ALLUVIAL GOLD : PROSPECTING AND EVALUATION *

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ABSTRACT

The limitations of the conventional practices, and their effects, in prospecting for and in the evaluation of alluvial gold deposits are briefly reviewed. Geophysical prospecting methods have demonstrated their complementary role in the delineation of deposits by reducing the number of boreholes which are primarily of a 'probing' type. Larger diameter boreholes, although more expensive on a linear basis, are much cheaper on a volume recovered basis. The need to have sufficient volume as well as number of samples is stressed. Classical statistical methods are not appropriate for such deposits as there is sufficient structure, or spatial correlation, to require the application of geostatistics. Quite reliable semi-variograms, but not in all cases, of the spherical scheme have been obtained. Subsequent kriging has, to date, been confined to unworked deposits; retrospective estimates to compare to production have not therefore been produced. However, the technique shows promise - but indicates a considerably greater borehole density (of the conventional diameter) may be necessary to produce confident estimates. Used in conjunction with larger diameter boreholes, a lesser borehole density may be sufficient, through radical reductions of the sampling error.

1. REVIEW OF CONVENTIONAL PRACTICES

The methods for prospecting, drilling, evaluating and working of alluvial gold deposits have been critically reviewed elsewhere (Romanowitz 1970, and Fricker 1976a).

Briefly they are :

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Prospecting - largely by hand panning with some geomorphological interpretations - highly developed as an art.

Drilling - deposits are drilled on an irregular grid by percussion methods - invariably a Keystone drill - broken core is removed by pumping at appropriate intervals - gold is recovered by screening, concentration, amalgamation, and subsequent parting (dissolution in nitric acid) - incremental data used to derive a borehole value using various correction factors (casing and core volume factors, discounting of high values).

Calculation of Reserves - method of sections, triangles, or polygons, usually the latter - further factors may be applied (dredge recovery and experience factors).

Recovery Methods - all methods essentially use washing, screening, concentration and amalgamation - concentration usually effected with riffled tables and jigs.

2. VALIDITY OF CONVENTIONAL PRACTICES

The validity of these practices is best illustrated by comparing recoveries with estimates, as in Tables 1 and 2. It is not surprising that any one annual estimate may depart significantly from the recovery, as the estimate would usually be derived from a few samples (perhaps 10, Fricker 1976a). However, over a period of years or over the life of the deposit, the R/E% could be expected to approach 100. In Colombia as the sample data increases (i.e. years of available figures), the R/E% is between 90 and 106, but the co-efficient of variation is still large. It is probably fortuitous therefore that the R/E% for all the Colombian dredges in Table 1 is 98.

The correlation coefficients of Table 2 are not impressive but could, in part, be attributed to a paucity of data.

Conventional practices therefore do not produce reliable annual estimates of production even with the use of drege recovery and experience factors. Global estimates (i.e. the whole deposit) may be more reliable but the level of confidence would appear to be low.

There are recognised deficiencies in the practices largely imposed by past technical limitations and economics. The most difficult deficien ces to cater for are :

Drilling

- the nature of alluvial gold deposits makes meaningful sampling very difficult.
- small drill diameter (effectively 15 cm).
- common departures of recovered core volumes from nominal volume.
- migration of value minerals away from or into hole.

Calculation of Reserves

- area of influence assigned by method of polygons is determined by bore hole spacing.
- the lack of replication from boreholes occupying essentially the same topographic position implies there is little or no area of influence.
- confidence levels cannot be determined using non-statistical procedures.

The most serious implication of the foregoing is the risk of rejecting marginally payable ground as uneconomic, because the methods of evaluation are too insensitive.

3. ALTERNATIVE TECHNIQUES

3.1 Prospecting

Drilling serves many purposes but in alluvial gold it has served - to delineate the limits of a deposit as well as the grade. Geophysical - prospecting methods demonstrated their usefulness in New Zealand many - years ago (Modriniak and Marsden, 1938) but they were not adopted by the industry. In the meantime drilling costs have relatively increased and geophysical methods have measured. Their value as a preliminary and complementary method to drilling have recently been demonstrated. Seismic refraction and gravity methods have indicated the configuration of gravels with a spatial accuracy of $\pm$ 10% as subsequently demonstrated by drilling (Peterson and others, 1968). Similar studies indicated that 40% of drill holes necessary to delineate a deposit could have been eliminated by using seismic methods at a cost saving of 30% (Tibbetts and Scott, 1972). The confidence in inferential geophysical information needs to be great - to offset the security provided by factual drill hole information. - Geophysical methods are currently being used by Gold Mines of N. Z. Ltd. in Central Otago.

