WHEN GOLD IS NOT WHERE YOU FOUND IT

Some Geological Problems in Reserve Estimation of Gold Deposits

An Address by

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Most of us have experienced, sometimes to our sorrow, the realisation that gold was not where we found it, or where we thought we had found it, or where we thought somebody else had found it. The exploration and evaluation of gold deposits presents special problems which are related to the nature of the mineralisation. Although poor sampling techniques may fail to take account of all the gold in the ore, experience has shown that initial interpretation and reserve estimation usually overstate both the grade and the continuity of gold mineralisation: rarely the converse.

The problems encountered in evaluation and reserve estimation include:

1. Our inherent optimism in making projections from the known to the unknown, often reflecting a naive or uninformed enthusiasm, but occasionally also the more sinister objective of deception.
2. Technical problems in sampling and assuring representivity of samples and of assay data.
3. Computational problems in determining what volume of ore samples actually represent and the contribution they make to the average grade of the ore as a whole.
4. The translation of the geological interpretation of the nature of the ore body (the “in situ ore reserve”) to the feed which is trucked to the mill (the “mining reserve”).

I will be addressing aspects related to the first three of these points but touching only briefly on the last which will be covered more fully by other speakers.

Some of these questions may sound technically pedantic, but their effect on the viability of a proposed venture may be critical and therefore of great significance to the securities industry of which you are members. For example, it should be of great concern to you if the grade quoted for the proposed development of a gold mine can only be determined within confidence limits of ± 20 per cent.

An example of the dependence of a project on grade is shown by two feasibility studies of typical small Western Australian open pit developments of resources of about 1.5 million tonnes (probably quoted as a “Proved Geological Ore Reserve” or some other undefined and possibly ambiguous category) and quoted grades of about 4.5g/t Au and 4.0g/t Au respectively. Based on similar capital and production cost criteria, TABLE 1 shows that these proposed developments have Net Present Values of $13.13m and $5.03m, discounting at 16 per cent, and Internal Rates of Return of 38 per cent and 25 per cent respectively.

If, after production has started, it is found that the “Proved Reserve” grade in fact cannot be sustained — after all, analytical precision may only be ± 15 per cent and the drill hole sample sizes may have been far from optimal for spotty gold ores — what would happen to the viability of the mine. If the grade was over estimated by 20 per cent, the actual “in situ ore reserve” would then contain only 3.6g/t Au and 3.2g/t Au respectively. Applying the same capital and production cost estimates, the Net Present Values reduce to $(1.44)m and $(7.90)m, discounting at 16 per cent, and the Internal Rates of Return to 13.34 per cent and 0 per cent respectively.

TABLE 1
Effect of Grade on Mine Valuation

<table>
<thead>
<tr>
<th>NPY</th>
<th>MINE 1 (1.5 MILLION TONNES)</th>
<th>MINE 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4.5 g/t</td>
<td>3.6 g/t</td>
</tr>
<tr>
<td>4%</td>
<td>$25.2m</td>
<td>$12.0m</td>
</tr>
<tr>
<td>12%</td>
<td>$21.5m</td>
<td>$10.3m</td>
</tr>
<tr>
<td>20%</td>
<td>$16.3m</td>
<td>$8.65m</td>
</tr>
<tr>
<td>30%</td>
<td>$15.3m</td>
<td>$4.04m</td>
</tr>
<tr>
<td>40%</td>
<td>$13.1m</td>
<td>$1.44m</td>
</tr>
</tbody>
</table>

Published Grade | Less 20% | Published Grade | Less 20%
NPY | 37.18% | 13.34% | 24.76% | 8.18%

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In recommending to your clients that they invest in these mines; or in agreeing to provide debt finance for their development, did you take the possibility of shortfall in grade into account?

If this degree of error can really occur, perhaps it is time to ask ourselves: What is an ore reserve?

Various definitions for ore reserves are used in the industry. Figure 1 summarises some common terms used in Australia. Terminology which has been defined by the AASE and The AustIMM is outlined. Precise definitions of the terms which are recommended by these organisations are

1. Australian Associated Stock Exchanges
2. The Australasian Institute of Mining and Metallurgy

given in the publications of both bodies.

