GRADE CONTROL AND RECONCILIATION

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1.0 THE PROBLEM

Many of the open pit gold mines in Australia suffer from lack of reconciliation between in-pit estimates and actual head grades delivered to the mill. This is often despite adequate grade control sampling and, very often, good geological control. The problem is usually one of dilution. That is head grades are lower than predicted.

The need to quantify dilution, both internal and external, is well known as an important factor in production forecasting. Of course the dilution factor depends on the physical parameters of the orebody. For example, the more complex the geometry of the orebody, the more potential dilution there is likely to be when mining. The dip of the orebody has a bearing on how much dilution will be incorporated within a given bench height. Smaller benches allow more control and hence less dilution. The mining method in general will affect how selective the operation can be.

What exactly is dilution? This term is a convenient explanation for a host of complex relationships giving rise to the observed phenomena.

2.0 THE CAUSES

2.1 Bias

The first and most obvious cause for concern is bias in the sampling program. For instance in certain cases blast hole sampling may consistently under or overestimate the actual grade of an orebody. A thorough investigation early on during feasibility studies involving analysis of different size fractions, replicates and sample masses would determine whether bias is likely. A common problem area is where coarse gold or small scale structures exist. The most accurate representation here is given by sample masses large enough to incorporate such structures. If sample masses are too small the tendency will be towards negative bias, giving the opposite of dilution, that is consistently higher grades when mined. Another problem often encountered is consistent bias in the opposite direction. Blast holes can give a higher grade than actual. This exaggerates the effect of dilution. Sampling bias is probably the most difficult error to measure and certainly warrants careful consideration during an early stage of mining.

Figure 1 illustrates the difficulty in attempting to reconcile grade control results from blast hole sampling with exploration

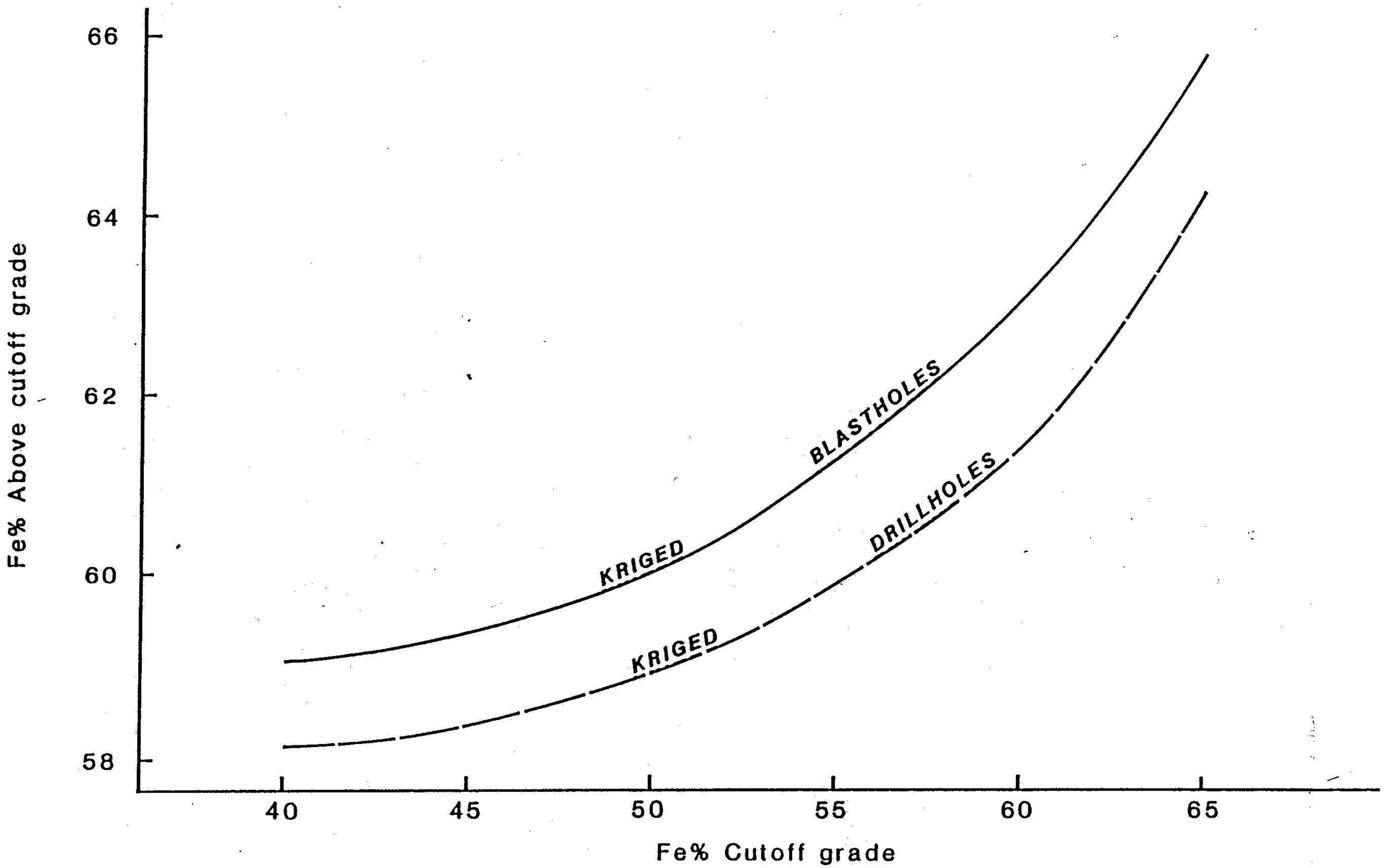


Figure 1 An illustration of the effect of sampling bias. Kriged blast hole grades are consistently higher than kriged drill hole predicted grades. The two estimates cannot be reconciled.

predictions from drillhole sampling. Although the Fe grade vs Fe cutoff curves are similar in shape blocks predicted from blast hole grades are consistently higher than blocks predicted from drillhole predicted grades. There exists an overall bias. The two estimates cannot be reconciled. A decision must be made to correct one set of sampling.

2.2 Regression Effect

Dilution is also partially explained by the so-called regression effect. This is the relationship observed empirically during many years of mining whereby in low grade areas sampling underestimates actual grades mined and in high grades areas it overestimates head grade. This is due to the fact that the mining blocks have a different distribution of average grades compared with the distribution of sample grades. Thus when a cutoff is set on sample grades a different effective cutoff is imposed on actual block grades. Figure 2 illustrates the ellipse containing the scatter of points found when actual block grades are plotted against sample grades. There is a regression relationship between actual and estimated grades which is not a 1:1 relationship. A given cutoff applied to samples corresponds to a different effective production cutoff on block grades. The actual grade and tonnes above cutoff depend on the distribution of block grades and the regression relationship between true block grades and observed sample grades.

