A Guide to the Understanding of Ore Reserve Estimation

by

HADDON F. KING,[1] Member, DENIS W. McMAHON,[2] Member
and GEORGE J. BUJTOR,[3] Associate Member

[1] Consultant c/- CRA Limited, 55 Collins St., Melbourne, 3000
[2] Consultant Mining Engineer, CRA Limited, 55 Collins St., Melbourne, 3000
[3] Technical Consultant, CRA Limited, 55 Collins St., Melbourne, 3000

Published by

The Australasian Institute of Mining and Metallurgy,
Clunies Ross House, 191 Royal Parade,
Parkville, Victoria, Australia 3052

Distributed as a Supplement to Proceedings No. 281, March 1982

Preface

The Institute has, as appears from a number of its publications, taken a professional interest in the estimation and reporting of ore reserves for nearly 30 years, the last 10 having been in conjunction with the Australian Mining Industry Council. The Joint Committee, whilst concerned primarily with the setting of appropriate guidelines for the public reporting of ore reserves has during the course of its work become aware of the need for wider discussion and review of the concepts and procedures involved in ore reserve estimation. The accompanying report, made available for publication by courtesy of CRA Limited, provides a comprehensive and wide ranging coverage of this subject, reaching far beyond the recommendations of the Joint Committee. In view of the extensive combined experience of the authors—ranging over mine operations where ore reserve estimates are of critical importance, familiarity with geological aspects of ore reserve estimation, together with an understanding of the uncertainties and opportunities afforded by geostatistics—the Joint Committee has recommended to the Institue that the report, representing the authors joint opinions, should be published as a contribution to the better understanding and eventual rationalisation of ore reserve estimation and reporting.

B. P. Webb,
Chairman,
Joint Committee on Ore Reserves
The Australasian Institute of
Mining and Metallurgy
and
Australian Mining Industry Council

3125

Foreword

The paper that follows is a reproduction of an in-house report to CRA Limited on a study of ore reserve estimation and reporting. It occupied three years and involved three separate visits by some of the authors, consultants and other collaborators to each of six of the CRA group's mining activities.

The effective date of completion was November 1980.

The report has been made available for publication by CRA Limited but the opinions are necessarily those of the authors.

H. F. King
D. W. McMahon
G. J. Bujtor

Contents

Preface, Conclusions and Acknowledgements

This guide to the understanding of ore reserve estimation is the revised version of a report with a similar title circulated within the CRA Limited (CRA) group of companies in mid-1980. It is the principal result to date of an Ore Reserve Study commissioned by CRA in late 1977.

The study was prompted by two ore reserve situations. The Zinc Corporation and New Broken Hill Consolidated, Broken Hill, had reached the point of having to find a replacement for their traditional ore reserve procedure and Mary Kathleen had to admit publicly that ore reserve predictions would not be realized. These were not however the only problems to be looked at. As mentioned more fully later, other ore reserve situations were known, or were met during the study, in copper, gold and nickel as well, where poor realization: expectation ratios had ranged from embarrassing to disastrous. These made it clear that ore reserve estimation had to be looked at afresh.

The fresh look has resulted in a broadening of the concept of ore reserve estimation from its traditional purely computational basis to an approach embracing all the many things that can affect expectation and realization as essential factors. Hence this guide represents a gathering together of what has been learned and what should be known to all those concerned with ore reserves in any of its diverse aspects.

The study has been marked by a number of changes of thinking. At first the aspects that appeared to require attention were two; recognition that an ore reserve statement was an estimate, not a precise calculation; and a search for an improved estimation procedure adapted to low grade ores with narrow economic margins. Three years later the view was that the need was to incorporate into ore reserve estimation all relevant aspects of the proposed mining operation from choice of a sampling method to sales contract specifications.

This study is thought to be unique in being frank about weaknesses in ore reserve estimation and in treating failures not as natural disasters (like drought or flood, which have to be endured) but as potentially avoidable. It has led to three principal conclusions.

1. Ore reserve estimation is not a matter of mere calculation but a procedure which involves, explicitly or implicitly, judgement and assumption about geological, operational and investigational factors. The calculations therefore form only part, and not necessarily the most important part, of the overall procedure.
2. An ore reserve statement should, where appropriate, be not merely an estimate of what is in the ground but a prediction, involving a futher stage of judgement and assumption, of what will be fed to the mill or recovered.
3. For practical and statistical reasons related to the limitations of sampling and the kind and character of the ore, accuracy of prediction, especially of grade, will rarely exceed and will commonly not reach two significant figures.

Thus ore estimation has come to be seen not as something that could be taken for granted but as an exercise requiring, especially in relation to low grade ores, the best that the profession could provide in the way of geology, mining and metallurgy—information, understanding and judgement. In this view it is the bridge between exploration, when successful, and mine planning. It is appreciated that established mines, so long as they have plenty of ore of accustomed grade and characteristics, may not need this broader approach. To a new venture or re-organization of an old mine approximating a new venture, the broader approach is seen as essential and perhaps crucial.

The answer to this estimational problem will be a range of probabilities, never a single figure. It will of necessity have to be expressed, at some stage and at some administrative level, as a single figure but the reality that it is merely one point in a range should be apparent and unavoidable all the way to the top of the executive and financial tree.

As illustrating the spirit in which this guide was compiled, it may be mentioned that it was originally intended to call it a "manual" but this was abandoned in favour of the less dogmatic "guide". In deliberate avoidance of text-book style, the guide discusses the various aspects in increasing depth, much as they might present themselves to users.

The authors have been asked how this guide should be used. They suggest that it should be used by makers of ore reserve estimates to avoid, and by users of ore reserve estimates to detect, hidden pitfalls in the process. Because it is designed principally to improve understanding, it avoids laying down procedures for making estimates. Regrettably, no good text on this subject is known and the best available source is the experience given in published case histories.

The authors wish to acknowledge a wide range of assistance. To the companies of the CRA group, Bougainville Copper Limited, CRA Exploration, the former CRA General Mining Division, Hamersley Iron, Mary Kathleen Uranium, Woodlawn Mines, Cobar Mines, Zinc Corporation and New Broken Hill Consolidated for generous co-operation and, to the last of these, for assistance by way of staff and facilities; to the Chairman and members of the Joint Committee on Ore Reserves, Australian Mining Industry Council (AMIC) and The Australasian Institute of Mining and Metallurgy (AusIMM), for much helpful discussion; to the Sydney Branch for its informative Symposium on

Estimation of Ore Reserves; to Sir Frank Espie, OBE who commissioned this study and has maintained an interest in it and to B. S. Rawling, CRA Group Technology, for some valuable suggestions.

Since the above was written, the mid-1980 version of the guide has been discussed with senior mine staff on the various sites. Many valuable contributions and suggestions have been incorporated and for these the authors are indebted to about a score of mining engineers, geologists, metallurgists and accountants.

The views expressed by the authors are entirely their own and do not necessarily represent those of CRA Limited or its associated Companies.

The authors wish to thank CRA Limited for permission to publish this report.

Introduction

Of all aspects of a mining operation, the ore deposit and its characteristics are alone in being unalterable. Any changes in our expectations are only changes in our knowledge or understanding. In all other directions, mistakes, miscalculations or misunderstandings are amenable to rectification if there is the need and the justification, but the ore deposit and its characteristics are beyond human modification.

Yet, despite this fundamental status, ore reserve estimation has been, and has remained to the present time, one of the most prickly topics in the mining profession and one on which various professional institutions have unsuccessfully sought consensus for many years. Recently, however, and as a result of the latest meetings of The AusIMM/AMIC Joint Committee on ore reserves,[1] the move towards consensus has yielded a symposium on ore reserve assessment as it affects metals, coal, oil and gas, and even industrial materials.

The reason for the slow approach toward rationalization has been the emphasis given in the past to differences between one orebody and another, between metallic orebodies and coal seams, and between these and other kinds of mineral concentrations. Until recently these differences were seen as precluding any common treatment. In passing one might note that this emphasis on differences rather than on similarities is not peculiar to ore reserve estimation. It was of course the principal obstacle to progress in biological thinking until 1860; it is still common in geology as well as in other quarters.