Three points can be made about this classification:

- Firstly, that there are two parallel streams using the same terminology. If the stream is not defined in the technical report (i.e. In Situ or Recoverable), confusion results. It should be noted that both streams provide results which have been modified from raw geological interpretation by the use of a "cut-off" grade. This is an undefined parameter which may have different meanings in each stream and is discussed later.

- Secondly, the classification starts from "Proved Reserves" and the less well proven categories of "Probable Reserves" and "Possible Ore" are defined as related to, or incremental to, "Proved Reserves". In an operating mine, this may be a suitable way of viewing the Reserves. In an exploration venture, however, it may mean that no Ore Reserves in the defined sense exist because the logic of exploration reverses the assessment process from Possible Ore to Proved Reserves.

- Thirdly, the categories are rigid and do not define or recognise any real measure of error or limits of confidence. In this matter, however, The AustIMM recommends that "tonnage and grade figures should be expressed so as to convey the order of accuracy of the estimates . . ." but envisages this as a rounding-off process based on estimates of "Precision" rather than a calculation of error. It should be noted that the definition of "Precision" is not included in the AASE list of definitions.

In summary, then, it is clear that within the rigid wording of the Australian definitions, the Ore Reserve terminology does not satisfy the requirements of those involved in the exploration, development and financing of new mines.

It is useful to carry this discussion a little further to look at some definitions which have been used elsewhere.

The US Bureau of Mines/US Geological Survey developed the classification shown in Fig. 2 which visually displayed the scope for "error" in any particular category. Important to our considerations is the following definition:

"**Measured** (proved): material for which estimates of the quality and quantity have been computed, within a margin of error of less than 20 per cent, from sample analyses and measurements from closely spaced, geologically well known sample sites."

Perhaps the most precise definition available in the categorisation of ore reserves has come from the German GDMB-Working Group which originally proposed in 1959 a classification based on varying levels of confidence and limits of error.

Recent studies by the GDMB-Working Group have produced a revised scheme which recommended, for both geological and mining (recoverable) reserves, the classification shown in Table II. This approach would seem to have great merit since it offers quantification of error. Whether sampling data of many deposits is
good enough to base these determinations on requires some study. I am indebted to Dr Wellmer of Metallgesellschaft of Australia Pty Ltd for a copy of his paper on the findings of this Group.

**TABLE 2**

**Recommended Scheme of Reserve Classification**

<table>
<thead>
<tr>
<th>Category</th>
<th>Upper Limit of Error</th>
<th>Level of Confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proven</td>
<td>±10%</td>
<td>90%</td>
</tr>
<tr>
<td>Probable</td>
<td>±20%</td>
<td>90%</td>
</tr>
<tr>
<td>Possible I</td>
<td>±30%</td>
<td>90%</td>
</tr>
<tr>
<td>Possible II</td>
<td>±50%</td>
<td>90%</td>
</tr>
<tr>
<td>Unclassified</td>
<td>&gt;±50%</td>
<td>90%</td>
</tr>
</tbody>
</table>

From Wellmer (1983)

The point of this lengthy preamble is threefold:

Firstly, to emphasise that “Proved” in Ore Reserves only means “proved within limits”; limits which are not quantified in Australia and may be determined in a subjective or even prejudiced manner, depending on the whims of the reporting body.

Secondly, to demonstrate the need for great care in determining what reported reserves represent in terms of the engineering parameters applied, and

Thirdly, to seriously propose, not only the revision of existing Australian standards, but also that research into better methods of computing and reporting reserves be undertaken by geologists and engineers professionally qualified to undertake such work.

The following briefly outlines some of the problems which are encountered in the assessment of gold deposits.