2.3 Variance-area Relationship

This leads to concern about the size and shape of the samples compared with the blocks being mined. Obviously there is more variability between sample grades than between mining block grades. Large blocks will tend to be less variable than small blocks. Less selectivity can be practiced on large blocks and hence there is more dilution. If the cutoff grade is below the mean grade blocks have more tonnes at lower average grade than samples (Figure 3). The opposite is true if the cutoff grade is higher than the mean grade. This is the variance-area relationship and it explains the degree of the regression effect. Figure 4 illustrates the distribution of sample grades compared with selective mining unit grades showing the smoothing or decrease in variance of mineable blocks.

2.4 Nugget Effect

Mining decisions are based on blocks estimated from sample grades. How certain can we be about the representativity of individual sample grades, assuming there is no consistent bias? Sampling error or “background noise” can be a problem. Even samples from the same location can be variable. The inherent variability or nugget effect is most serious where there are small scale structures such as coarse gold giving rise, say, to differences between samples from two halves of a split core.

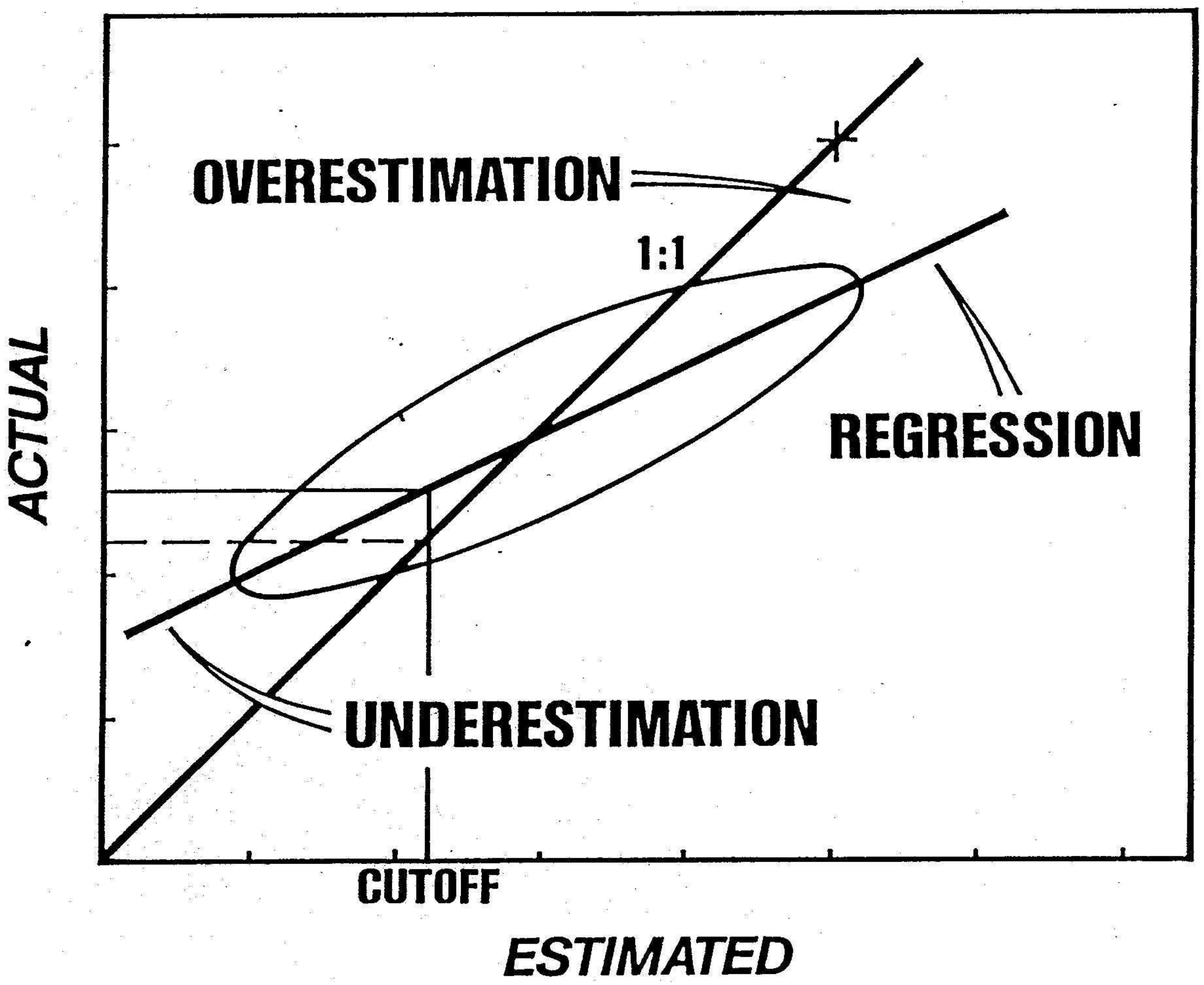


Figure 2 Illustrating the regression effect. The ellipse contains the scatter of points found when actual block grades are plotted against sample grades. Note that there is NOT a 1:1 relationship.