Thus this guide suggests that there is no difference in principle between reserve estimation in various kinds of deposits. They all involve quantity and quality (tonnage and grade) of a (usually) hidden resource and various permutations and combinations of in situ resource, recoverable reserves, economics and governmental constraints.

In the context of metals, reserve assessment has been bedevilled by a meaning attached to the word "ore" in the last (perhaps) sixty years that the contained metal must be amenable to profitable extraction. In the industry generally, the word has a wider more mineralogical connotation as it has in a 1747 text[2] recently reprinted by the Institution of Mining and Metallurgy. The authors of this guide prefer this wider usage as in ore deposit, ore intersection, ore sample, etc. and suggest that the economic connotation should be attached to the "reserves" rather than to the "ore". This study therefore avoids a definition of ore and leaves the way open for differing meanings in individual siutations.

Despite the apparent precision of terminology and the usual precision of reporting, ore reserve estimates are recognised by the profession to be far from precise. Twelve years ago a paper on ore reserve estimation with an eminent Canadian academic and former mine geologist[1] as senior author, contained the following passage,

> "When we ask a mining engineer or geologist to name the precision within which he knows the deposit he is mining, we often get the answer of 20 per cent. He will not dare say 10 per cent, as this somehow would seem to him to be too accurate, nor will he answer 30 per cent, because this latter figure may reflect on his engineering abilities. If we ask him what chances there are that he is right within 20 per cent, he becomes baffled".

This quotation is of interest firstly as the only known published statement on the subject, secondly, as to the level of imprecision and, not least, for the frankly non-technical reasons given.

In Australia, in the last generation, some 50 new mining ventures (coal excluded) reached the production stage. Of these, fifteen were based on large, good grade deposits, relatively easily assessed. Of the remainder, ten suffered ore reserve disappointments more or less serious and some mortal.

Together with the Broken Hill and Mary Kathleen ore reserve situations already mentioned, these disappointments provide the justification and establish the necessity for this study. To identify them all or to name them would not, it is felt, contribute to the aims of the study. It should be sufficient to mention that they include predicition: realization ratios (in grade) of about 100:75 in a large gold mine, 100:70 in a major uranium mine, 100:55 in a sizeable copper mine and 100:80 in a small nickel mine. The point here is not merely the size of the shortfalls; it is that all of these happened to some of the most experienced companies in the industry.

By contrast with its performances in most technological fields, the mining industry generally has not made itself expert in ore reserve estimation. One reason is that, so long as ore reserve estimation was seen as mere calculation requiring only mathematical competence, it tended to be treated like a surveying problem where accuracy of measurement and computation are the only criteria and where (in some situations and except in relation to ore reserve statements) involvement of senior people was not seen as necessary. It manages well in easy situations but often poorly in difficult situations which, with the trend toward lower grades, are becoming more common.[2] The professional literature (even the

---

[1] In early 1978, CRA made available to the Committee copies of the First Report of the Ore Reserve Study.

[2] William Hooson, MDCCXLVII *The Miners Dictionary*. (reprinted in 1979 for the Institution of Mining and Metallurgy: London)

[1] Professor Roger Blais, Ecole Polytechnique, Montreal, in Blais, R. A. and Carlier, P. A. (1968), Application of geostatistics in ore evaluation, *C.I.M. Spec.* 9: 41-68.

[2] For example, the CRA Group has not met a simple estimation problem since Mount Tom Price in 1964.

latest textbook known to us) does not, except as mentioned in an earlier paragraph, acknowledge the inherent imprecision of ore reserve assessment and the shortfalls mentioned above have not so far had any influence on ore reserve estimation in general. Instead the industry has continued to report ore reserves as though they were precisely calculable.

One Australian move in the direction of improved ore reserve estimation was made in 1970 when the Australian Mineral Industries Research Association (AMIRA) commissioned the Australian Mineral Development Laboratores (AMDEL) to make a study of ore reserve estimation. The principal reports were presented in 1973 and 1976. The reports suggest that even up to that time, the industry continued to see the problems of ore reserve estimation as mainly computational.

A principal aim of this study has been to reduce the possibility of gross error by reaching, and passing on to makers and users, a clearer understanding of ore reserve estimation. It will be seen that the hazards are found much more in the realms of assumption and judgement in the geological and mathematical fields than in the computations. As a result this guide will be concerned more with concepts than with calculations. We have been encouraged in this by a conclusion of the oil-men that some of their estimators appear to become fascinated by figures and to lose sight of their meaning.

A secondary aim has been to see and if possible choose a way toward refinement of ore reserve estimates. The modern trends toward low grades and open cut mining both create situations which do not have the latitude enjoyed by operations based on high grade underground deposits with an undeveloped potential. This refinement is perhaps even more difficult than avoidance of gross errors because of the unavoidable imprecision of any estimate based on sampling. The route toward this objective is undoubtedly statistical but again with the danger of over-emphasis on figures at the risk of under-emphasis on everything else.

The study as it has developed has consisted mostly of identifying, and marking, the perils and pitfalls along a route that every mining venture must travel. Most make the journey successfully. This guide seeks to offer greater comfort through the subsidiary discomfort of fuller awareness of the dangers.[1]

At this point it may be appropriate to interpose the comment that if one is dealing with a high grade deposit which can live, or perhaps even thrive, on 60% realization of what was expected, then much of what follows is important but not critical. However if we want to be able to make a fine judgement at a particular time as to whether a low grade deposit is mineable, then nothing less than the fullest possible understanding of ore estimation is good enough.

It has been encouraging to find, in the last days of this revision, November 1980, that a comment on ore reserves by the current President of the Institute of Mining and Metallurgy, London,[1] is in considerable agreement with some of the conclusions of this study.

Reserves and Resources

Because there is an overlap in the meaning of these terms and because, even in highly sophisticated writing one finds "reserves" (multiplied by 2 or 5 as in "The Limits to Growth" 1972[2]) used as if this represented "resources", we should look first at the usage of these words in the context of ore reserve estimation.

The relevant (Oxford) dictionary definition of "resource" is: "A means of supplying some want or deficiency". Presumably the definition contemplates a hypothetical as well as an actual situation, i.e. a copper discovery would be a means of meeting a copper deficiency. "Reserve" is defined as "something stored up . . . or relied upon for future use". "The Limits to Growth", page 113, seems to emphasize the distinction with the phrase "resource reserves", i.e. the resource is the material and the reserve is the amount that can be relied on.

For example, Australia in 1945 was short of, or lacking iron ore, bauxite, copper, nickel, tin, manganese, uranium and tungsten. By 1975, all these except the last were known to be present in major to very large quantities. We would say then that in 1945 Australia had limited or no reserves of the eight materials named but it possessed a large potential of these. There was not only unawareness of this potential resource but Government decisions in the context of iron ore and bauxite showed that no such potential was envisaged.

Therefore resources can be known as well as unknown. The pyrite deposit at Dial Creek in Tasmania is a known resource of iron and sulphur which for economic reasons is unlikely to become a reserve in the foreseeable future. The known chromite resources (and reserves) of Australia are negligible. Any additional resources are unknown.

Reserves by contrast can only be known. As they are shown to exist in the ground, they represent an 'identifiable potential raw material supply'.[3] Part of the theme of this guide is to examine the several deductions, extractional, metallurgical, marketable and governmental, that have to be made in order to achieve an estimate of what the reserve will yield.

A reserve, then, is a resource on which investigational work has established a basis for decisions as to technological and economic feasibility. On Bougainville, it cost more than $A20 million to convert a geochemical hope into an economic venture. The work

---

[1] Paraphrasing Josiah Stamp, Ideals of a Student, 1933.

[1] J. T. M. Taylor, 1980. On being a mining engineer, *Trans IMM*, 89: A108.

[2] Meadows, D. H., Meadows, D. L., Randers, J. and Behrens, W. H. III, 1972. *The Limits to Growth* (Universe Books: New York).