1. **Continuity of Mineralisation**

Traditional methods of ore reserve computation encourage the testing of lodes, usually by drilling, by regular grids of samples within vertical cross-section lines lying parallel to each other. This sampling pattern provides detailed information along the direction of sampling (i.e. along the drill holes) which is usually across the shortest dimension of the mineralised body. A “fence” of such drill holes, possibly with significant separations, make up the cross-section. The cross-section lines, distributed along the longitudinal axis of the mineralisation, may be quite widely separated.

This pattern of drilling assumes that we know that the mineralisation has more continuity in its long direction than in depth, or in its width. With most metallic deposits, this presumption may prove to be correct. With Gold deposits, however, the longitudinal continuity which may be observed in a structure, a reef, or even a set of reefs, may not reflect continuity of grade in the mineralisation which may in fact be very erratic in nature, or may show continuity in some other direction.

Fig.3 is a diagrammatic longitudinal section of an epithermal vein gold mine showing grade distribution as Isograds which have been compiled from mine records of development and stoping data. Quite clearly, this lode is made up of several rich steeply plunging shoots whose long axis is not in the longitudinal direction of the vein outcrop and the design of both exploration and evaluation testing programmes should take this into account.

Geostatistics introduced a concept of “range” as a calculated distance over which sample assays are shown to display mutual dependence. Averaging of assay values, whether by classical or geostatistical means, outside the range over which dependence can be demonstrated introduces zones of mineralisation which may contain large volumes of ore of totally unknown grade bearing no relationship to the surrounding measured assays. Philip and Watson (1985) stated that “the definition of grade as a spatial average requires multiplication of the interpolation functions expressing the spatial distribution of these functions ...” (i.e. grade and thickness or, perhaps more importantly, grade and volume). This concept recognises the presence of saddles and troughs in the contoured surface of the grade and thickness functions which are ignored in normal averaging techniques. The actual determination of the interpolated value of the functions by any method of computation may be very difficult to achieve but is the key to successful grade estimation of an ore body. This difficulty is also demonstrated by Fig. 3. If a grid of possible drill hole intersection points is superimposed over the Isograd contours, the likelihood of improperly evaluating the lode can be seen and the difficulty of developing a mathematical model for such an ore body is highlighted.

The importance of properly designed valuation programmes which take into account the variability of the ore in three dimensions cannot be overemphasised.

**Figure 3**

![ISOGRAD CONTOURS - GOLD LONGITUDINAL SECTION EPITHERMAL GOLD MINE](image-url)
Companies using geostatistics will look to the measured "range" in any direction as a maximum allowable sampling interval but will still require the acquisition of detailed infill information to give strength to the projections in the longer dimensions. Companies which are grid drilling using dimensions of convenience may well find that their interpretations of continuity do not stand up to testing in the mine face.

2. Some Sampling Problems
The problems of sampling gold ores have been widely reviewed but are often ignored in exploration practice.

It is easy to see that a few small samples may adequately define the chemistry of an homogeneous material.

Gold ores (and some ores of tin and tungsten), however, are often characterised by small scattered accumulations of highly valuable minerals in an uneven — or spotty — distribution throughout an essentially barren matrix.

Sampling theory for these ores must introduce the concept of "probability" since it is more likely that a small sample will be representative of a block of mineralisation containing many small grains of gold than it will a block of mineralisation containing a few discrete aggregates of gold; even though the total gold content may be the same. In the extreme case, it may be necessary to take all the mineralisation before one can be reasonably assured that the few aggregates of gold within that block will, in fact, fall into the sample in the right proportions.

Govett (1983) demonstrated the relationship between grain size and sample size — Fig. 4. This showed a dramatic increase in the size of sample needed to gain reproducible analyses as the grain size of the mineralisation increases. This diagram assumes an analytical reproducibility in the laboratory which displays a relative standard deviation of 10 per cent. The relationship in Fig. 4 applies to all levels of sampling.

The problem of reproducibility can be demonstrated from actual samples in repeat assays of laboratory sampling of an ore — Fig. 5 — which display up to 20 per cent variation in the assays below the highest value; in repeat channel sampling of an open pit face — Fig. 6 — which show up to 47 per cent variation in assays from a particular location below the highest value; and — Fig. 7 — which shows that there may be a 63 per cent maximum difference between block grades averaged from channel samples and from various drill core samples.