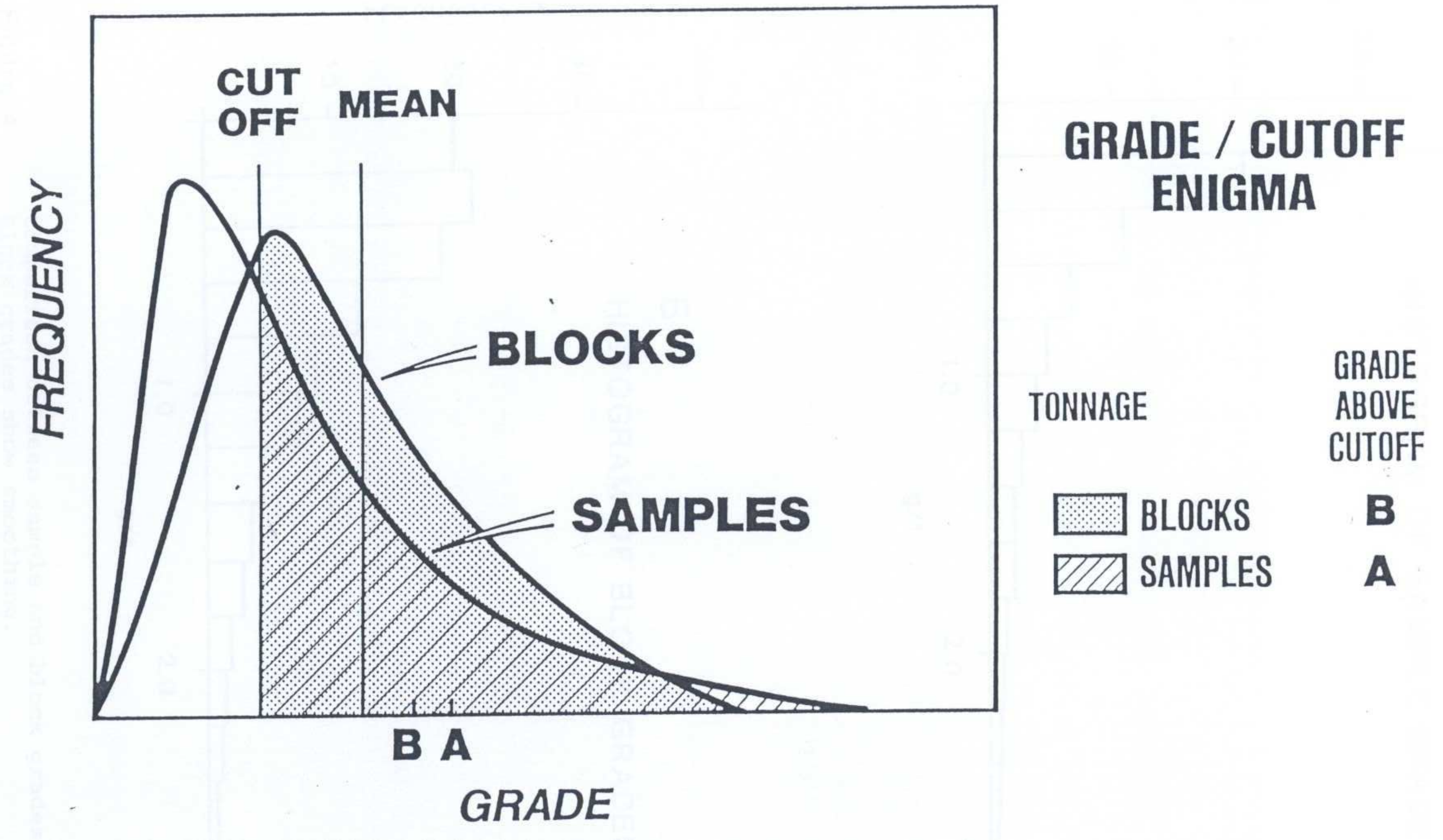
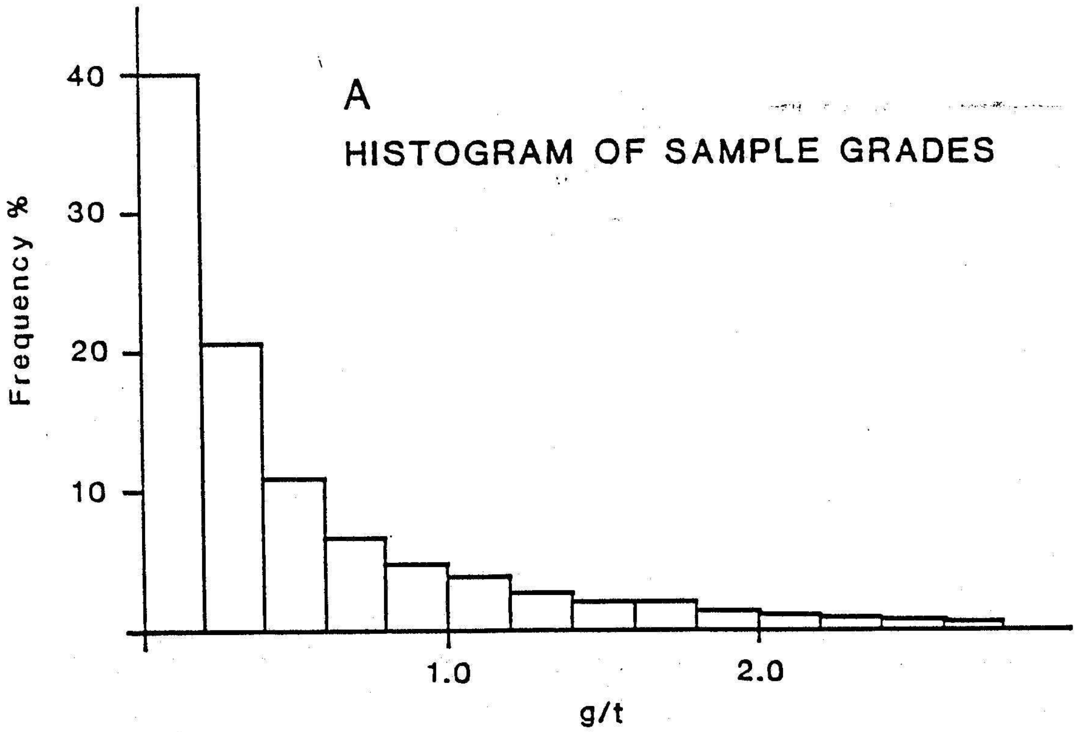


Figure 3 Illustrating how for the same cutoff grade blocks have more tonnes at lower grade than samples.



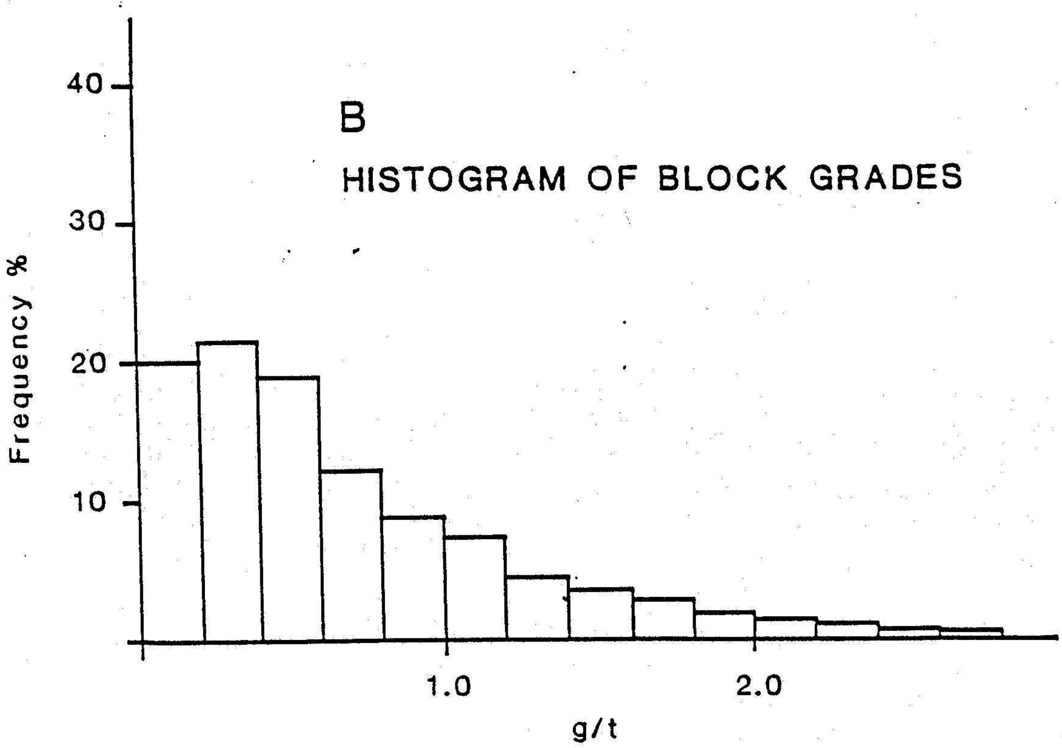


Figure 4 Comparison between sample and block grades. Block grades show smoothing.

