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Practical Reserve Estimation in a Shear-Hosted Gold Deposit, Zimbabwe

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INTRODUCTION

Evaluation of reserves on a production scale within a shear-hosted gold deposit is complicated by the nature of the mineralisation itself. The 'payable' ground seems to be confined to areas with intense shearing, while the remainder of the deposit is characterised by 'background' mineralisation at a very low level.

The evaluation problems, therefore, would seem to split into two stages:

- identification of the probable location of sheared zones; and
- evaluation of grades within these zones.

However, investigation of the distribution of gold grades within a proposed mine area in Zimbabwe revealed the presence of three, not two, distinct populations, each of a lognormal nature. That is, between the 'high grade' sheared zones and the 'background' gangue there was a third (possibly disseminated) zone which contained both pay and unpay values.

Lognormal distribution analyses were used to identify the three population components. 'Discriminator values' were determined which characterise the two overlap zones; background/disseminated and disseminated shear zone. These discriminator values were used as indicator 'cut-offs' to produce geostatistical analyses showing the continuity of the three geological zones within the deposit

Within each zone, lognormal distribution models were produced and lognormal semi-variograms constructed to represent continuity of grade values over each zone.

The final evaluation model consisted of four stages:

- indicator analysis at the background/mineralised threshold value, yielding the probability of mineralisation;
- indicator analysis between the disseminated and sheared mineralisations (eliminating background), yielding the probability of shearing given that the zone is mineralised;
- lognormal analysis of disseminated values only; and
- lognormal analysis of sheared values only.

These four quantities were combined together with a background value to produce an estimated value for a particular zone within the planned mining area. This somewhat complex approach has been compared with actual blast hole sampling within the open pit.

THE MINERALISATION

The deposit discussed in this paper is a shear-hosted gold deposit situated in Zimbabwe, Southern Africa. Because of confidentiality it is not possible to locate the mine more precisely or to reveal actual grade ranges and/or tonnages. Although the geological setting can only be discussed in generalities, it is felt that the valuation problems described here are of sufficient interest to be presented *in vacuo*.

At the beginning of this study it was supposed that the major gold mineralisation within the deposit existed only within zones of intense shearing. That is, there were localised shear zones within the area which appeared to be mineralised to a payable level. These zones were surrounded (in three dimensions) by a virtually barren unsheared 'country' rock. The deposit is mined by open pit methods, so that country rock must be mined as waste in order to access the mineralised shear zones.

Valuation for mine planning purposes, therefore, consisted of:

- identifying local shear zones from bore hole plans and sections, and constructing a three-dimensional envelope around the projected mineralised zone; and
- estimating the gold grades for mineable blocks within (or intersecting with) the shear zone, from the available local bore hole information.

process leads to two potential sources of error or bias in the estimated block grades. The three dimensional envelope for the shear zone is constructed from geological sections and plans, using proprietary software on a Unix-style workstation. The known dip on the local stratigraphy is incorporated in the judgement necessary for matching intersections on neighbouring drill holes. However, as will be seen, the mineralisation is not confined to the shear zones, neither is the division between sheared and unsheared ground as clear-cut as this approach would suggest. Constructing a 'hard' barrier between sheared and unsheared ground does not allow for local fluctuations in the so-called contact or for the disseminated gold which exists around the edges of the sheared zones.

A less obvious problem identified in the early stages of this study, was that bore hole cores with grades below a certain threshhold had either not been assayed or had simply been omitted from the database used in die block estimation process. The software used for evaluation has, therefore, only access to bore hole cores with measured values of gold grade. The effect of this is that there is no 'fade off' of gold grades between shear and unsheared zones in the estimated values. The significant gold grades are carried right up to the hard-and-fast boundary imposed by the outlining of the three dimensional shear zones as interpreted from the sections.

These two problems compound one another, leading to a model of the deposit which consists of solid three-dimensional volumes filled with payable, and relatively high grades alternating with absolutely barren country rock.

SAMPLE INFORMATION AVAILABLE

The information available for this study consisted of two types of sampling. Diamond drilling has been carried out over the planned mine area and core sections were assayed at regular intervals in each hole. Mine planning has been based on estimating values in rectangular blocks over the mine area. Since mining commenced, blast hole sampling has been carried out on a regular basis. Blast holes are identified according to irregularly shaped blast areas within a particular bench. Reconciliation of reserves consists of comparing the arithmetic and geometric means of the blast hole samples with a suitably weighted average of the rectangular blocks in that area.