[3] After W. Mackay, Woodlawn Mines.

may also indicate infeasibility as in Namosi, Fiji, where the result of $A15 million expenditure (1968-79) was a sub-economic grade at the scale of operations envisaged in the initial feasibility study. The estimate does not attempt to forecast results under different marketing, industrial or governmental conditions.

The resulting statement of ore reserves needs to be seen as dynamic, not static. Professional standards of how ore reserves should be assessed and expressed must be expected to change from time to time and with time; especially in low grade deposits, ore reserve estimates must reflect substantial changes in economic factors.

Accuracy and Uncertainty

The 1979 annual report of a successful and competent mining company quotes ore reserves of its subsidiaries. Three of these read

Mine A— 8 192 000 tons 0.174 ounce gold per ton,
Mine B— 27 251 000 tonnes 1.87% copper,
Mine C—152 533 400 tons 7.11% zinc.

Let us commence by looking at the scientific/mathematical meaning of figures as they are used in the guide and as they apply to ore reserve statements.

1. "The number of digits about which we feel reasonably sure is called the number of significant figures". (Physics, 1965)[1]
2. "A rough but extremely useful method of expressing the precision of a number is found in the number of significant digits. A number with three significant digits indicates uncertainty of somewhere between one part in a hundred and one part in a thousand". (Foundations of Physics, 1965)[2] This definition of precision is preferred for our purposes to that of close reproducibility as in chemical experiments.
3. "To write additional figures that have no meaning is worse than a waste of time. It may mislead the people who use these figures into believing them" (Physics, 1965)[1]

The ore reserve figures quoted earlier imply that ore reserves (in general we cannot speak of these particular reserves) can be estimated with an exactness, as to tonnage, of between one in ten thousand and one in a million, and, as to grade, of between one in a hundred and one in a thousand. By contrast, the Blais and Carlier comment and mining experience (both on p. 3) suggest that divergences between prediction and realization may reach and even exceed one in five.

Statements of ore reserves to three, four or even seven significant figures may therefore be over-precise (pseudo-precise) to the extent of one to five significant figures. They may contain, even conceal from some users, an uncertainty factor far greater than the figures suggest.

To put ore reserve estimation in some sort of perspective, in lieu of treating it as an exercise only for those well informed about a particular ore deposit, let us look at some other kinds of estimates.

First, the bank balance, exact to the smallest unit of currency, for the reason that the "reserve" is amenable to actual count. Next the quantity of water in a reservoir, determinable by measurement of water level. Here are two basic inexactitudes; the water level cannot be measured more closely than say 1 cm and the bottom profile may be known only from 50 foot contours. Nevertheless, as volume, the answer is directly derivable from the measurements.

At a different level of precision we might think of a company balance sheet, exact as to figures but necessarily inexact as to contingencies. Here we have precise figures for an imprecise situation. Any assessment involves judgement.

This brings us close to ore estimation, commonly also a precise statement of an imprecise situation, but here we have two new factors. The basic data are not obtained from measurement in toto but by sampling; and a new factor has to be considered, assessment of quality. In tonnage, range of sample values is usually small both in ore widths and in specific gravity (commonly in the range 2 to 5). In grade, quality is metal or mineral content ranging from an average of a fraction of one ppm (part per million) to more than 60 per cent, or 600 000 ppm. Moreover under some conditions grade is not uniquely determinable as composition but dependent on other physico-chemical factors. (In such instances, grade may be value per tonne rather than metal content per tonne. It may also be value in multi-metal ores where relative changes in metal prices affect the economics.)

Quantity is usually much simpler to estimate because it is based mainly on measurement, dimensions and specific gravity, leaving bulk density to be inferred. Though changes in estimates of bulk density may affect tonnage estimates by several per cent, quantity becomes critical only in relation to scheduled production in that certain tonnages should be available at particular rates which usually means in particular places. For these reasons the rest of this discussion will be concerned only with estimating grade.

The first point to be made about a grade estimate is that, because costs and tailing loss must be subtracted from metals in millfeed, the economics of an operation are disproportionately sensitive to grade. In a low grade copper mine where the cut-off may be 0.3% Cu, the difference in economic value between 0.7% and 0.5% mill head grade is not 7:5 but is 2:1. The second is that after a lapse of forty years,[1] it is still not widely enough appreciated that the mean value is merely one point on a

---

[1] Physical Sciences Study Committee, 1965. *Physics* pp. 35-36 (D. C. Heath: Lexington).

[2] Lehrmann and Swartz, 1965. *Foundations of Physics* (Holt, Rinehart and Winston: New York).

[1] King, H. F., 1950, Geological structure and ore occurrence at Norseman, Western Australia, *Australas. Inst. Min. Metall.* 156/157: 143 (Based on work done in 1940).

range of statistical probabilities. For example in a low grade lead deposit[1] where the range would be relatively small, a mean value of 5.3% was subject to a 2 in 3 chance (67% Confidence Interval) of between 5.0% and 5.6% and a 19 in 20 chance (95% Confidence Interval) of between 4.7% and 5.9%. In practice we would be concerned mostly with the chance of less than 4.7% mean grade. Leaving aside, for the present, the question of whether this degree of risk is acceptable, we must recognize that whilst it can be reduced (at a cost) it cannot be eliminated.

In practice the statistical spread is affected by three non-statistical factors, the drilling density, the proportion of the valuable constituent in the ore and the spottiness or inhomogeneity of its distribution. The lower the proportion of the valuable constituent in the ore the greater is the possible range of assay values.[2] In iron ore the range is from about 20% to over 70% in magnetite, in lead 0.5% to 25%, in copper 0.1% to 10%, in gold 0.1 gms to 1 000 gms. The greater the spottiness, the wider will be the spread of the assays over the range. In iron ore the most frequent assays will be around say 90% of mean value; in gold ore the most frequent assays may be less than 20% of mean value. Low proportion and spottiness tend to go together and a high proportion usually excludes spottiness. (The Mary Kathleen deposit is unique, so far as we know, in having both a relatively high proportion of the rare earth mineral allanite (which contains the uranium) and extremely large scale spottiness of the allanite.)

Fig. 1 illustrates the relationship.[3] It is significant not only in indicating the degree of risk in estimating grade but in identifying a geological factor in that risk; the concordant deposits (i.e. sedimentary and biological, indigenous) occupy the lower end of the scale of risk and the discordant deposits (i.e. migratory, exotic) the upper end.

Another factor needs to be considered in relation to a grade estimate; samples are not always all complete. In diamond drilling there is always some loss of core; an underground drive may expose only part of the orebody for sampling. The resulting incompleteness can be

1. ignored, i.e. taken as the average of recovered material,
2. taken as barren or
3. taken at some other value.

The value assigned will depend in part on the sensitivity of the average and of the estimate to lost core, a nil value obviously being the safest. In any event the value assigned depends on judgement not on a physical demonstration. Some part of the assigned value must inevitably be in doubt and, depending on core recovery, the doubt could represent say one percent to five percent of the metal content which in low grade deposits is significant. Core loss should therefore not be considered only in the aggregate, but as individual sections and the value to be assigned determined from the nature of the adjoining material and an informed guess as to the kind of material lost.

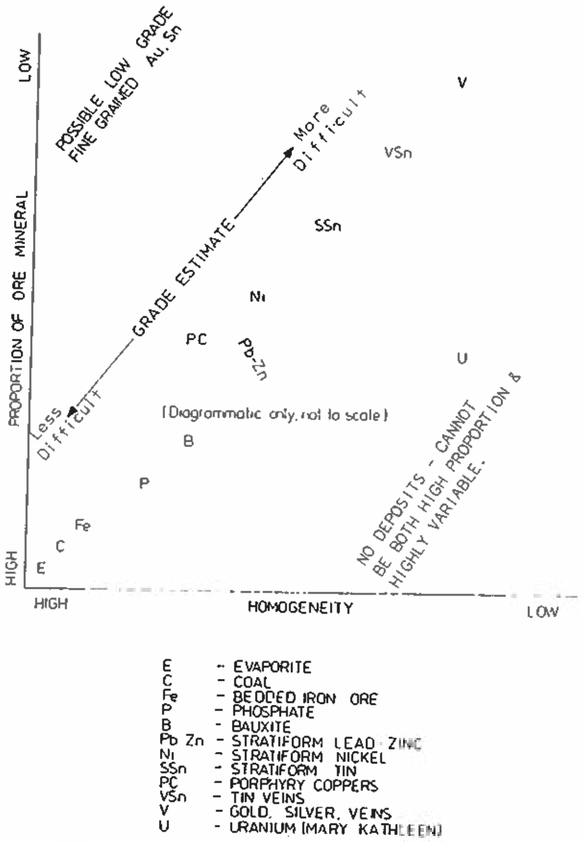


FIG. 1 — Proportion of ore mineral versus homogeneity.