3.0 THE CRITICAL PARAMETERS

The parameters of concern when attempting to reconcile production with forecasts thus include the following:

Block size and physical parameters
Cutoff grade
Head grade
Tonnage

The block size controls the amount of selectivity possible. Larger blocks have more internal dilution. Hard rock mining is susceptible to more external or mining dilution than soft rock.

Cutoff grades should be applied to blocks rather than samples where blocks represent a selective mining unit.

The head grade incorporates both internal and mining dilution but not mill recovery. Tonnage is measured by weightometer.

4.0 THE SOLUTION

One should thus place a great deal of emphasis on the calculation of block grades to match the degree of selectivity achieved. Successful prediction above cutoff depends on incorporating all these known issues in arriving at a recoverable grade and tonnage estimate. The issues to be considered in calculating the recovery of selective mining units include:

- sampling method
- frequency distribution of grades
- continuity of mineralisation
- mining method
- interpolation method

4.1 Frequency Distribution

The frequency distribution of grades is important to consider. For example one should check for normality or log normality and for mixed populations. Every effort should be made to separate geological domains in cases of bimodal grade distribution. If data is not normally distributed appropriate steps should be taken to account for deviation from normality. Figure 5 presents log-probability plots for a single lognormal distribution and for two mixed lognormal distributions. Figure 6 gives a bimodal histogram of SiO_2% derived from a mixture of banded iron formation and goethite.

4.2 Continuity of Mineralisation

Geological continuity can be quantified using semivariogram analysis. This defines not only the overall variability but also the range of influence in given directions and the nugget effect. Figure 7 is a semivariogram plot showing that at small distances samples are correlated. The range of influence is 12 m. Beyond 12 m there is once more an increase in correlation (decrease in semivariogram value) illustrating a hole effect. This semivariogram is typical of the continuity found in a direction

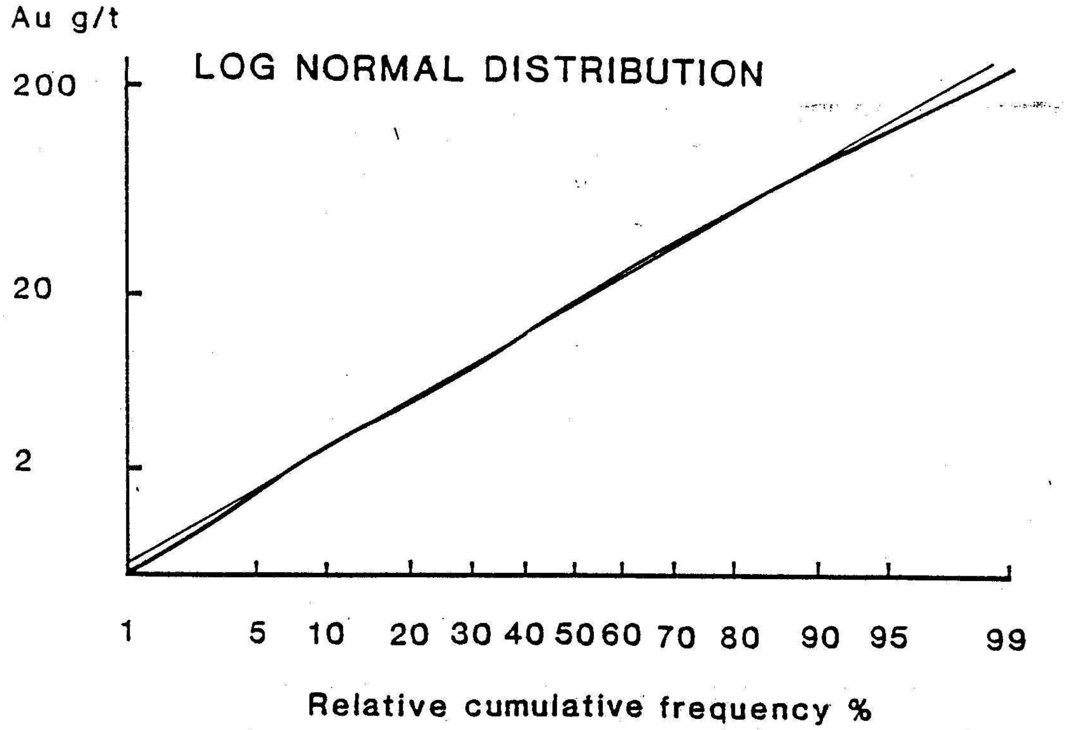


Figure 5A Log-probability plot illustrating lognormal distribution of Au (g/t)

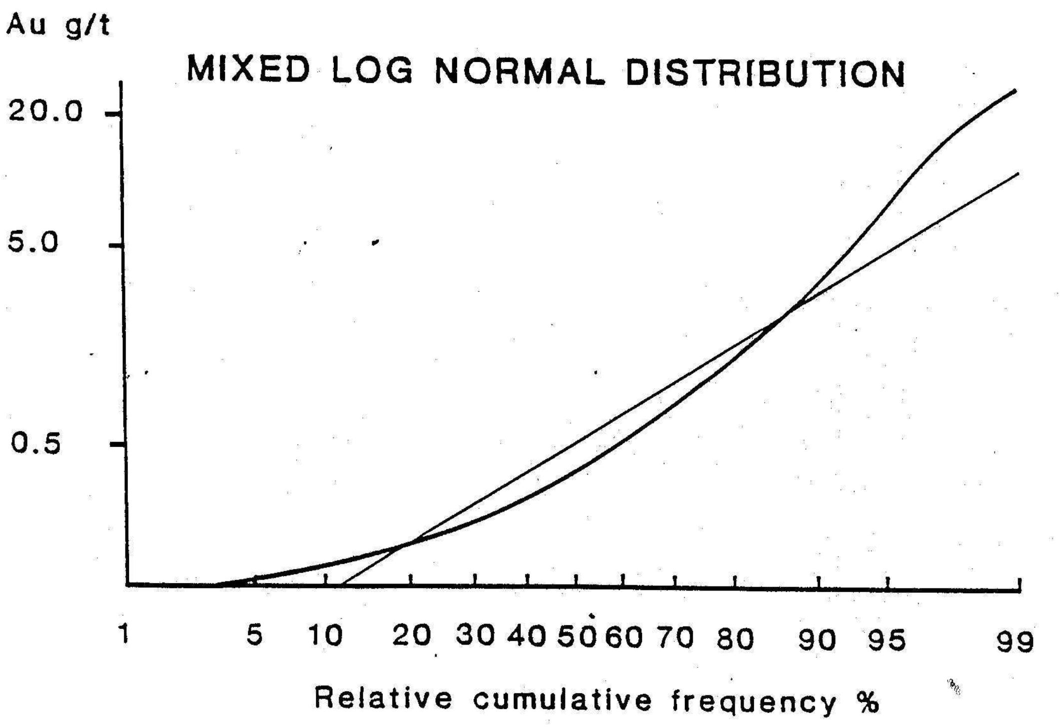


Figure 5B Log-probability plot illustrating a mixture of two near lognormal populations of Au (g/t)