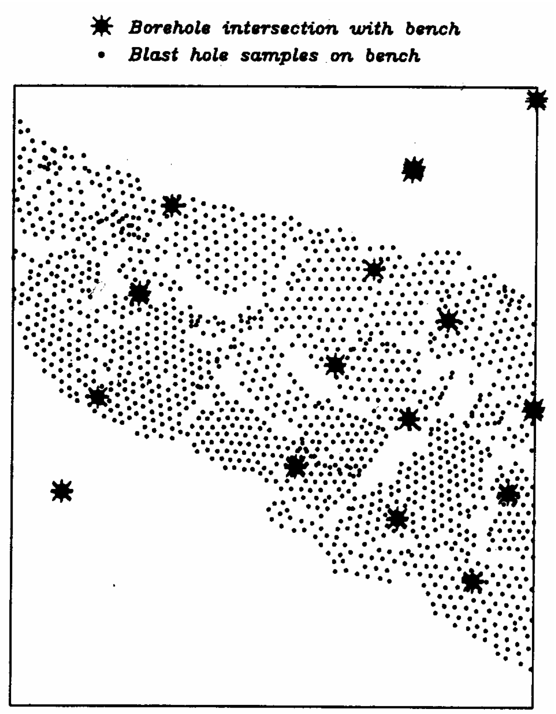

Fig 1 - Bench plan - subset area for study.

Figure 1 shows a small region of one bench, detailing the intersection of the (inclined) diamond drill bore holes and the corresponding blast hole samples which have been analysed during production. Individual blast areas can be identified by the concentration of blast holes in each sub-area.

The results discussed in this paper were based on around 2000 blast hole samples and roughly 2500 bore hole core sections. This latter number includes the 'fictitious' cores added to the database to delineate the virtually unmineralised country rock.

STATISTICAL ANALYSIS OF BORE HOLE DATA

Before it was possible to carry out any meaningful statistical analysis of the bore hole information, it was necessary to assign values to those cores which had been omitted from the database. That is, those comparatively barren sections of core between shear zones had to be filled in with an arbitrary background value so that the software was aware of the barren material between the payable grades. This virtually doubled the number of samples which had to be handled. However, it did allow for the identification of a 'transitional zone' between the comparatively high grade shear zones and the completely barren country rock.

Figure 2 shows a probability plot for the borehole core section data after the background values had been inserted into the database. The break between unmineralised country rock and mineralised ground is clearly demarcated at an easily identifiable value. It is interesting to note, however, that the best break point between the two is slightly above the arbitrary background value assigned to the 'missing' cores. That is, there are some measured low grades in the country rock which have been included in the main database.

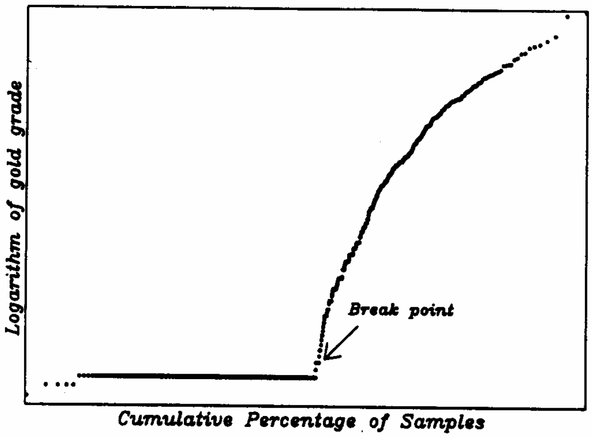

Fig 2 - Probability plot for all bore hole sections.

Figure 3 shows a probability plot on the same scale as Figure 1 but only plotting the samples above the break point shown in Figure 1. That is, the values identified as being in country rock have been removed leaving only those samples which have been supposed to be in shear zones. The interesting feature of this graph is the consistent curvature on the graph and a readily identifiable break point in the graph. This sort of graph suggests that there are two phases of mineralisation within the deposit There appears to be a high grade lognormal type mineralisation which corresponds closely with the highly sheared zones within the mine. However, there is an intermediate medium grade mineralisation which forms a transitional zone between the shear zones and the unsheared country rock. This suggests that there is a dissemination of gold outward from the shear zones into the supposedly barren unsheared zones.