Geomorphological studies have been made in Colombia (Shlemon 1970). Whereas the study was useful and is being continued, its success requires, initially at least, quite extensive drill hole information to confirm the interpretation of surface geomorphological features. The objective of minimising drill holes may not be readily achieved therefore.

Onshore placer deposits generally fall within well-defined types - (Kartashov, 1971). Their characteristics are such that they require different methods of locating, prospecting and sampling. The methods used to evaluate placers do not appear to have consciously recognised type - differences, but the 'experience' factors used to modify estimates may - well have subconsciously taken this into account.

3.2 Drilling

The small diameter of drill holes is of some concern in obtaining meaningful data particularly for low grade coarse gold (Hester, 1970). -

It has been suggested (Fricker, 1976a) that larger diameter holes would be more meaningful. However, the rate of increase in the 'reliability' of the borehole value for increasing hole diameter may not be as great as would be expected (Royle, 1972). Nevertheless, there is the additional advantage of obtaining larger volumes of sample.

Mineracao Tejucana S. A. a Brazilian placer gold and diamond producer, sank 70 cm diameter holes in order to obtain sufficient material to evaluate (Fricker, 1976b). Although such holes were six times more expensive than Keystone drilling on a linear basis, they were three times less expensive on a volume recovered basis.

A similar caisson technique has been applied to a Nevada gold placer (Hildebrand, 1976). 100 cm diameter cased holes were sunk through 12 m of gravel and broken rock. The cost was three times more expensive than Keystone drilling on a linear basis, but nine times less expensive on a volume recovered basis.

The need to have sufficient volume of sample to evaluate should not be underrated (Clifton and others, 1970; McLellan, 1974). For any given situation there is probably an optimum mix of hole diameter and number of such holes. This is less applicable to zones outside the workable part of the deposit since these holes are essentially probing holes to find bedrock and which may be substituted by geophysical methods. A further advantage of large diameter holes is the minimising, perhaps elimination, of the migration of value minerals. Similarly discrepancies arising from recovered core volumes would not arise.

3.3 Calculation of Reserves

The doubtful validity of estimates based on conventional practices could be due to the quality of the sample data or the manner by which estimates are calculated or both. Having incurred considerable costs to obtain these data as much meaningful information should be extracted from them as possible. Individual bore holes values appear to have little significance. Collectively they have an almost perfect lognormal distribution, typical of low grade mineral deposits. Collectively, if not in subsets, it should be possible to extract more information using statistical methods.

Since the quality of the individual datum is suspect, it is desirable to evaluate other estimation methods by producing retrospective estimates - and comparing them to production. The metallurgical efficiency of the - dredge (or other method of working) is yet another variable, but over a period of time (equivalent to the sample set examined) it is likely to be fairly consistent.

Most attention has been focused on the Taramakau river as successful estimation methods applied in retrospect could be immediately applied to undredged ground ahead of the dredge.

3.3.1 Classical Statistics

There was evidence from a study of borehole values elsewhere that the correlation between pairs of boreholes was low. It was not unreasonable therefore to consider the values had a near random distribution for which classical statistical procedures could be used. A procedure for lognormally distributed values was investigated (Sichel, 1966). This - method first idealises the lognormal distribution (if necessary) by using a location parameter.

Sichel's estimator t is defines as :

$$t = e^{\bar{x}} F_n (V)$$

Where

$$F_n (V) = 1 + \sum_{r=1} \frac{(n-1)^r \quad V^r}{2^r \, r! \, (n-1) \, (n+1) \, \ldots \, (n+2r-3)}$$

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i$$

$$V = \frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^2$$

$x_i = \log_e (Z_i + a)$ where Z_i is the borehole value or borehole value x depth,

and a is the location parameter.

By the use of tables it is possible to derive an estimate for the mean grade from either the individual grades or accumulations (grade x depth) and associated confidence limits.