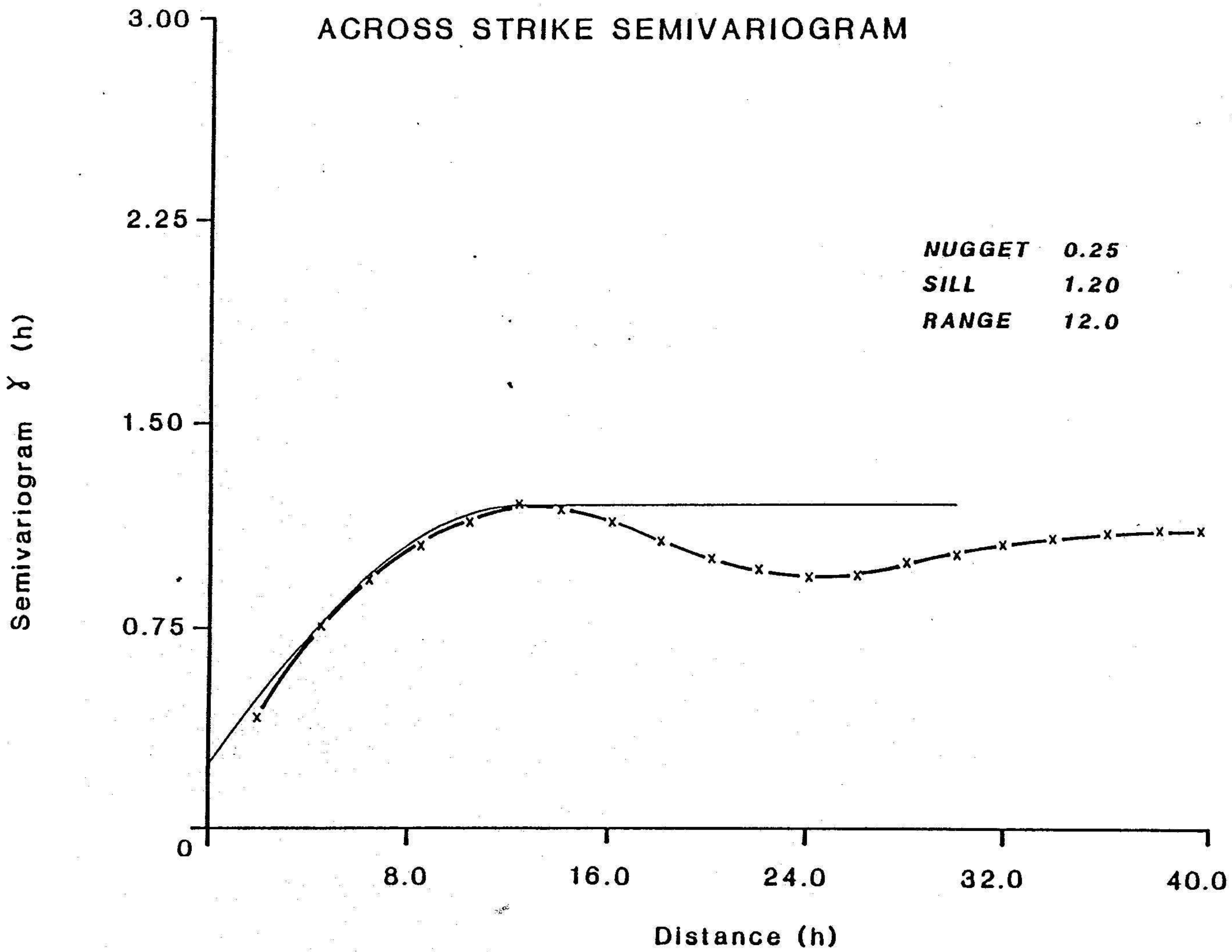


Figure 7 Across strike semivariogram illustrating hole effect

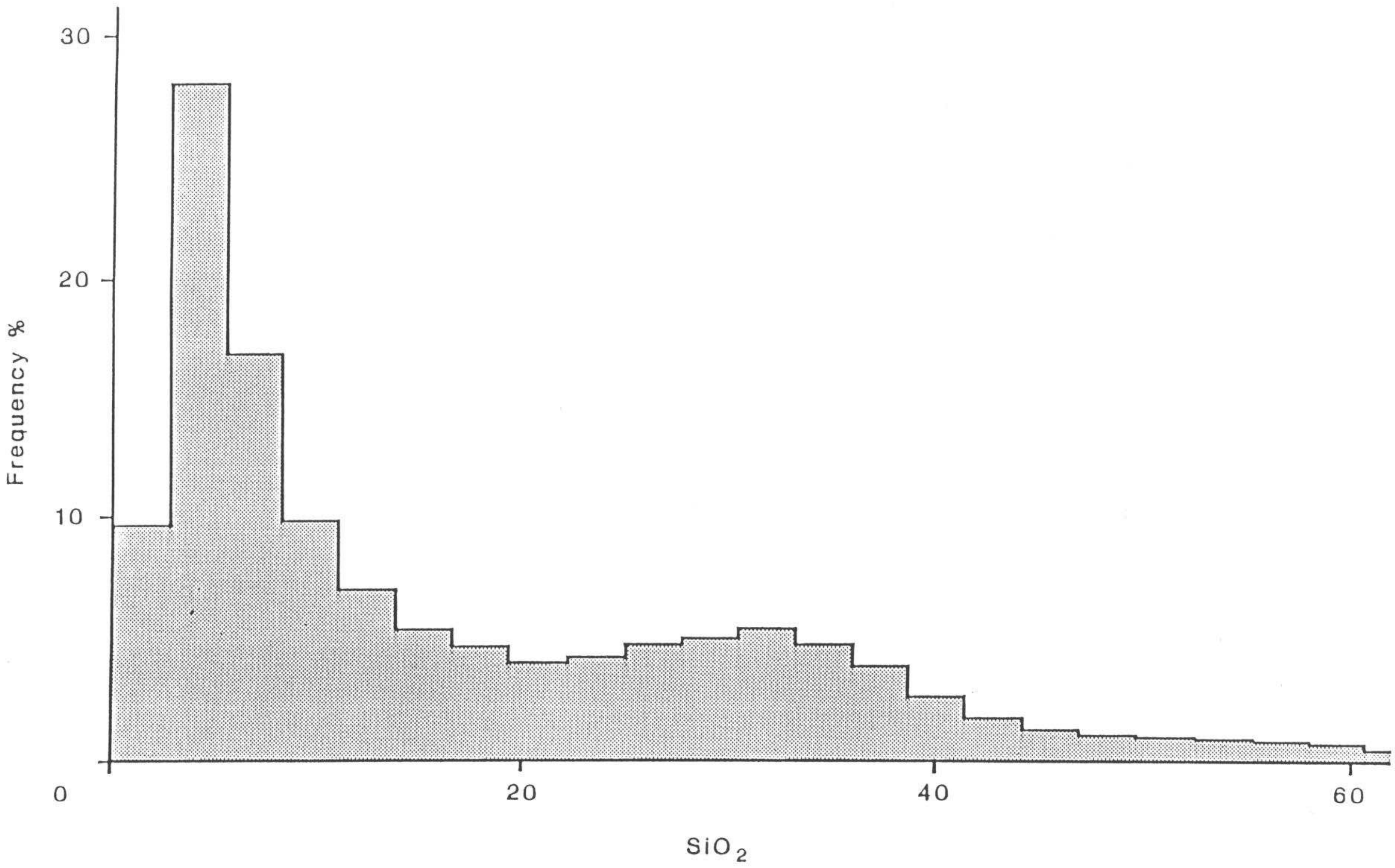


Figure 6 Histogram of bimodal distribution

perpendicular to strike. The nugget effect is the degree of inherent sampling error.

Geological continuity has a direct bearing on the magnitude of the variance-area effect for a given block size and mining method. The orebody structure, hardness of the rock and size of operating equipment, together with the overall scale of operation all influence the size of the selective mining unit.

4.3 Interpolation Method

The interpolation method needs to take account of this interwoven complexity of relationships. Estimation can be improved by reducing the variance of estimation hence reducing the regression effect. Economic cutoffs should be placed on selective mining units, not sample grades. Appropriate smoothing techniques such as inverse distance weighting, or preferably kriging, can assist in creating a block model for which grade/tonnage relationships more realistically predict actual production.

5.0 RECONCILIATION

Many reconciliation anomalies are readily explained by the variance-area relationship and the regression effect. Production grades and tonnages defined as polygonal estimates are accurately predicted at a 1 g/t cutoff in figure 8.1. At a 1.5 g/t cutoff the deviation from production is marked. In both situations the kriged blocks accurately reflect the tonnes and grade produced. However there is a marked difference between the cutoff set on blast holes and the effective production cutoff on blocks. A 1 g/t blast hole cutoff equates here to a 1.67 g/t block