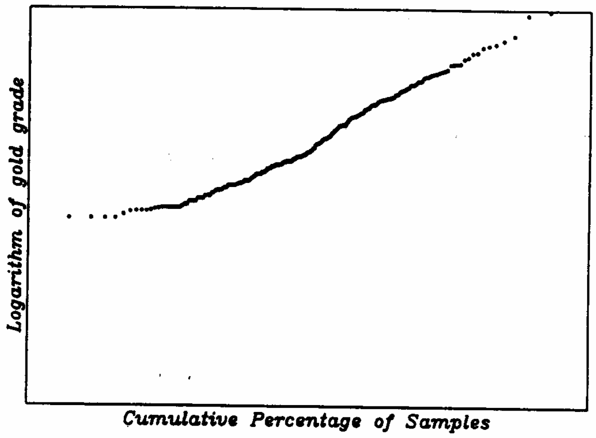

Fig 3 - Probability plot for all 'mineralised' sections

Figure 4 shows the samples whose values lie above this second break point, that is, the higher grade mineralisation which is confined to the shear zones. This plot is now almost ideally lognormal apart from a little drift at the lower end of the graph, where the high grade population overlaps with the medium grade disseminated mineralisation.

The identification of three components to the mineralisation radically alters the approach which must be used to obtain realistic grade estimates. A 'hard' boundary between unmineralised and mineralised ground is no longer appropriate if a disseminated zone exists around each shear zone. Estimation of the value of a specific block of ground must first determine how much of the block is unmineralised/medium grade disseminated/high grade sheared. Separate analyses can then be used to assign gold grades to each of these categories and a composite estimate made of the most likely gold grade within a block.

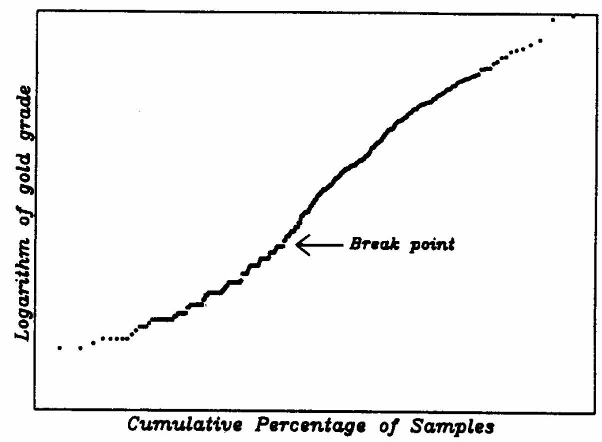

Fig. 4 - Probability plot for 'high grade' sections

INDICATOR GEOSTATISTICS

The determination of how much of a specified block is unmineralised/medium grade disseminated/high grade sheared is carried out in two stages:

1. using the break point shown in Figure 2, an indicator transform is applied to distinguish between unmineralised/mineralised ground; and
2. using the break point shown in Figure 3, and having eliminated all unmineralised samples, an indicator transform is applied to distinguish between medium and high grade mineralisations.

Indicator geostatistical analysis follows the same-two stages as more routine geostatistical analyses. That is, a semi-variogram is constructed from the sample data and modelled. Block values are then estimated by kriging using the sample data and the spatial semi-variogram model. In this case, however, the values used to construct the semi-variogram and to estimate block values are 'indicator' transforms. In brief, a cut-off or 'discriminator' value is selected. AU samples with values below this cut-off are given a value of zero. Samples with values above the cut-off are given a value of one. The semi-variogram model thus becomes a model of the continuity of 'likelihood of being above cut-off'. The values estimated into a mining block may be interpreted as the proportion of that block which is likely to contain material above the cut-off.

The two indicator stages proposed previously will yield two values for each block: the proportion which is likely to be mineralised at all and the proportion which is likely to be in the high grade mineralisation. With a minimum of manipulation this can be converted into the three proportions of unmineralised/medium grade disseminated/high grade sheared zones within the particular block.

LOGNORMAL GEOSTATISTICS

Having determined what proportion of the block is likely to be in (say) the high grade zone, it remains only to estimate the value of the high grade material within the block. This is

done by considering only the high grade mineralisation within the local area. An estimate of the average of the high grade mineralisation within the block is found from a standard lognormal kriging approach using high grade samples only. This grade is then applied to that proportion of the block which is supposedly high grade mineralisation.
A similar lognormal approach is used to determine the grade of the medium grade proportion of the block, using medium grade bore hole core sections only.