Selected results are shown in Table 3. The Sichel estimator is no better but no worse than the conventional estimate except where several high values are not discounted. The 90% lower confidence level in each case is greater than the actual yield. Similar results were obtained for smaller parcels of worked out land and on comparison to conventional estimates for large tracts of unworked land elsewhere.

The Sichel estimator is therefore no improvement over conventional estimates which reflects either the quality of the data, the inapplicability of the method or both.

3.3.2 Geostatistics

Classical statistics ignores spatial or serial correlation and assigns the same confidence limits to random or regular sampling patterns. Instinctively we feel we obtain more information about a deposit that is sampled regularly, even if we don't know the reasons why or are unable to fully extract that information. Classical statistics may grossly overestimate the variability in an array of values which exhibit spatial trend.

Geostatistics recognises spatial correlation by progressively summing the squares of successive difference in producing a semi-variogram, defined as :

$$\gamma(h) = \frac{\sum (F(x+h) - F(x))^2}{2\,(N(x+h,\ x))}$$

where F (x) is the value of position x, F (x + h) the value of position x + h and N (x + h, x) is the number of pairs whose differences have been squared and summed.

The semi-variogram is a measure of the variance with distance and is obtained in a similar manner to the variance of classical statistics. Semi-variograms may take several forms but a common one is that shown in Figure 1. A theoretical model to this experimental semi-variogram is the spherical scheme :

$$\gamma(h) = C_o + C \left[\frac{3}{2} \cdot \frac{h}{a} - \frac{1}{2} \cdot \frac{(h)}{(a)}^3 \right]$$

where C_o/ C is the nugget effect.

C is the sill

C_o + C os the classical or random variance

h is the distance, and

a is the range of influence.

Semi-variograms are best obtained using a computer and are usually obtained in several directions to look for anisotropy within the deposit. The regionalised variable x may be borehole value, depth or their product (or any other property in the general situation). Unless a reliable semi-variogram is obtained there is little point in calculating estimation variances.

Estimates for the deposit are then derived by a process of kriging, usually of blocks within the deposit. Kriged estimates are obtained by weighting adjacent blocks using weighting co-fficients. The coefficients are obtained from the nugget effect and range of the semi-variogram and in such a manner as to give minimum estimation variance and to eliminate bias. This requires the solution of complex matrix systems and simultaneous equations. Fortunately tables exist for regular grids and small nugget effects. Even so the computer is necessary to reiterate the process over the whole deposit for each block. In the process the kriged variance for each block and the whole deposit is obtained, and thus the confidence levels of the estimates.

A fairly comprehensive bibliography on geostatistics and kriging is to be found in Royle (1977).

The semi-variograms for Section A of the Taramakau had little recognisable form, whichever regionalised variable was examined. It was then applied to the data of an unworked deposit and satisfactory variograms were obtained. The regionalised variables examined were borehole grade, weight of gold recovered from each borehole, depth and the products of the first two with depth, and logarithms of all of them. Subsequently interest was confined to logarithms of borehole value and to depths - the latter being normally distributed.

Attention was then refocused on the whole of the Taramakau including the unworked lower part, represented by a total of 370 boreholes. The variograms are most distinct and possess some of the spherical scheme. However, they need to be re-run to sharpen their features. To date therefore we have no retrospective kriged estimates to compare to production.

Kriging of the aforementioned unworked deposit however derived:

(a) similar estimates of volumes to the conventional estimates

(b) lesser estimates of mean grade to the conventional estimates - of an order comparable to the expected recovery after applying the discount factor.

(c) 90% confidence limits for a mean grade of 100 mg/m^3 where the sampling grid blocks are 100 m square of 45 and 235 mg/m^3.

Geostatistical techniques may therefore, provide satisfactory global estimates of alluvial gold deposits. However, further drilling (say halving and regularising the conventional grid spacing, thus quadrupling the number of holes) would be desirable for mine planning purposes e.g. dredge paths. This would also be necessary if the cash flows in feasibility studies are to have real meaning. It is still desirable to test this conclusion against production data. Hopefully, this may be possible on the Taramakau.

The nugget effect, a characteristic of this type of deposit, is responsible for the need to close the sampling grid in order to reduce the variance of blocks of ore within the deposits. A significant amount of this nugget effect could however be self-induced by the sampling errors, i.e. the drilling technique. Larger diameter holes could lesses this effect and could also lessen the need to close the grid by as much.

