THE SAMPLING OF LOW GRADE ORES OF HIGH VALUE MINERALS

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(Refer explanatory note page 12)

ABSTRACT

Meaningful sampling of low grade ores of high value minerals can be extremely difficult, particularly where the values are coarse or are not amenable to conventional sample size reduction. The spatial distribution of values in prepared material is likely to be random, samples from which should follow the Poisson distribution. The minimum sample weight for a given level of accuracy and confidence is almost seven times as great as that obtained from a modification of Gy's formula. These sample weights are often large but may lend themselves to preconcentration. Even so analytical concepts may have to be enlarged or a statistically derived analysis obtained. It is suggested sample weights be determined assuming random distribution until data obtained enable the development of a more suitable model.

INTRODUCTION

The limiting economic grade of lode deposits of high value minerals is usually considerably greater than that for alluvial deposits. An easily and cheaply mined alluvial deposit may have a very low cut off grade, e.g. where gold is discrete and coarse enough for simple and complete recovery. A large alluvial operation, enjoying the economies of scale, may have a total operating cost of 50 cents m^{-3}. This is equivalent to 30 cents/tonne at 1.6 t m^{-3}. At a gold price of \$ 20 g^{-1} (\$ 620/ troy ounce) the cut off grade would be 15 mg t^{-1} or 15 ppb or 25 mg/m^3 (1980 figures).

Thus when proving alluvial ground grades of this level, or even lower, may need to be considered. If the gold is relatively coarse, the number of grains in a large and seemingly adequate and representative sample may be few, or even absent. The malleable nature of gold does not permit, with any confidence, the reduction of sample size by successive comminution stages, firstly because it resists breakage and secondly because it tends to be beaten onto the machinery employed. Certainly at the initial stages, when the size range of the gold as well as the grade are required, comminution cannot be employed. Hence the practice of obtaining pan concentrates for evaluation. But how large a sample should be taken, even for a pre-concentrating step?

Gold within an alluvial deposit is likely to be irregularly distributed in all planes, but is unlikely to be randomly distributed. Although attempts are made to ensure a regular spatial distribution of gold on the mixing and division of samples for evaluation, uniformity, in fact, is unlikely to be achieved, since there are so few value grains. Thus the distribution of high value minerals in prepared samples of low grade ores, particularly alluvial deposits, is more likely to be random rather than regular. Sampling methods should accommodate this. There follows a comparison of sample size for regularly and randomly distributed values and as obtained from a modification of Gy's formula (Ottley, 1966).

Consider the general system where g, d, and c are the specific gravity, equivalent spherical mean diameter (in millimetres) and the concentration (in ppm by weight) of the value mineral respectively. For the purposes of mathematical treatment it is necessary to consider the value mineral distribution to have a mean, preferably spherical, size. As an additional safeguard when determining the requisite sample size, it may be desirable to consider a spherical diameter equivalent to a near top size (known or estimated) of the distribution rather than a mean diameter.

1. <u>Regularly Distributed Values</u>

The few value grains are considered to be equally spaced within the mixed sample. The weight of one grain of value mineral of size d

$$= g \frac{4\pi}{3} \left[\frac{d\, 10^{-1}}{2} \right]^3 = 0.52\, g\, d^3\, 10^{-3} \text{ grams}$$

Therefore 1 grain would be contained in

$$0.52\, g\, d^3\, 10^{-3} \frac{10^6}{c} = 520\, g\, d^3 c^{-1} \text{ grams of sample}$$

Thus the minimum and all representative sample weights will be multiples of 520 $g\, d^3\, c^{-1}$. In reality, of course, there will be a size range and the concept of multiple minimum sample weights is invalid. This weight rapidly diminishes, to the third power, with decreasing size.

Since the values are regularly distributed the probability this sample size will give a true mean assay is 100%. Experience, however, tells us otherwise.

2. Randomly Distributed Values

The few value grains are considered to be randomly distributed in an infinite population of other mineral grains. The probability of sampling these few grains can be expressed by the binomial distribution, or more easily by the approximation at infinite population and for small distribution means, i.e. the Poisson Distribution (Guttman and Wilks 1965, Mode 1966) :

$$p_x = \frac{u^x}{x!} \exp\ (-u)$$

where p_x is the single probability of an event x occurring and u is the distribution mean of that event.

Thus in a situation where a sample is expected to contain an average of one value grain, the probability that any single sample will contain that one grain is :

$$p_1 = \frac{1^1}{1!} \exp(-1) = 0.3679, \text{ i.e. } 37\%$$

This degree of probability is too low to be useful and it is necessary to enlarge the sample size to contain on average several value grains, or in the general case n grains. Thus the probability of selecting 0, 1, 2 ... x grains in any single sample becomes :

$$p_x = \frac{n^x}{x!} \exp(-n)$$

The Poisson distribution is for discrete events, i.e. where value grains are of the same size and shape, and is therefore a discontinuous function. However, it is reasonable to treat it as a continuous function where the values are likely to have a continuous but limited size distribution using an equivalent, but not necessarily spherical, single size. Figure 1 depicts the probability a single sample will contain at least certain proportions of the average number of grains. In other words, the probability the single sample will assay at least a certain proportion of the true mean value, assuming no losses or analytical errors. (Conventional Poisson probability graph paper B depicts the same, but less obviously).

A sample size which has a high probability (say 95%) of containing the average number of grains (say at least 90% of them) would be desirable to minimise total error. An inspection of Figure 1 reveals that the probability a single sample will contain at least a low number of value grains, x, relative to the average number, n, is high but diminishes markedly as x approaches n. Thus an inordinately large sample, where the average number of grains is very high, would be required to satisfy a near true mean assay at high probability. The sampler or analyst has then to decide which is the most desired parameter.

