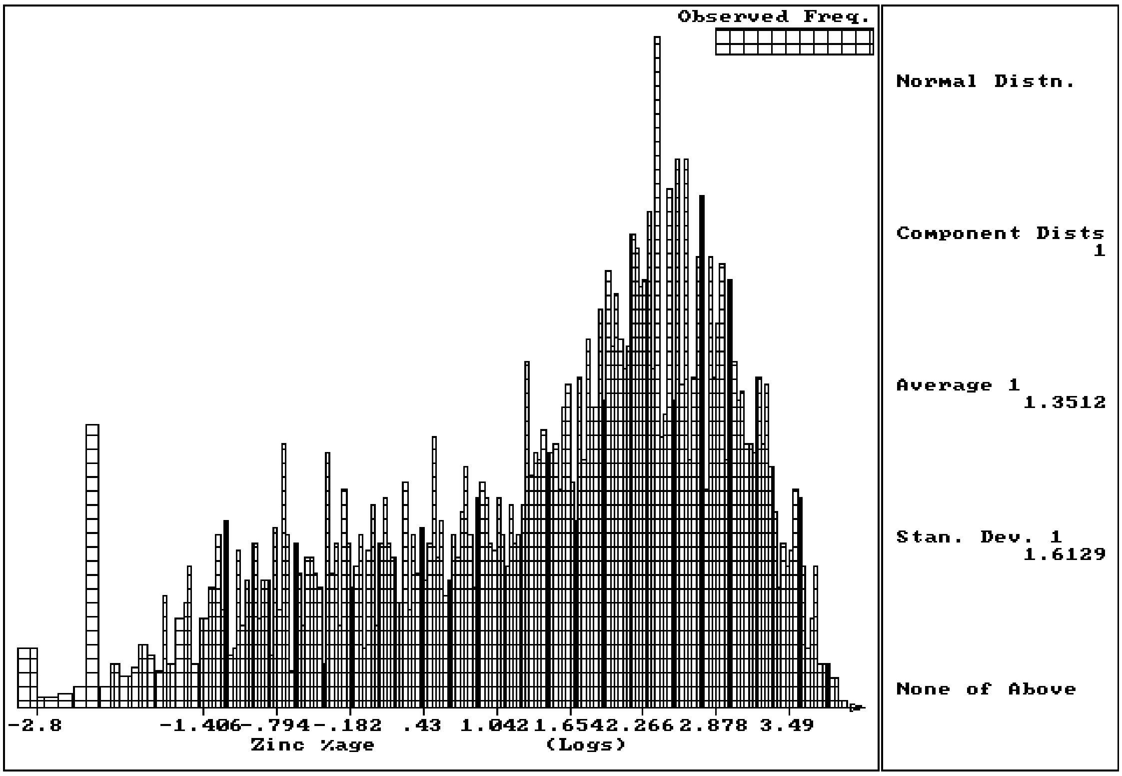
Cross validation was carried out for all models and found to be satisfactory. A cross validation exercise was also carried out for the combined estimate versus the original value of each sample. This was also found to be satisfactory. Trial runs were carried out using all samples as opposed to restricted by rock type. These were not found to be satisfactory. This is a firm indicator that the mineralisations are strongly controlled by the host rock type.