The determination of sample size is critical to good grade estimation and an understanding of the ore is therefore important to enable the design of a proper sampling programme. From Fig. 4, it can be determined that ore grading 4ppm Au with gold particles measuring 0.5mm should be tested with samples weighing about 15kg.
It should be noted that, if drilling is done “BQ” size (36.4mm diameter core), then one metre of split core will constitute a sample of less than 3kgs. “HQ” core (diameter 63.5mm) provides a split core sample of nearly 9kgs. Clearly the scope for error in the drilling programme using the smaller core is much greater than in the latter and even the “HQ” drilling programme is far from ideal. The situation may be reached with coarse gold ores — particularly in alluvial deposits — where any form of drilling is inadequate to give a satisfactory and reliable test of the deposit.

A further observation is that gold may not be broken into smaller particle sizes during laboratory crushing and grinding of the samples. Thus the same sample size requirement may apply to the laboratory samples as apply to the field samples. In this case, attempts to further split the sample in the laboratory to produce an aliquot for analysis may introduce errors of very great magnitude. The treatment of such ores in the laboratory requires the application of specialised techniques which, I regret to say, are very often not used. As an example, it was recently reported to us that a heavy mineral concentrate of a bulk sample with visible gold was laboratory sampled by a lg aliquot for assay and the results were duly reported as meaningful. This practice serves to emphasise the need for proper supervision of all aspects of exploration projects.

Grain size plays a major part in determining the true value of alluvial sediments. Reference to Fig. 4 suggests a typical deposit grading about 0.4ppm (0.6g/m³) with 2mm diameter gold flakes should be bulk sampled with large volumes of alluvium. An actual example of analytical data from an alluvial deposit is shown in Fig. 8. This deposit contained flattened grains of gold in the basal alluvial sediments with diameters approaching 2mm. The results indicate that sample size, and sampling technique, have the capacity to make or break such a deposit and that drilling may be a quite inappropriate method to test it.

**Figure 8**

<table>
<thead>
<tr>
<th>COMPARISON OF ALLUVIAL GOLD SAMPLE ANALYSES</th>
<th>AVERAGE OF SAMPLES TESTING A PARTICULAR AREA</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAMPLER METHOD</td>
<td>SIZE OF SAMPLE</td>
</tr>
<tr>
<td>COMPANY 1 BULK</td>
<td>4 - 10 CUB METRES</td>
</tr>
<tr>
<td>COMPANY 2 BULK</td>
<td>50 LITRES</td>
</tr>
<tr>
<td>CONSULTANT 1 CHANNEL</td>
<td>SEVERAL kg</td>
</tr>
<tr>
<td>CONSULTANT 2 BULK</td>
<td>5 CUB METRES</td>
</tr>
</tbody>
</table>

* NOTE Assayed by physical extraction of visible gold prior to normal sampling and analytical techniques.

Other problems encountered in sampling include:

- Sample recovery of core or percussion chips. Few companies using percussion techniques have any idea what proportion of chips they are recovering and as a consequence the validity of samples sent for assays are suspect.

- Field sampling methods may range from selective sampling of good looking chips to careful channel sampling using mechanised techniques. Drill core may be split by machine or chip sampled at random; percussion chips may be passed through a cyclone and hence to splitters, they may pass through rotating samplers of a type used in metallurgical plants, or they may be simply scraped up by hand from around the collar of the hole and put into a bag.

- Laboratory sampling methods range from standard laboratory riffling or quartering, to elaborate techniques of heavy mineral concentration and sizing of particles prior to analysis.

- Analytical techniques range from hand picking of coarse fragments, amalgamation of free gold with mercury, fire assay and Atomic Absorbtion Spectrophotometry.

Various specialised techniques must be applied under different conditions depending on the context in which the work is being done. Unfortunately proper sampling may be expensive if suitable techniques are rigorously applied. Many ventures are undertaken on slender budgets to “see what's there”. However, this restriction on proper (and expensive) techniques is soon forgotten in the heat of promotion and the results of these inadequately performed programmes are sometimes expected to stand up to the rigid standards of resource estimation.