By contrast with the ore reserve figures quoted at the start of this section, many Australian ore reserve statements are more realistically rounded. Yet there is still over-precision (not to be confused with overstatement) in such statements of grade as 0.43% copper, 9.6% zinc and 17.1 grams gold per tonne.

In such instances the stated figure is presumably that resulting from calculation, as it comes off the machine, perhaps slightly rounded. From such statements it is obvious that there is a view in the profession and in the industry that the user should be left to draw his own conclusions as to the uncertainty factor in these figures. The authors feel differently; the critical part of the estimator's responsibility is to assess, or at least in-

---

[1] Browns' Prospect, N.T., in King H. F., 1965. Estimation of ore reserves in Exploration and Mining Geology, Volume 2 (Ed. L. J. Lawrence) p. 296 (Eighth Commonwealth Mining and Metallurgical Congress: Melbourne).

[2] Further increased by compositional factors, e.g. sphalerite (Broken Hill) 52% Zn; galena 86% Pb; gold 100% metal.

[3] A similar diagram prepared independently by R. Cooke of Rio Tinto South Africa was produced at an RTZ conference in London in April 1979.

vestigate, the range within which the answer may lie, i.e. to estimate rather than merely calculate.

There seem to be two approaches available toward putting a value on the range that should be contemplated. In another field, that of structural engineering, which likewise relies on testing of small samples (and judgement of strength of riveted and welded joints), the safety factor used is commonly about three to four times. In ore estimation one approach is via statistics which in the form of "geostatistics" offers a measure of the accuracy of an estimate. However, it is necessary to realize that the answer refers only to the figures available, and not to the deposit, i.e. the answer cannot allow for the influence of assumptions and judgements made in relation to core loss, unrepresentativeness and other factors.

Even however if the answer, i.e. the range of probabilities, is regarded as applying to the deposit, the user still has a difficulty. The situation being estimated will not be repeated 20 times or even 3 times, it is almost certainly unique. Moreover a 1 in 40 chance of a result below the relevant confidence level may not be economically acceptable. There does not seem to be any easy answer to the question of what shortfall (at this stage on purely statistical grounds) should be contemplated for this particular deposit at its estimated grade.

In addition to the shortfall that should be contemplated on statistical grounds, there are other factors that could lead to divergence from the mean. Again we need be concerned only with adverse movements. We might look at three of these.

1. Assaying. We know of an instance where there was a difference of 0.02% copper, with control assaying being the lower. This is small and possibly unresolvable but in a low grade copper ore, it may represent a significant proportion of the copper content.
2. Lost core. If the lost core has been taken in at some value, some part of this must be in doubt.
3. Geological factors. Some of these are represented by Fig. 1. These may guide a judgement as to whether the deposit is high-risk or low-risk and what figures should be attached to the doubts. It will be found that in low-grade deposits the aggregate effect of the statistical probabilities and values attached to other uncertainties is not negligible. We suggest that the estimator is best placed to suggest what these qualifications should be and that such an estimate, albeit subjective, is preferable to ignoring these possibilities.

   However, it is no more possible to make a precise estimate of risk than it is of grade and therefore the judgements that must be made should be fully informed as to the factors involved. Adoption of a single figure for purposes of calculation at some stage is unavoidable but the fact that it is only one point in a range of possibilities should never be lost sight of.

Having looked at the various approaches and limitations to grade and tonnage prediction, let us now turn to the ultimate test of ore reserve estimation, reconciliation of prediction with realization. This is not as easy as might be thought.

The crudest comparison but financially the most important is departure from "plan", especially planned grade. Since however operations do not conform exactly with plan, the reconciliation involves allowances for many factors such as, mining different from plan, extra or less dilution, grade of material delivered by mine to mill not always exactly known, material stockpiled or used as fill, mill weightometer not exact within some percent, tonnage of unknown grade tied up in stopes, ore passes, and ore bins, moisture content of concentrates, etc.

As a result, the grade of the part of an ore deposit mined during a particular period can never be known exactly. The imprecision is probably between one and some percent, smaller differences not being significant. The inability to predict grade exactly should be kept in mind in relation to sales contracts, debt repayments and similar obligations.

In large deposits such as bauxite and iron ore which would fall into the lower corner of Fig. 1 and where drill hole samples may be numbered in hundreds rather than tens, the inaccuracies may be quite small. Hamersley experience is that with drilling at 30 m spacing, expectation: realization may be as close as 100:97. However, in most mining situations where the deposits would lie further up the scale of risk on the diagram, and where the number of samples may be restricted for reasons of depth and cost, the economics of an operation should allow for a possible shortfall in grade of say, at least ten percent.

Finally we must ask ourselves why is the discrepancy in grade usually adverse especially since, in the broader field of ore occurrence, it is common to find more ore than could have been expected or predicted at some earlier stage. Australian instances of this are the orebodies of the Zinc Corporation, Broken Hill, which proved to be much shallower and larger than could have been expected; the "A" and "B" lodes, New Broken Hill Consolidated, developed in a part of the Broken Hill deposit which had been drilled inconclusively; the Mount Isa copper bodies which proved at two stages to be better than they could have been expected to be. Central Norseman, Renison Bell, Mount Whaleback and Paraburdoo all proved to be more productive than they were expected to be in some view at some stage. Yet it is so rare for an ore reserve estimate to understate grade that we know of only two such instances in Australasia; Bougainville where at least two identifiable factors[1]

---

[1] Loss of sulphides in early diamond drilling and failure of the vertical drilling pattern to intersect some small high grade vertical breccia pipes.

resulted in upgrading in the first few years; and a recent gold mining operation in Western Australia where diamond drilling resulted in poor core recovery.

In gold mines it used to be thought that grade was exaggerated by "erratic" high assays and consequently these were cut back severely. Even when the statistical element came to be appreciated, it was thought that somehow the number of high assays was greater than it should be. This cannot of course explain shortfall in say the Broken Hill mines, where the frequency distribution of assays is much less skewed but where nevertheless milling results yield only about 90 and 85 percent (lead and zinc, respectively) of the grade estimated from drill hole assay values.

The answer to our question, we feel, must lie in the imponderables and in the human element in the estimation procedure. For example, a successful drilling campaign ends, as already mentioned, on a high note, not on a low. Interpretation of drilling results is commonly more favourably disposed towards the better alternatives. Experience has shown that some traditional computational procedures may have a positive bias. Dilution, perhaps the most important of the judgements, is often greater than estimated because in production the emphasis is on tonnage and in many underground operations miners are paid for tonnage mined, not for ore extracted. Some other factors will be discussed in later sections but the tendency for grade to be less than estimated reinforces the need already foreshadowed for an estimate to be based on experience as well as assay data.

Representativeness and Reliability

In the preceding section we have looked at what is known and thought about accuracy of prediction attainable from a given set of data and assumptions. The result is regarded as amenable to independent reproducibility. Now in following our plan of increasing depth of examination, we need to look at the data-base itself, not necessarily reproducible, remembering that if this is not adequate or representative no estimational procedure can make it so.