FOUR-STAGE KRIGING FROM BORE HOLE DATA

The final estimate for the value at a specified location or over a specified block consists of a four-stage kriging approach:

- indicator analysis at the unmineralised/mineralised threshhold value, yielding the probability of mineralisation;
- indicator analysis between the medium and high grade mineralisations (eliminating background), yielding the probability of 'high grade' given that the zone is mineralised;
- lognormal analysis of medium grade values only; and
- lognormal analysis of high grade values only.

Assigning a background grade to the 'unmineralised' proportion and combining the three grades in the relative proportions yields the final estimated grade for a block or a specified location.

This may seem a rather complex approach to the estimation of block values. However, it is a method which combines the geology as identified in the mine area with the values which have been assigned to each bore hole core section.

COMPARING PREDICTIONS WITH BLAST HOLE DATA

Two levels of comparison between this estimation method and actual blast hole data were undertaken. Values were estimated using only the bore hole core section data at:

1. the location of each blast hole sample; and
2. over each entire blast area.

Figure 5 shows the comparison of the estimated values as produced by the four-stage kriging approach and the actual blast hole samples at each location. It can easily be seen that trying to predict the value of an individual blast hole sample using only the relatively sparse bore hole data is an unrewarding task. The fact that there is some correlation between estimated grades and actual grades, however, has to be seen as an encouraging factor.

Figure 6 shows the comparison of the estimated averages over blast areas with the average of the blast holes within each area. These results were obtained from one bench covering the whole of the mine area at the pertinent date. It can be seen that, apart from one (aberrant) area, the correlation between the kriged estimates and the actual values mined from those areas is extremely high. Even with the extreme value, the correlation between the two sets of figures is almost 0.8. It would seem therefore, that the four-stage kriging approach is predicting the average value over a projected blast area with a high degree of accuracy. This is particularly so in the higher grade areas.

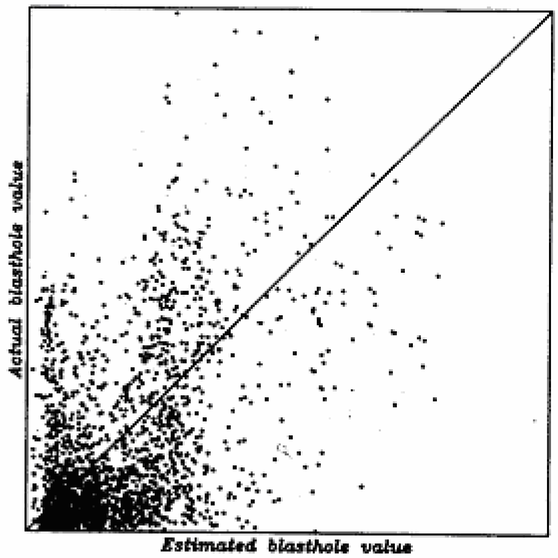

Fig 5 - Comparison of actual and kriged blast hole values.

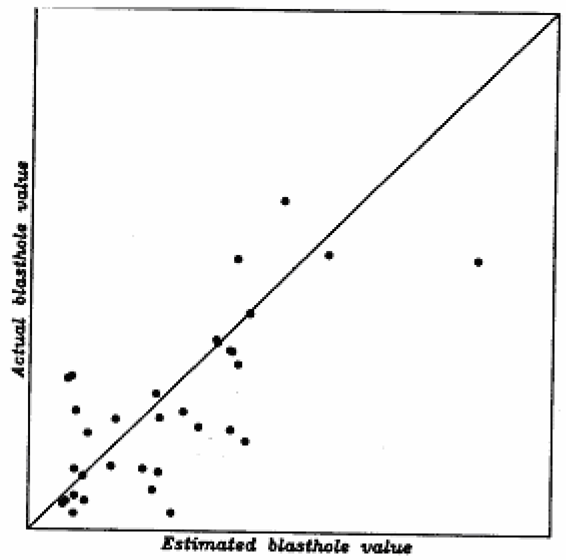

Fig 6 - Comparison of actual and kriged values averaged over blast hole areas.

SUMMARY AND CONCLUSIONS

A routine grade control program has been developed which reflects the geology of the deposit without requiring visual identification of the projected shear zones from geological plans and sections. While this approach is complex computationally, it is automatic once the semi-variogram models have been produced for the two indicator discriminators and for the two lognormal populations.

The method has been validated against actual blast hole sampling already available within the producing mine. Projected averages over selected areas using only bore hole information compare favourably with the averages indicated by the production blast hole sampling.

The complexity of the evaluation method is a direct consequence of incorporating the complexity of the geological nature of the deposit into the analysis.