Summary of study

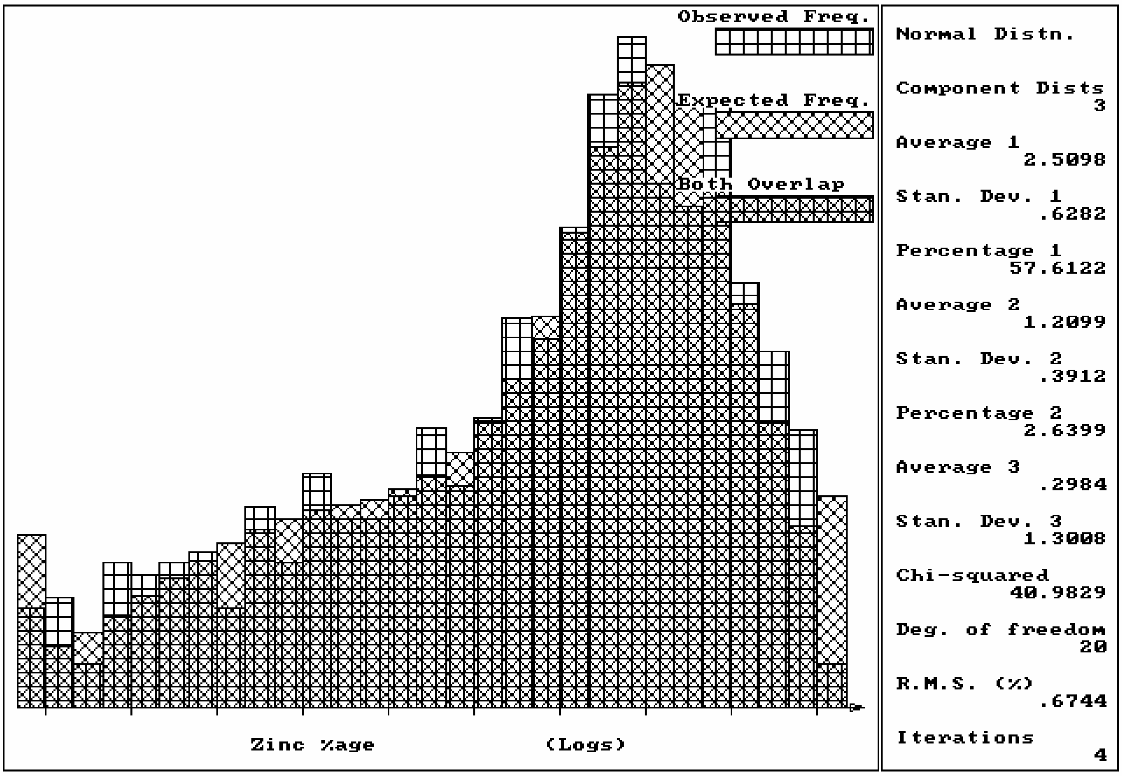
Statistical and geostatistical analysis of the borehole data reveals the presence of three phases of mineralisation throughout the economically mineable area of the project studied. There is, apparently, geological evidence for multiple events although current discussions are divided between two totally different genetic models. The picture is further complicated by oxidation and apparent enrichment in the 20 metres immediately below surface.

Estimation could be improved dramatically if efforts were made to identify the component geological populations. Grade control during production will be far more effective if the geological complexities are identified and incorporated into the estimation process.