The data will be derived from sampling, manual sampling of sub-surface exposures and drilling of various kinds, diamond core drilling, percussion drilling, rotary drilling. All of these have their weaknesses in relation to completeness and representativeness of the material recovered. Fig. 2[1] illustrates a major geological factor in representativeness. The general aim of evaluation is to make the result secure against the possibility of substantial surprises, especially adverse, which may require trying to visualize what could go wrong in an apparently straight-forward interpretation. The conclusions will be based on analysis and interpretation of a set of samples equivalent in the aggregate to perhaps one ten-millionth of the body being studied. Avoidance of bias is therefore paramount. It is important also that all available information should be utilized, e.g. supplementary drilling should not be overlooked in ore estimation merely because it was done primarily for metallurgical or engineering purposes.

Fifty years ago, before the statistical nature of ore samples was appreciated, attempts to achieve representativeness centred on the well-taken sample. In sampling the "ore in sight" extraordinary efforts were made to avoid bias in location, disproportions in content of hard and soft material and contamination of any kind at any stage. In sampling for a buyer, the sampling and the samples were typically never out of sight of the engineer until they were locked away in the assay office.

By contrast, we have formed the impression that, now that such close personal supervision is no longer feasible, the critical sampling stage is sometimes taken too lightly. Looking first at the more inconspicuous (and more likely to be taken-for-granted) procedures, it should be borne in mind that contract drillers are paid for footage, not for care in sampling, so that handling of core and cutting should not go unsupervised. Then, there are at least three stages of sampling, splitting of core, crushing and reduction of sample size, grinding and selection of portion for assay, which together reduce bulk to say 1/10 000 of core, none of which can yield a unique result.

It is essential that particle size should be reduced before any reduction in sample weight and that sufficient independent checks should be made to establish freedom from significant bias. Two examples will suffice. The first, a recent porphyry copper assessment found that between the assays of its own laboratory and those of an operating porphyry copper mine there was an average difference of 0.02% Cu. A negligible difference under most conditions but not negligible where grade was estimated to 0.01% Cu and where 0.02% Cu represented five percent of the average copper content of the ore.

The second, splitting of drill core in ZC/NBHC, Broken Hill is done by hand, i.e. somewhat roughtly compared to splitting by diamond saw. The differences between assays of the two halves are greater than expected and comparison of assays from the two halves suggests more careful splitting of lower grade intersections.

Supervision and care are as important today as they were when they were thought to be the total approach to an accurate estimate.

A major factor in this reliability aspect is the nature of the sampling programme, i.e. numbers of samples and completeness combined with locational and attitudinal relationships to the ore and lithological pattern.

---

[1] Contributed by Dr. D. H. Mackenzie, CRA Exploration Pty. Limited.

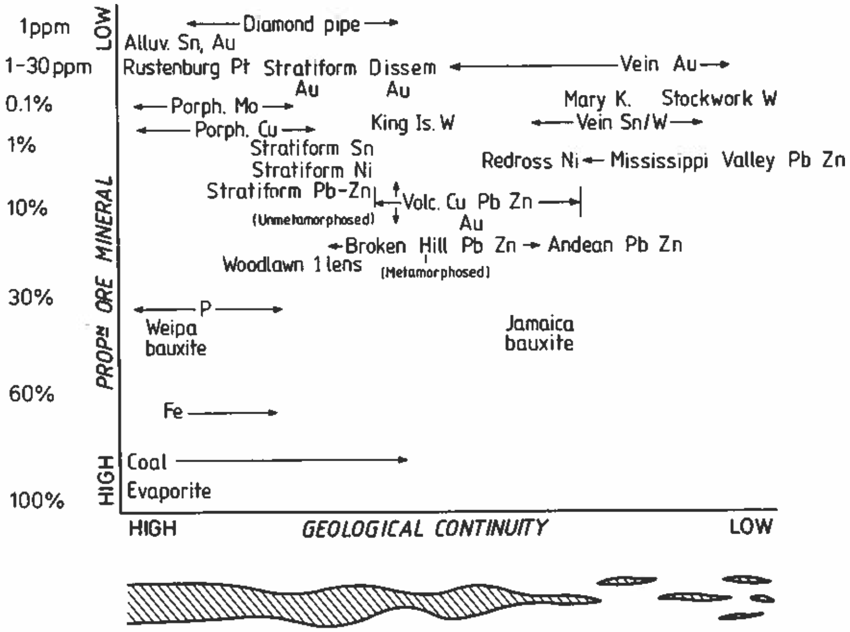


FIG. 2—Ore mineral versus continuity plot.

The numbers of samples or sampling points, e.g. drill holes, is usually what is thought to be appropriate or feasible or affordable. It is seldom what would be chosen after the character of the mineralization is known. In this particularly subjective realm the factors which tend to limit the number of samples are many; a viable result has already been indicated, why do more?; avoiding delay in making decisions; avoiding increase in pre-production costs. Yet it is easy to see that some of the difficulties which some new ventures have had to face have been due, in hindsight, to inadequate sampling, to having stopped exploration too soon. The study has shown that even in some large and other-than-precious-metal orebodies current ideas of 30 m and 60 m spacing as close drilling may not be close enough to give a reliable estimate of grade or establish physical continuity. Differences in assay and mineralogy therefore deserve closer attention than they ordinarily receive.

Statistical analysis will provide an assessment of whether, on statistical grounds, in relation to the statistical character of the sample population, the number of samples is adequate. In lieu, or perhaps in addition, we would hope that this guide will provide an indication of the level of knowledge required for estimation of ore reserves. Working backward from this may yield a useful if subjective answer to the question of sampling adequacy.

Location of sampling sites is likewise usually determined by an early selection of drilling site and spacing which, once established, would be changed only with great reluctance. The reasons for this are good. For most purposes, from estimation to mine planning, the sampling results should be amenable to representation on plans and cross-sections with a minimum of uncertainty due to the projection of drill holes onto plans or cross-sections. This means systematic testing with as nearly as possible uniform spacing and direction of drill holes. Random data can be utilized, especially with computers, but the result is more difficult to understand and to visualize and to use for planning purposes.

Completeness is variable. In underground workings, partial exposure for sampling is common, and systematic complete exposure rare, principally because the openings are designed primarily to serve extraction, not ore estimation. In drilling, transverse completeness (except for lost core) is easily achieved. Whilst full core recovery is rarely attained and a high core recovery affects speed and cost of drilling, the emphasis should be on the loss rather than on the recovery. A recovery of 90% leaves metal content of 10% of the deposit suppositional.

Fundamental to this question of reliability is the attitudinal relationship. In most steeply dipping (or plunging) ore deposits a large angle of intersection with the trend of mineralisation (and in some cases also with the lithological pattern, as in Fig. 3A) is regarded as essential. In some deep mines many hundreds of metres of driving and cross-cutting costing hundreds of thousands to millions of dollars are done merely for establishing drilling sites which will yield a large intersection angle.

One reason for preferring a large angle is that the sample should indicate mineable width as well as grade. An intersection at right angles gives "true width" directly; up to 45 degrees the intersection indicates true

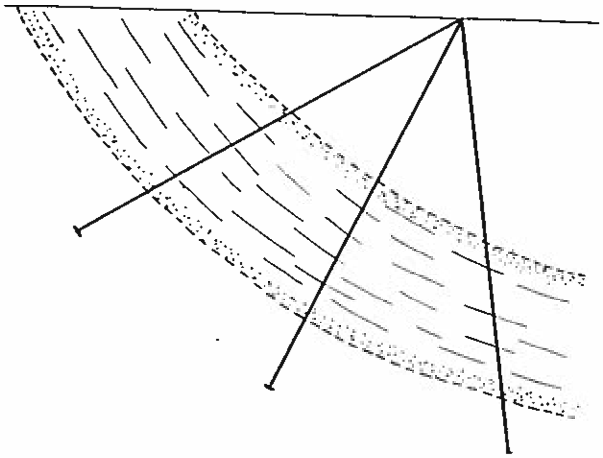


FIG. 3A—Large angle of intersection yielding samples representative of what may lie between drill holes.

width within say a range of 2:1; below 30 degrees the core length of the intersection ceases to be an indication of width and the sample no longer represents anything corresponding to the ore face that would be exposed in development or stoping.