4. CONCLUSIONS

4.1 Conventional practices do not produce sufficiently reliable estimates of grade even on a global basis.

4.2 There are considerable cost saving in geophysical techniques to complement the drilling programme.

4.3 Larger diameter holes are cheaper to drill on a volume recovered basis; they should eliminate many of the errors associated with the Keystone drill; and, if assisted by geophysics and geostatistics, their number could be minimized by judicious spacing.

4.4 Classical statistics are not appropriate for alluvial gold deposits as they possess sufficient structure to require spatially correlated methods. Quite reliable semi-variograms have been obtained from some deposits.

4.5 Geostatistical methods appear to offer an advantage over conventional evaluation procedures but the case has yet to be proved.

Global estimates appear satisfactory but reliable subestimates may require an impractical increase in the borehole density. Larger - diameter boreholes may not require an increase of borehole density by reducing the sampling errors and therefore the nugget effect.

4.6 There appear to be an optimum mix of inferential prospecting - methods, borehole diameter and number, and method of estimating of reserves for any particular deposit, and which are to some extent interdependant.

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TABLE 1.- Comparison of annual recovery to estimate ratios (ex Fricker, 1976 - except data for Colombia) Based on R/E% - a single figure of recovered grade to estimated grade as a percentage.

Country Place/Company	Years R/E% Available 19-	Nº years R/E% Actually Quoted	R/E% Range	R/E% Mean	Coeff. of Variation
DREDGES					
New Zealand					
Arahura	40-60	17	47-70	63	10
Barrytown	38-45	8	32-60	46	20
Kanieri - at Kanieri	40-53	14	36-93	65	29
- at Taramakau	57-61	5	37-101	71	34
Ngahere	40-45	6	31-65	44	27
Australia					
Wellington Alluvials Ltd.	50-59	8	61-98	84	15
Canada					
Yukon Consolidated - all dredges (min. of 4)	35-63	28	85-143	110	14
Colombia - Mineros de Antioquia S.A.					
Dredge Nº 1A	46-66	21	41-137	90	27
2	39-66	28	60-143	98	20
3	39-75	37	63-185	106	23
4	43-75	33	65-147	105	17
5	39-75	35	50-191	91	30
6	49-58	10	27-179	84	51
7A (4)	53-69	17	71-124	92	15
8	64-75	12	67-123	95	22
9	1975	1	53	53	-
Total :	39-75	37	75-129	98	14
HYDRAULIC OPERATIONS					
Canada					
Paradise Hill (4)	52-60	8	55-277	173	47
Dominion Benches (4)	58-63	6	38-112	78	35

Coeff of variation $= \dfrac{100\ S}{\bar{x}}$

TABLE 2. Comparison of annual recovered and estimated grades.
Based on actual recovered and estimated grades.

DREDGE	Nº YEARS FIGURES AVAILABLE	CO-EFFICIENT OF CORRELATION
Arahura	17	0.47
Barrytown	8	0.60
Kanieri		
- at Kanieri	14	0.56
-at Taramakau	5	0.11
Ngahere	6	0.68

$$\text{Coeff. of Correlation} = \frac{S_{xy}}{(S_x^2 \; S_x^2)^{1/2}}$$

where x and y are the recovered and estimated grades.

A correlation coefficient of 0 indicates no correlation.

" " " of ± 1 indicates perfect correlation.

TABLE 3.- Retrospective estiamtes of mean grade (mg/m^3) using Sichel's estimator compared to production.

SECTION	A	B	C[1]	D[1]	TOTAL
Nº OF BOREHOLES	69	67	30	39	205
Actual yield (mg/m^3)	95.8	108	126	115	113
Conventional estimate (mg/m^3)	159	143	165	176	159
Sichel's estimator					
Based on bore values only					
- mean grade	145	159	315[2]	155	172
- 95% confident grade is greater than	113	124	187[2]	129	160
Based on value x depth					
- mean grade	161	147	232	127	163
- 95% confidence grade is greater than	123	121	148[2]	(127)[3]	137

NOTES

1. the data for sections C and D are not truly lognormal and should not, strictly speaking, be treated in this manner.
2. these higher values reflect the effect of four holes with very high values which were reduced to 420 mg/m^3 in the conventional estimate.
3. a quirk of the method for imperfect data.