cutoff and a 1.5 g/t blast hole cutoff to a 1.8 g/t block cutoff. In both cases the cutoff on blast holes represents a much higher cutoff on selective mining units. It makes economic sense to lower the block cutoff hence expanding the reserve considerably in this example.

Figure 9 reinforces the grade/cutoff relationship by comparing the grade/tonnage relationship for selective mining estimates with that of bulk mining blocks. Selective mining above 0.5 g/t achieves similar tonnes and grade to bulk mining above 0.7 g/t.

The classification of ore and waste is sensitive to whether the cutoff grade is based on sample grades or on true block grades. Figure 10 illustrates how true waste blocks can be classified as ore on the basis of sample grades and how true ore blocks can be discarded as waste. This is because of the regression effect. In order to minimise the areas of error the estimation of blocks needs to be improved, leading to a tightening up of the variance of estimation as illustrated in Figure 11 and hence to less potential misclassification.

In conclusion it should be emphasised that grade control can be carefully monitored and reserves can be optimised by applying careful consideration to the factors described. An understanding of the grade/cutoff enigma and the role of block variability can go far towards assisting in the calculation of recoverable reserves and in reconciling various estimates with production records.

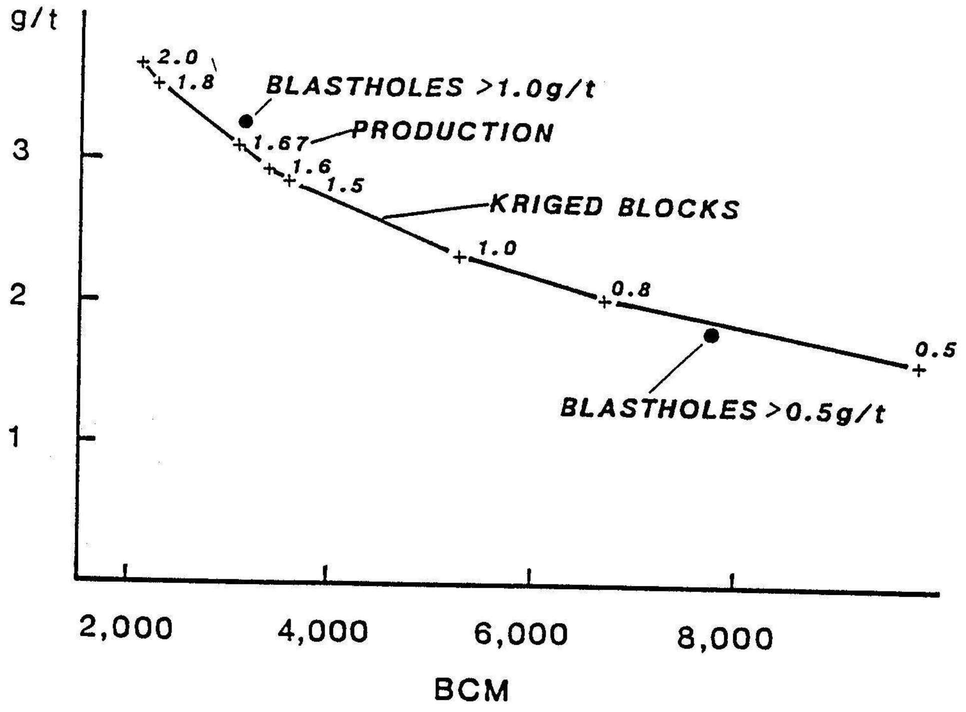


Figure 8.1 Close reconciliation between blast hole delineated blocks >1.0 g/t compared with smoothed blocks >1.67 g/t. Good reconciliation between kriged blocks >1.67 g/t and production