Therefore where, as in Bougainville (Fig. 3B), topographic feasibility as well as custom dictate a vertical drilling pattern on a steeply plunging ore deposit, steeply plunging both as to (most) veins and all lithological boundaries, one is doing the kind of drilling that in, say, Broken Hill or Mount Isa would be regarded as useless in evaluation. At this point however numbers become important and in the event it is known that Bougainville had a sufficient number of sampling points to yield a satisfactory estimate.

This was not altogether so, however. With both the drill holes and the lithological boundaries being vertical, and some rock types being low grade or barren, the internal ore:waste ratio was subject to significant uncertainties. In addition, the vertical drilling pattern missed some small vertical breccia pipes which proved to be high grade.

Ideally, in retrospect and economics permitting, a deposit like that at Bougainville would be best tested from underground by a pattern of parallel horizontal drill holes aimed to intersect veins and lithological changes at optimum angles thereby providing good horizontal sections of the steeply plunging deposit. The justification, timing and economics of such a test might all be difficult. Mount Charlotte, Kalgoorlie, (as another disseminated deposit consisting of a swarm of veins, but gold-quartz), assesses ore reserves by parallel underground drill holes inclined and directed to yield an optimum intersection of the vein pattern.

An outstanding example of the attitudinal factor occurred in Broken Hill. A 1948 attempt to test the deposit 600 metres (2000 feet) south of the then most southerly workings encountered an unexpected change of dip which made two deep drill holes ineffective and inconclusive. The section was not immediately or systematically re-drilled from the opposite direction (diamond drilling being slow, expensive and, on this experience, of doubtful value) and the ore position was not cleared up until suitable underground drilling stations became available about ten years later.

A minor but unfortunate example of the same thing was Redross[1] where the drilling, good attitudinally and regarded as close, did not provide a sufficient number of intersections to indicate the variability of width, i.e. the drilling results were not representative and another similar campaign could conceivably have yielded a different result.

Thus in appraising an estimate of ore reserves we are not merely or even principally concerned with the calculational steps but with the inbuilt assumptions and judgements and with the geology on the broadest basis that can be visualized.

It follows that a 'quick look' at an ore reserve estimate is almost worthless.

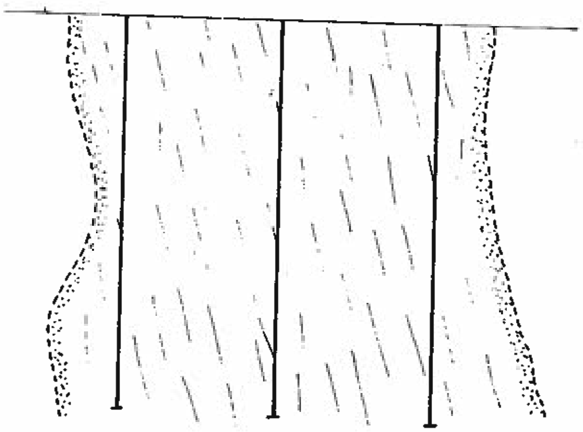


FIG. 3B—Small angles of intersection yielding samples not representative of material lying between drill holes.

In Situ and Recoverable

With two exceptions in recent years, Mary Kathleen and Bougainville Copper,[2] ore reserves have been traditionally stated as so many tonnes of such and such a metal content. Insofar as the statement is intended for the information of a user, he is left to work out what part of this is realizable.

The distinction between the two forms of estimate is that whereas the "in situ" estimate depends chiefly on sampling, assaying and geological interpretation, the "recoverable" estimate involves also factors like the choice of a mining method, judgements or predictions

---

[1] a small nickel deposit, W.A.

[2] where ore reserves are stated as recoverable product and recoverable ore respectively

on recovery (of ore in mining, and of minerals in milling), dilution, of the presence of contaminants and of the effects on production of such non-technical factors like environmental constraints.

During the period of this study, a conclusion has been reached by the Joint Ore Reserves Committee of The AusIMM/AMIC[1] that ore reserve statements should specify whether they were in situ or recoverable, with a preference for the latter.

The introduction mentions that this distinction is shared also with coal and oil reserve estimation. In coal, the substantial proportion that has to be left for roof support is increased by the difficulties of mining adjacent seams and further increased by prohibition of mining within certain slope angles of surface installations and under National Parks, to the point where the in situ tonnage is no longer a significant figure. In oil, the emphasis is on estimation of pore space and on the proportion of this (commonly about one third) that can be emptied. Even in metal mining, where in situ and recoverable reserves are usually much closer, we need to recognize that an overall tonnage/grade estimate may be of limited value.

Exceptions are where grade is high enough to allow the poorest material within ore outlines to be mined as ore rather than waste; and in iron ore mining where the day to day requirements of blending and of producing a planned, rather than maximum, metal content make a forecast of mineable tonnage inappropriate.

In the more common situations, especially open-cuts, production will not be from the deposit as a whole; mining will commence in accessible or developed areas, therefore we are interested in the grade (and/or the tonnage of ore as distinct from waste) in restricted areas or blocks. The question of grade determination of these blocks can be left for later discussion but in estimation the distinction between in situ and recoverable reserves should be pursued to the point where an estimate is convertible into a schedule of production, and to where possible short term variations within the overall estimate can be seen. In a different field, insurance companies are very sensitive to similar short term departures from an overall estimate.

The principal factors in the conversion of the in situ to a recoverable reserve may be identified in the following.

1. Cut-off grade, i.e. deciding what portions of the deposit should and can, by reasons of width or metal content or location, be excluded from the production plan. (A cut-off may also have been used at the in situ stage.) In this sense, cut-off grade is not an operating control, it is a planning decision and also an assumption regarding metal prices for a period of commonly some years needed to prepare and mine out a stope. However cut-off grade can also be used as an economic operating control concept in both surface and underground operations; it can be decided not to mine a particular stope where the grade is below a revised cut-off grade.

   The stope outlines for large long hole stopes often require the inclusion of below cut-off grade material. The inclusion of this material therefore increases the tonnage of the ore reserve but decreases the grade.

   Often the concept of cut-off grade does not help in the understanding of the orebodies. In these cases it imposes a totally alien concept on the geology. The element of time is as much a variable as mineral chemistry in determining cut off grades, i.e. as far as practicable, any chemically or spatially marginal material which could conceivably be mineable, should be tested and in some cases possibly even developed prior to production planning.

2. Percentage mineability. Depending on ground conditions, mining method and grade and geometry of the orebody, an appreciable proportion of the ore in an underground mine may be tied up for long periods or permanently in pillars. In addition, in discontinuous deposits, small portions of the ore deposit may not be economically reachable.

3. Dilution comes in two principal forms, barren or low grade material from outside the ore outlines and, especially in open cuts, internal waste incompletely eliminated in mining. A third form of dilution is from fill in underground filled stopes, partly unavoidable and partly uncontrollable.

   In addition there is a statistical component of dilution. The ore reserve estimate is based upon drill samples, whilst the production grade control is based upon complete stopes or sections of a blast. This results in below cut-off material as identified by the drill sample being included in the reserves as measured by the stope or blast.

   Estimation and realization depend not only on the closeness of drilling but also on the judgement, experience and skill of estimator and operator and also on the size and availability of equipment. It is natural perhaps that dilution is invariably underestimated and grade to mill is over-estimated.

   In addition to displacing ore from the mill feed, dilution has a secondary effect. Since any particular mill-ore combination tends to yield a stable tailings assay, an increase in dilution tends to reduce not only the grade to mill but also the percentage recovery. In addition, increased dilution may adversely affect the nature of the millfeed. Both factors may further depress the output of concentrate.

4. Grindability. In the course of the study the quality of grindability appeared as a factor in ore reserve estimation. Variations can affect throughput and thereby, in effect, cut-off grade.

---

[1] Reporting of Ore Reserves, Report of the Joint Committee of The Aus.I.M.M. and AMIC March 1981. Published by The Aus.I.M.M.