3. **Computational Problems**

The application of simple statistics presumes the independence of variables and the random nature of sampling. In most ore deposits, neither of these conditions apply. The variables are usually dependent on each other as part of a cohesive entity — the ore body. They are also dependent on other variables such as structure, rock type and the chemistry of the host rocks. Sampling is rarely random because drilling programmes are deliberately biased into sections and patterns based on the presumption of testing the best mineralisation at minimum cost.

Furthermore, the application of simple statistics presumes that the data — in this case the grade — falls into a normal statistical distribution. If such were the case, the arithmetic mean of all assay values would be close to the average grade of the mineralisation, if all samples had equal representivity in terms of volume.

Where distributions of sample values occur which are not normal — for example gold deposits are typically in the form of a log normal curve, Fig. 9 — averaging requires the “normalising” of the distribution by artificial means; e.g. by logarithmic transformation in the above case, before meaningful results can be
Traditional mining practice recognises this problem which it has attempted to overcome by the introduction of empirical factors based on experience in the mine. These are variously called “cut” or “call” factors. They work in practice, because they reflect practice, but are scientifically unsound and may be more a reflection of poor operating practice than of inaccurate reserve estimation. In fact, although such factors represent a crude (and usually unintentional) attempt to normalise the statistical distribution of values, they have no place in the estimation of reserves for exploration and development purposes.

Finally, a word about “cut-off grades”. “Cut-off grades” are applied to a geological interpretation to provide outer limits for volume measurement and grade estimation of a mineralised body for resource estimation purposes. In determining the “In Situ Reserve”, the cut-off level or levels used may be dictated by sharp natural boundaries to the mineralisation, or may be based on some quasi-economic estimate of break-even grade.

In a “Recoverable” (or Mining) Reserve, the cut-off grade (or grades) reflect engineering estimates to maximise the profitable extraction and treatment of ore. These “cut-off grades” vary with the economics of the project, and may even vary within a particular development.

The application of a cut-off grade in mining practice always lowers the head grade below the calculated average and reduces expected gold returns because of the effect of errors in estimation. Figure II illustrates this effect and demonstrates how this short-fall occurs when some ore goes to waste, and some waste goes to the mill for treatment. With improvements in grade assessment, and a reduction in the width of the ellipse enclosing the errors, actual practice approaches the theoretical grade. I am sure that this will be discussed further by later speakers.
By way of a Conclusion, let me summarise:

1. Ore reserve classification in Australia is not adequate for the assessment of exploration projects, nor for providing estimates of risk for developing and financing new ventures. In practice, reserves can only be determined with limits and I believe you are entitled to know what those limits are. I believe that we, as geologists, and you as representatives of the finance industry should be actively encouraging bodies like the Joint Committee of The Australasian Institute of Mining and Metallurgy and the Australian Mining Industry Council on Ore Reserves to address the problems of standards and techniques of Ore Reserve computation and reporting. We must promote investigations, by financially supporting research at suitable institutions, into the estimation of risk or error in the calculation of ore reserves for the classification of reserve categories at the exploration and development stage of mine financing.

2. Companies and venturers hoping to bring properties to development must be prepared to make greater expenditure ensuring adequate sample distribution within the mineralisation, and that proper attention is given to field and laboratory sampling techniques.

3. Computational methods for gold reserves must take account of sample representivity and recognise that the (grade x volume) product used for weighting in the averaging computation contains two variables, both of which must be estimated. Sample averaging, or weight averaging of grid blocks may grossly over estimate the gold content of a body. Methods must be used which provide the best estimate of this three dimensional spatial variance.

4. You are urged, in the interests of your clients, to ensure adequate finance is made available prior to development for proper professional assessment of the deposits to minimise the very real risk to the investor.

REFERENCES

Mining Magazine 1974 “Classification of Mineral and Energy Resources” March.