In the initial stages of an evaluation a high confidence in the assay being at least a certain level is perhaps more important than a lower confidence in a near true mean assay. Thus in choosing high confidence levels, the sample size, and therefore analytical error may be summarised in Table 1 :

TABLE 1.- Selected parameters from Figure 1

Average number of grains in sample, n	Degree of probability any single sample will contain at least 0.25	0.5	0.75 of the average number
2	94	87	75
4	98	91	76
6	99.2	94	78
8	99.7	96	81

Generally the sample size is selected to contain an average of four grains of the equivalent distribution size (Jones and Gavrilovic 1968). Thus the minimum sample size for random distribution is four times the grams per grain.

$$= 2080\ g\ d^{3}\ c^{-1}\ \text{grams},$$

and the probability that this sample will contain at least two of the four mean grains, i.e. the assay will be at least half the true mean assay, is 91%.

In preliminary field assessments therefore we would select a sample size derived from a grade one half that of the limiting economic or cut off grade. At a later date it may be necessary to return to retained samples of marginal grade to determine the true grade.

3. Gy's Formula

Using the Ottley modification (Ottley 1966), the sample weight is given by

$$M = K \frac{d^3}{S^2} 10^{-3} \quad \text{(d is in millimetres)}$$

where $K = 40000 \text{ g c}^{-1}$ for alluvial low grade deposits of high - value minerals, and is the multiple of the shape, - size distribution, liberation and mineralogical composition factors.

and S^2 = desired sampling and analytical variance.

In order to obtain S^2 the distribution has to be normal (Gaussian) or capable of being 'normalised', e.g. log normal. Many low grade ores, e.g. lode tin, have log normal distributions but there are many such ores which have distributions which cannot be normalised (Jones and Beaven 1971).

For a normal distribution, 84% and 97.7% of the samples will contain at least (1-S)n and (1-2S)n value grains respectively where n, as before, is the average number. For a log normal distribution the corresponding figures are (1-S) ln n and (1-2S)ln n.

To obtain the same order of confidence as for randomly distributed values reference is made to Figure 1 for n=4 and for the above probabilities. The standard deviation ranges from 0.35 to 0.36 for a normal distribution and 0.33 to 0.47 for a log normal distribution. By taking a value of 0.36 for S the minimum sample weight becomes

$$40000 \text{ g c}^{-1} \quad \frac{d^3}{0.36^2} \quad 10^{-3} = 310 \text{ g}d^3 \text{ c}^{-1} \text{ grams}$$

This is quite a large variance and not normally acceptable in the application of Gy's formula.

Comparison of Minimum Sample Weights

If the value mineral is gold (s.g. 18) and the equivalent spherical diameter (the mean or near top size) is selected on the basis of some knowledge of its nature, e.g. from pan concentrates, the minimum sample weights, for various grain sizes and concentrations are given in Table 2.

Table 2.- Minimum sample weights

Distribution		Regular	Random	Gy's Formula (Ottley modification)
General expression for minimum sample size		$520\ gd^3\ c^{-1}$	$2080\ gd^3\ c^{-1}$	$310\ gd^3\ c^{-1}$
Approx. ratio		1.7	6.8	1
Degree of confidence sample will contain at least half the average number of value grains		100	91	91
d (mm)	c (ppm)		Sample size (grams)	
1	0.2	45×10^3	180×10^3	27×10^3
1	1	9×10^3	36×10^3	5.4×10^3
0.5	0.2	5.7×10^3	23×10^3	3.5×10^3
0.5	10	110	460	70
0.2	0.2	380	1500	220
0.1	0.2	45	180	27

The sample size for randomly distributed values is also depicted graphically in Figure 2.

DISCUSSION

It is apparent the minimum sample weights as indicated by Gy's formula or by assuming regular distribution may be too small for the subsequent analysis to have reliable meaning. Gy's formula is known to be unsuitable for low concentrations which can be non-Gaussian in distribution. To assume uniform distribution, no matter how careful the mixing, is somewhat unrealistic. In situations of this nature it is probably safer to assume random distribution of values and determine minimum sample weights using the Poisson distribution, until data thereby obtained is sufficient to develop another model or modify this one.

No matter how large these weights, sample size reduction through progressive comminution is not recommended for malleable value minerals. Since discrete grains are inferred sample size reduction should be effected by physical (gravity) means, if possible, ensuring or assuming value minerals are not lost in the process. The sample should be reduced to a size convenient for analysis, even if this requires enlarging analytical concepts. If sufficient reduction cannot be effected, as it may well be, additional statistical treatment will determine the number of assays required, to maintain the same significance, on manageable portions of each reduced sample size.

In the evaluation of such alluvial deposits, all assays obtained by this procedure which are greater than half the anticipated cut-off grade have high significance. It should be remembered, of course, that the values distribution in the material from which the minimum sample weight is taken should itself be random. Inherent irregular distribution should be broken up by mixing. The method of material extraction, e.g. churn drill cuttings, will assist in mixing but will not thoroughly mix the total cuttings. It may of course be easier to pre-concentrate the total sample, e.g. by tabling, rather than select a prepared portion.

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Note: In the period between when this paper was first conceived, late - 1970, and the date of formally writing it, November 1973, the publication

Sample Size and Meaningful Gold Analysis, by H.E. Clifton, R. E. Hunter, F. J. Swanson and R. L. Phillips, United States Geological Survey Professional Paper 625-c, 1969.

- became available in New Zealand unbeknown to the author.

The Clifton et al paper covers all and more of the subject that - this paper covers, except that the latter, through its relative simplicity, may be more practical.