At this stage ore reserve estimation commences to merge into mine planning. The reserve data not only provide the basis for mine planning but should be available in the form required for planning purposes, i.e. this phase of the estimate should be done with an appreciation of the needs of the planner. In practice, the planner should be involved in the conversion of in situ to recoverable. A need for additional drilling may appear at this stage with possible consequences on the reserves already estimated.

A tacit assumption made here is that metallurgical recoverability is well established.

The Early Years

Implicit in the preceding section, but important enough to be given separate treatment, is the question of prediction: realization during the early years. It may be useful as well as obvious to mention that if this is not good enough, the accuracy of the overall estimate may become (for the operating company) purely academic. These years are so crucial that there is a case for considering special testing of the ground to be mined during the first, say, five years, which may correspond with the pay-back period.

This arises partly because there is a natural tendency, on the grounds of time and cost, to stop drilling when a viable tonnage/grade appears to have been reached. If the tonnage/grade result should be marginal, additional drilling may be done in the hope of improvement, but drilling merely to confirm an apparently viable result is unknown to us. In the course of this study we have learned of two instances, South African[1] and Swedish,[2] where confirmatory drilling would have provided critical information.

Adequacy of sampling is one of the aspects of ore estimation that is geostatistically regarded as amenable to mathematical evaluation. In the context of early years performance we would suggest that the need for maximum information about the early years extraction is, in addition to the minimum drilling density, required for a mathematically acceptable overall estimate. Closer than average testing of the early years portion of the deposit is worth considering. Statistically this is equivalent to raising the confidence level in the general as well as the statistical sense.

At this point it is no longer sufficient to assume satisfactory metallurgical recovery. Just as it is necessary to have better-than-average estimation of grade and mineability, so it is necessary to have better-than-average assurance of metallurgical performance.

The Later Years

Conversely, there appears to be no need for the rest of the deposit to be equally well tested. Its importance is as potential (e.g. it was the existence of a large potential at Bougainville that made possible the large-tonnage concept that conferred viability) but beyond say ten years changes in metal prices, and other factors, make close estimation of grade less important.

Therefore it seems that in the evaluation of a large deposit the closer testing of the early years ore could be accompanied by less stringent testing of the later years ore. This suggestion of differential degrees of testing has much in common with the traditional distinctions of "proved", "probable", "possible" with the difference that in lieu of reporting how much of the reserve is "proved" it would indicate how much should be proved, again having some relation, as in the preceding section, to the pay-back period.

A variant of this appears in iron ore mining where, in an ongoing operation and for operational reasons, it may be necessary to treat a body of iron ore as a reserve, and to incur preliminary expenditure to facilitate future mining, many years before it can be known to be economic.

Metallurgical Recoverability

Two metallurgical factors have already been mentioned under 'In situ and Recoverable'. This section together with the section on 'The Early Years' suggests the need for explicit recognition of metallurgical recoverability as a factor in ore reserve estimation. Except in the instance of Mary Kathleen where, as already mentioned, ore reserves are stated in tonnes of recoverable product, this factor has not yet made an overt appearance in ore reserve estimation.

This brief section is intended to make two points, first that the use of the term reserve assumes and should imply that the valuable constituent is economically recoverable, and second, in relation to the first few years of an operation, that recoverability is assured, since in these years there may not be time to cope with unexpected metallurgical problems.

Acceptance of this further widens the reach of ore reserve estimation. Instead of being, as it so often is, a matter of dimensions and grade, it becomes an assessment of the whole production process from in situ definition to separation of a saleable product.

---

[1] Anon., 1980. Ranfontein mine, *The Miner Newspaper*, Jan. 21-Feb. 3.

[2] Anon., 1978. Stekenjokk Mine, *World Mining*, 31(4).

Geology in Ore Estimation

If one could achieve, either on the basis of much more sampling or of much greater predictive ability, a complete three-dimensional interpretation of the internal features of an ore deposit, ore reserve estimation in situ would be a straightforward calculation. Iron ore density of drill hole testing with hole spacing being equal to or less than ore thickness approaches this simple situation but in less favourable circumstances a 10 to 1 to 30 to 1 ratio of hole spacing to ore thickness has to be accepted. Alternatively it may be necessary to accept, even for topographical reasons, a difficult attitudinal relationship. In practice therefore there is usually room for unexpected developments between drill holes.

In the course of the study it is the geological factor that has impressed itself on us more and more as being the key deficiency where serious weaknesses in ore reserve estimation have appeared, especially in grade. In case this conclusion should look like someone pushing his own (former) barrow, it may be mentioned that one of the authors is not a geologist and that the others reached that conclusion only in the course of this study, having for most of their professional life been concerned with the large-scale rather than small-scale features of ore occurrence.

In venturing to take the reader as untediously as possible through the geological complexities affecting ore reserve estimation we should first look at the forms and characteristics of some typical ore deposits.

For a start, let us contemplate five classes of ore deposits,

1. veins, composed of migratory material, as in say Bendigo, Norseman or Aberfoyle, which are important sources of gold, silver (especially in the Americas), tin, wolfram, and only rarely of base metals,
2. stratiform bodies, conforming with the layering of the rocks and now thought to be of about the same age as the enclosing rocks, are the principal sources of lead and zinc (Broken Hill, Mount Isa), and important sources of iron (as hematite, Hamersley), copper (Mount Isa) and manganese (Groote Eylandt),
3. massive and/or disseminated bodies, consisting of veins and other disseminations in otherwise barren rock, are important sources of copper (as porphyry coppers, world wide), molybdenum (North America), diamonds (South Africa and perhaps also Kimberleys, WA). Mount Charlotte, Kalgoorlie, is an important gold orebody of this type,
4. surficial deposits, formed by weathering processes at the present or a former land-surface—bauxite, lateritic nickel, some deposits of iron, uranium and manganese, and
5. alluvials, stream deposits in present or former drainage channels, important or major sources (past and present) of gold (California, Klondike, Victoria) and of tin (Malaya). Beach deposits of gold (NZ) and rutile (Australia) are of similar detrital origin.

This guide will discuss principally the first three, chiefly because the fourth and fifth are of more limited, if not of lesser, interest. In the fourth class, evaluation is facilitated by a near-surface location and attitude which make close sampling feasible. In the case of bauxite which, because of a high proportion of valuable constituent falls into the lower part of Fig. 1, spottiness remains a problem in prediction of average grade. In the fifth, securing a fair sample of the granular incoherent material is recognised to be as much an art as a technique and one that has to be learned rather than adopted.

The first of the five classes of ore deposits includes most of the classical mines of earlier times, Germany, Cornwall, North and South America and Australia. Being formed of migratory constituents, somehow arrested or captured during their passage along fractures or openings in the rock, they have no genetic tendency toward areal uniformity or persistence. Moreover, the mode of origin leads to a coarse crystalline texture which results in the valuable material being spottily rather than evenly distributed through the vein, both along and across its three dimensions.

As ore deposits, veins are individually small; in Western Australia a one million tonne vein deposit being unusually large. Their mineralogical make-up may make them difficult to sample, e.g. hard quartz and brittle cassiterite. In addition, being relatively narrow, they are commonly subject to substantial dilution. For all these reasons, veins are usually difficult and, in relation to tonnage, expensive to evaluate.

The bodies forming the second of the classes, for long regarded as differing from veins only in attitude toward the enclosing rocks but now thought of as being approximately contemporaneous, are typically larger than veins in all dimensions. By reason of their mode of origin they usually also have a much greater areal uniformity and lateral persistence. Therefore as lead and zinc producers they tend to be large (Broken Hill say 200 million tonne of ore from six layers) and, as iron ore producers, much larger (Mount Whaleback in excess of 1,400 million tonne, Mount Tom Price in excess of 600 million tonne). Having a moderately to extremely large proportion of the valuable material, they are less difficult than veins to sample and evaluate.

The third class of deposits includes the porphyry coppers which are also large in all three dimensions (and commonly in excess of a hundred million tons) and therefore provide a very large data-base for evaluation. Though metal content may vary significantly in sympathy with lithology, they are not spotty. The metal tends, however, to occur in swarms of thin veins and this, combined with low average grade, makes porphyry coppers difficult to evaluate to the precision demanded by economics. Molybdenum deposits are similar but even lower in metal content. Diamond bearing pipes present the most difficult evaluation of all in having an extremely low proportion of the valuable constituent, and being extremely spotty and highly variable in product value.