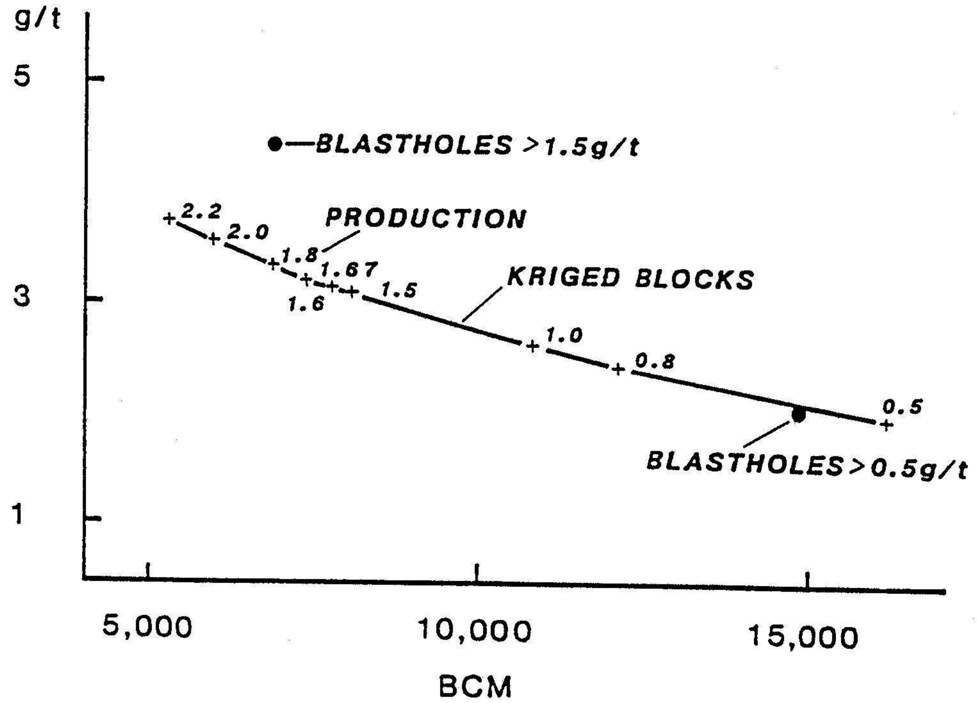


Figure 8.2 Poor reconciliation between blast hole delineated blocks >1.5 g/t and production. Good reconciliation of kriged blocks >1.8 g/t with production.