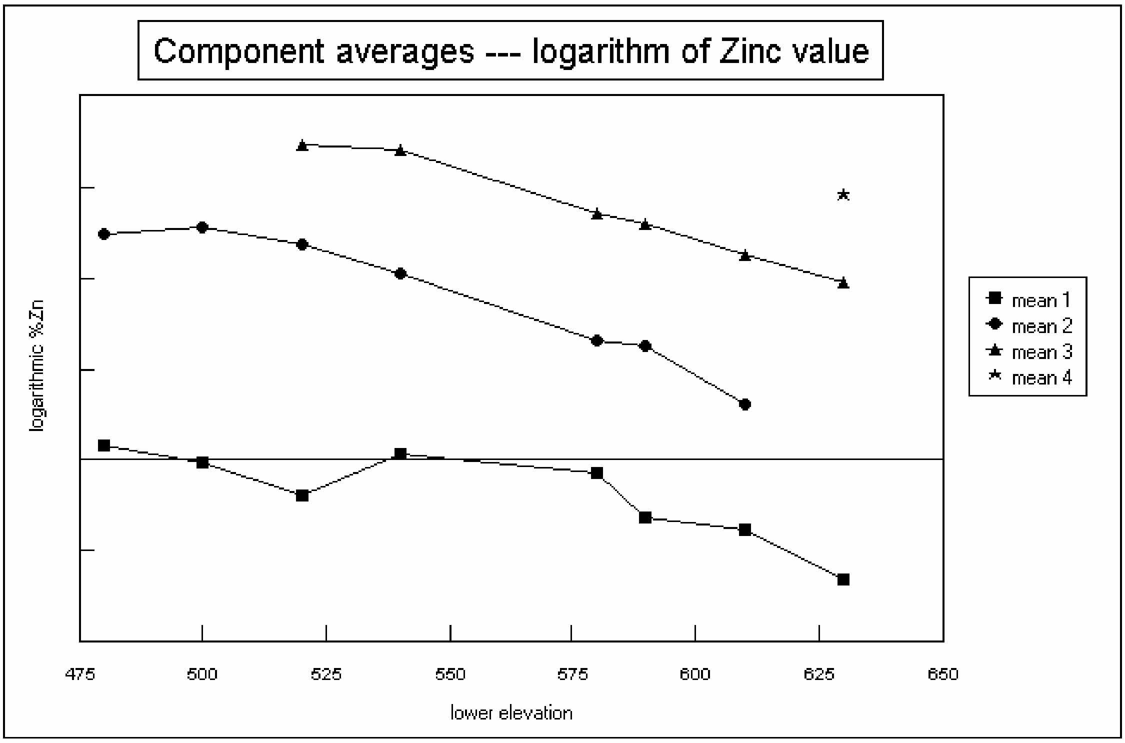
Figures

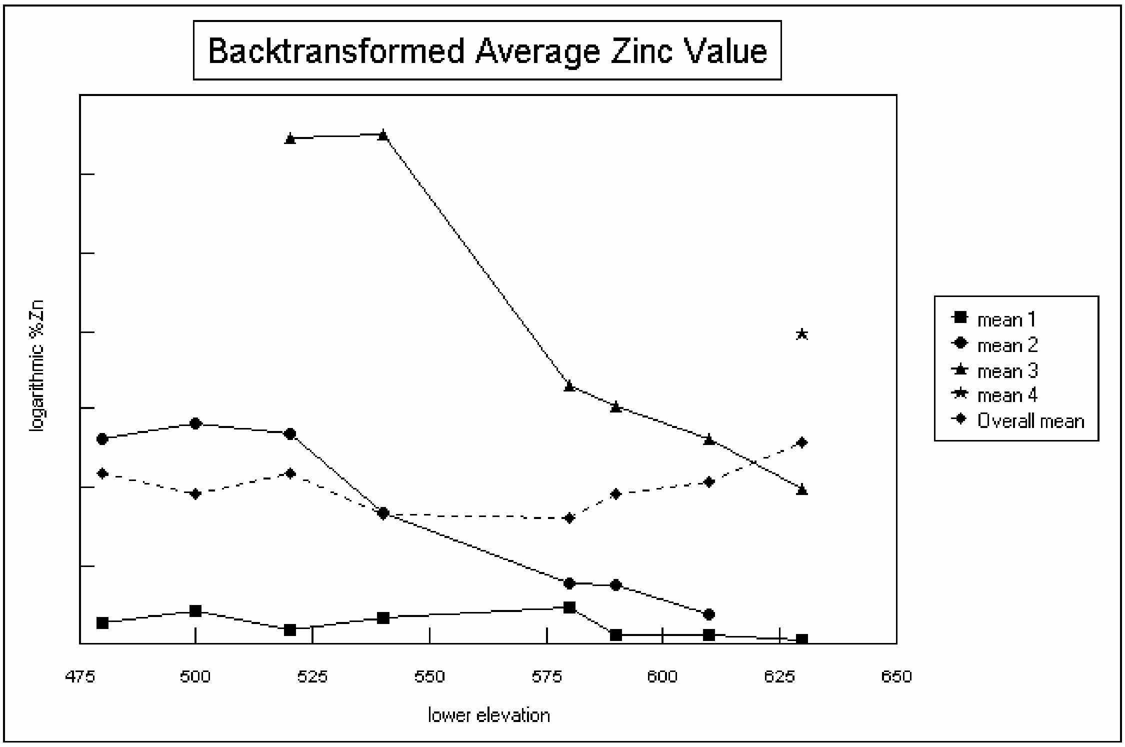


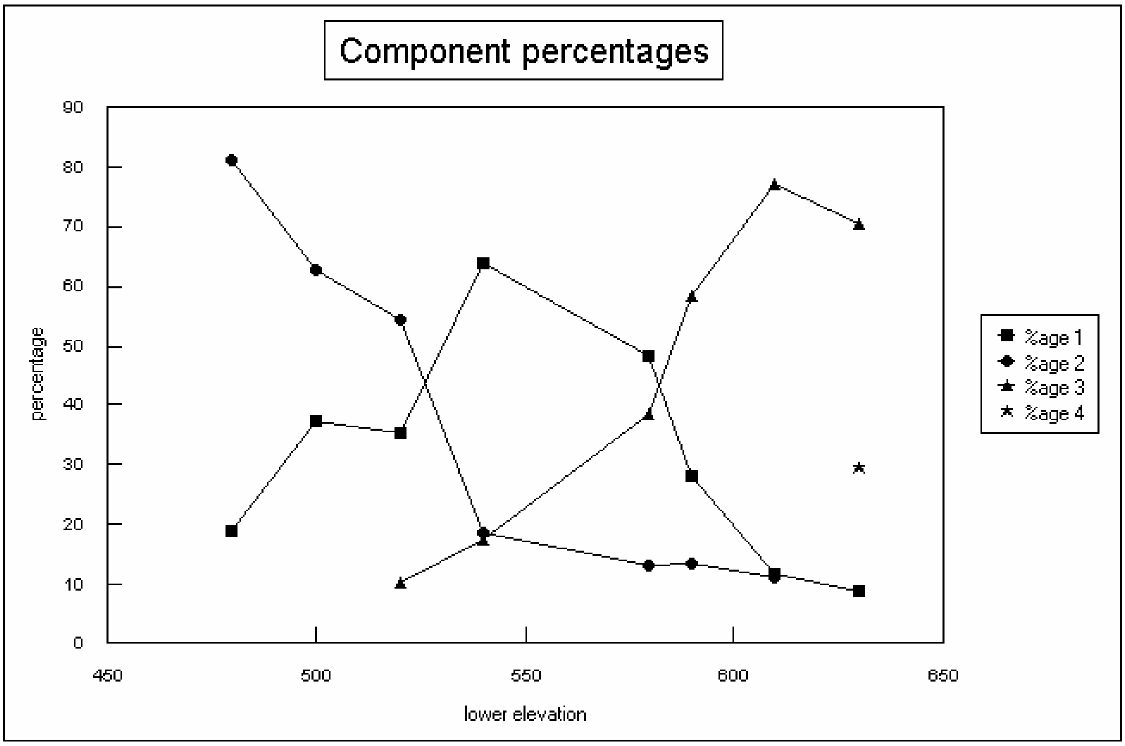
Histogram of all arkose samples

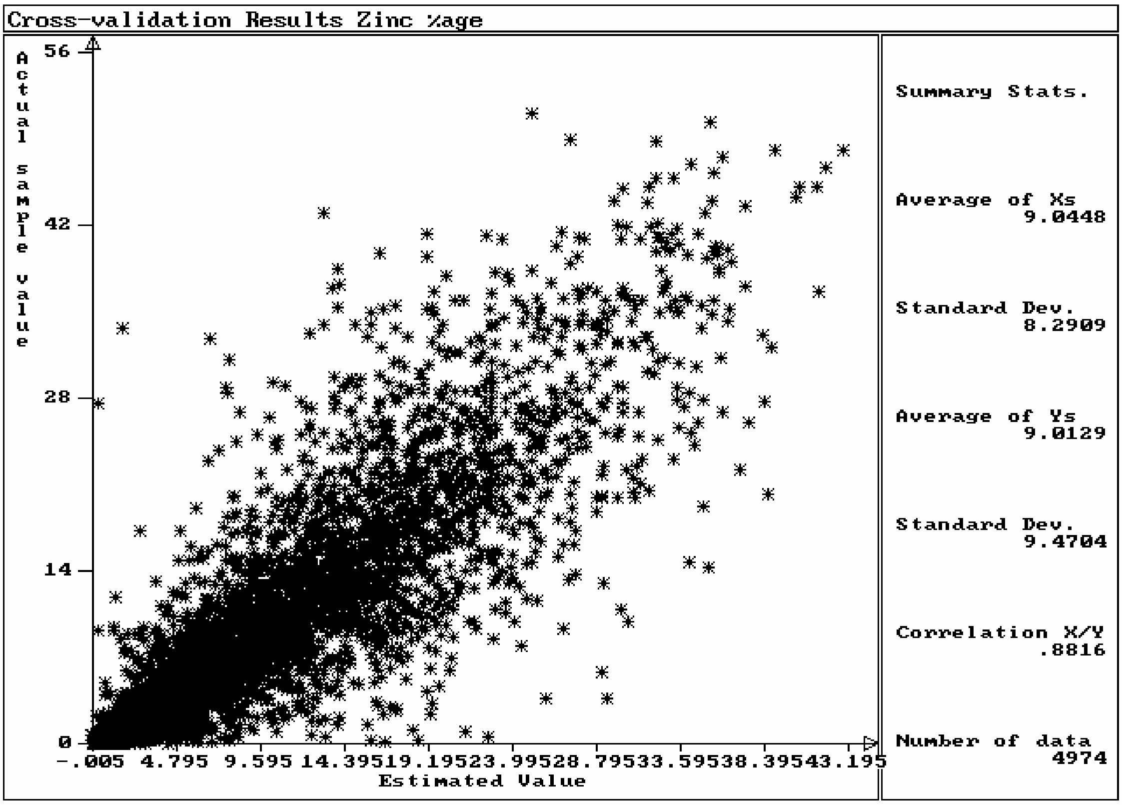


Example of multicomponent distribution fitting (central strip, all depths)


Component averages --- logarithm of Zinc value
logarithmic %Zn
475
500
525
550
575
600
625
650
lower elevation
mean 1
mean 2
mean 3
mean 4


Backtransformed Average Zinc Value
logarithmic %Zn
475
500
525
550
575
600
625
650
lower elevation
mean 1
mean 2
mean 3
mean 4
Overall mean





graph produced from cross validation exercise on all arkose samples