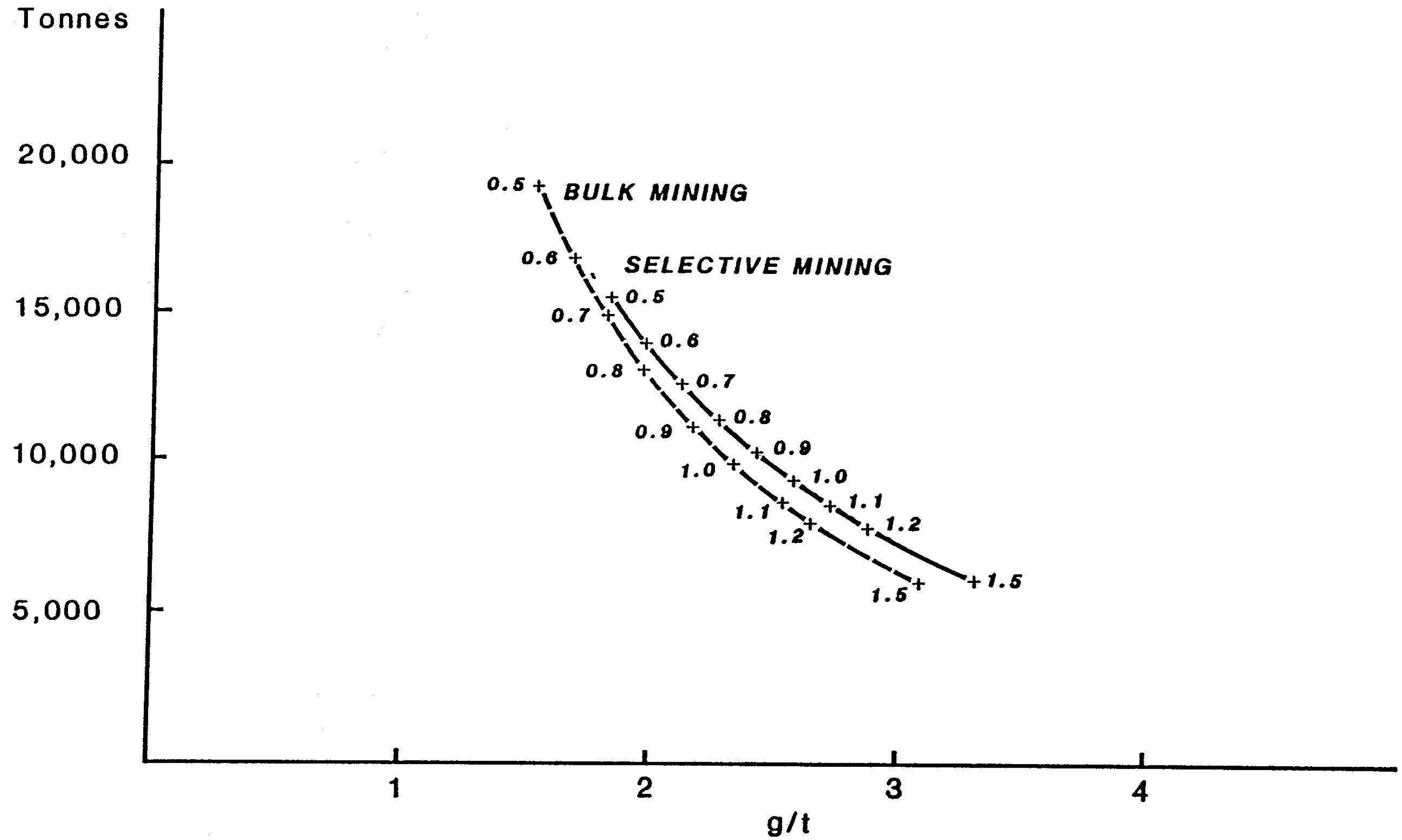


Figure 9 Grade tonnage relationship for Bulk and Selective Mining Units

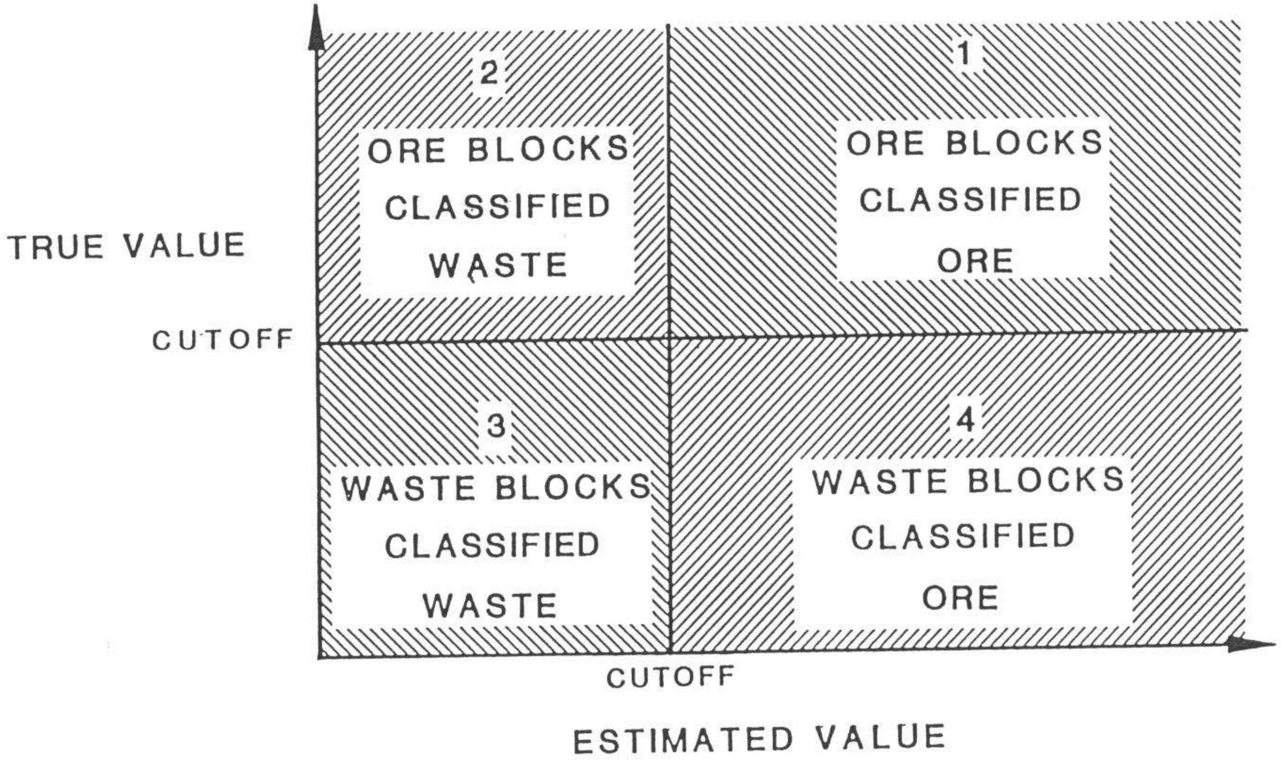


FIGURE 10 ORE/WASTE CLASSIFICATION

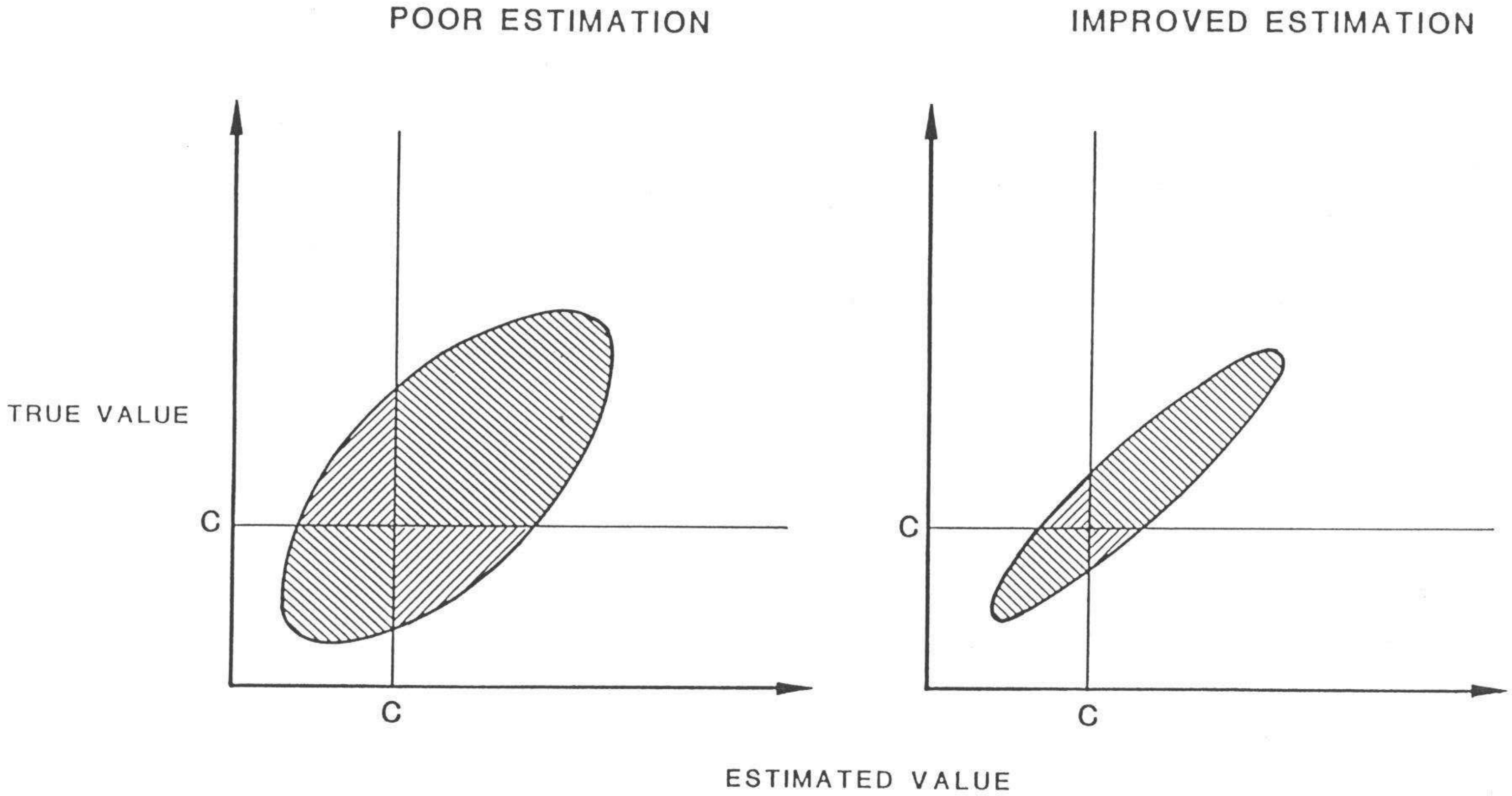


FIGURE 11 EFFECTS OF IMPROVED ESTIMATION