Tabulating some of these metal proportions, we have;

Metal or mineral	Percentage of element	Percentage of mineral
Diamond	1/50 ppm[1]	same
Gold (in veins)	5 to 10 ppm	same
Tin	0.3% to 1%	0.5% to 1.5%
Copper	0.5% to 3%	1.5% to 10%
Nickel	1% to 4%	5% to 20%
Lead plus zinc	10% to 20%[2]	15% to 30%
Iron (high grade)	60% to 65%	85% to 93%

[1] One-fiftieth.

[2] In Australia. Overseas mining grades are much lower.

Spottiness (or inhomogeneity) is best expressed by the curve of frequency distribution of assays. A "normal" frequency yields a bell-shaped curve in which the greatest frequency coincides with the mean value and where the diminishing numbers of high and low values are equal. Frequency distributions in ore are usually skew, depending on three factors.

1. The character of the valuable constituent. If this is hematite with a theoretical iron content of 70% and if the poorest material included in the ore outline is 20% Fe, the possible range of assays is 3.5:1. With copper the range is likely to be 100:1. If the valuable material is gold, the possible range is infinite and the range that may be encountered is several thousand to one.
2. The spottiness of the ore. In iron ore where the minimum economic grade (direct shipping) is about 60% there physically cannot be much intermixed low grade material. In copper, 90% to 99% of the material at particle size is barren. In gold, more than 999,900 ppm (say) are devoid of metal.
3. The limited size of the sample. With samples of around 1 kg the tendency in the leaner ores is to find more low than high assays (despite an equal tendency to overstatement of grade). In a spotty gold ore, the lowest category of values may form the largest group. Drill core samples are in this size range and consequently reflect this distribution even within ore outlines.

Combining proportion and spottiness yields Fig. 1 expressing in qualitative fashion the relative dependability (representativeness, accuracy) of an estimate of various kinds of ore. Therefore it is possible for the maker or the user of an estimate to know without mathematics whether he is in a low-or high-risk ore type.

The degree of risk may also depend on inhomogeneities of other kinds, related to larger-scale features of the geology.

For example in porphyry coppers there is commonly an association between lithology and higher or lower metal content, making interpretation of lithological outlines an essential ingredient of ore estimation. In layered deposits, there is commonly a pattern of strong and persistent contrasts between adjoining layers. These latter are keenly studied when they offer stratigraphic marker horizons but as ore layers they are usually lumped together into a stoping width.

Unfortunately for ore estimation, it straddles, often uncomfortably, a gap between mining engineering and geology. The former, as the technical basis of production, is concerned with dimensions and grade. The latter in its exploratory form is concerned with the external characteristics of orebodies. Thus an estimate via the engineering route will be short on geology and one via the geological route will be short on the internal geology of the orebody which is important to engineering. Ore estimation may therefore be seen, if one is so inclined, as a bridge between mining engineering and geology.

Thus it has become evident in the course of the study that ore reserve estimation (in situ) is in part a facet of ore geology, that it requires an extension of mining geology to the internal character of an ore deposit and that, for these purposes, dimensions and grade are no longer enough. Studying of drill core should furnish a basis of between-hole correlation at least equal to assays. So far as possible it should anticipate the needs of mining and metallurgy at both the planning and production stages. It should recognize for example that metallurgical test results based on ore samples may not represent those from mill feed which will contain an admixture of internal and adjacent rock-types. A mine manager experienced in ore reserve estimation[1] has suggested that diamond drill core should be logged by the mining engineer and metallurgist as well as by the geologist.

Procedures of Estimation

Much of the prickliness of ore reserve estimation centres around the procedures employed to assess reserves and especially grade. It may help to get this aspect into perspective if we remind ourselves that, if sample spacing could be sufficiently close (for example, the bottom contour of a reservoir is the equivalent of an infinite number of depth measurements) estimation would be a matter of simple arithmetic.

Nothing approaching this is feasible in testing an ore deposit. It may help to be explicit about this factor. Where drill hole spacing is 400 feet (122 m) and core diameter is 1½ inches (38 mm), we know, more or less, the character and metal content of ¾ inch (19mm) laterally at the site of the drill hole and have no samples

---

[1] The late M. R. L. Blackwell, Woodlawn.

of the intervening 4798.5 inches of untested ground. In the most closely tested deposit known to us (Mary Kathleen), a drill hole spacing of 50 to 100 feet still tests only 1 in 1,000 to 1 in 2,000 of the area of the orebody in longitudinal projection. Even where, as in Redross, there is confidence in the geological continuity of the mineralization between holes, a 30 to 1 ratio of drill hole spacing to ore thickness leaves plenty of room for changes not indicated by the 200 foot spacing of drill holes.

Estimation procedures are therefore the means of 'fleshing out' the slender skeleton provided by the sampling (usually in terms of metal content though in some instances recoverable or net values may give a better measure of economics). In general the closer the sample spacing the less important the procedure; the sparser the data the more critical the procedure, not only quantitatively but also qualitatively because of the greater dependence on subjective assumptions.

An appreciation of the nature of estimation procedures may best be obtained by looking briefly at seven different methods, each involving its own assumptions.

1. **An old style approach** (Fig. 4) in which the samples are lumped together for calculating average grade and width. This simple and crude procedure is in effect the one principally used in estimating from underground openings (drives, rises, etc). In exploration, the method may be used in early stage judgements of whether the deposit is in the grade range appropriate for its size and character. In its traditional form the method assumes that each sample represents width and grade halfway to the next sample. Statistically this is equivalent to treating the samples as random. Regular spacing is the approach to avoidance of bias.
2. **The polygonal method** (Fig. 5) in which, in suitable instances, each drill hole is at the centre of a polygon bounded by median lines within which, for purposes of the estimate, thickness and/or grade are assumed to be uniform. The assumption is obviously unreal at the boundaries of the polygons and, as will be mentioned later, may in practice be arbitrarily modified where thought to be necessary. The method has a disadvantage in giving greater weight to isolated holes.

   It will be seen that by comparison with all other methods, assay values are used only once. A variant of this polygonal method using the holes as corners of the polygon is mentioned again below.
3. **The triangular method** (Fig. 6) in which each hole is taken to be at one corner of a triangle, or a number of them, with width and grade of the block assumed to be equal to the average of its three corner holes. In this we see two new steps; more than one hole or sample is used to value a particular block and the samples are used more than once.

   That the samples may be used an unequal number of times is part of the fringe problem; how far should ore be assumed to extend beyond an outside hole, or opening, in ore. This problem is common to most procedures.

   A polygonal variant of this multisample method would differ only in using larger blocks and more than three samples per block.
4. **A sectional method** (Fig. 7) in which dimension and grade between two (e.g. drilled) sections are assumed to be equal to the mean of the sections. A larger number of holes is used to value an individual block and again the assays are used more than once.
5. **A contouring method** (Fig. 8) yielding areas (and thereby volumes) of differing grades. It assumes continuity of values between drill holes or blocks of similar grade and is basically a means of deriv-

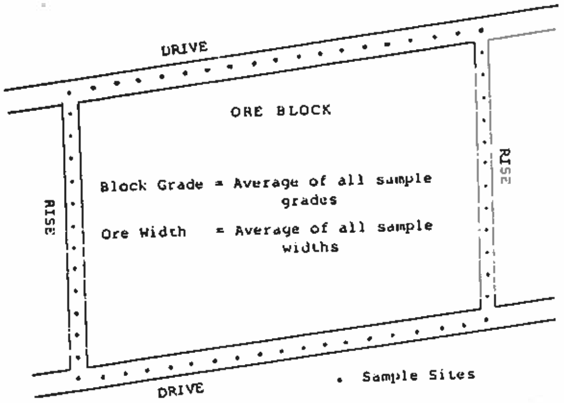


FIG. 4—Old style approach.

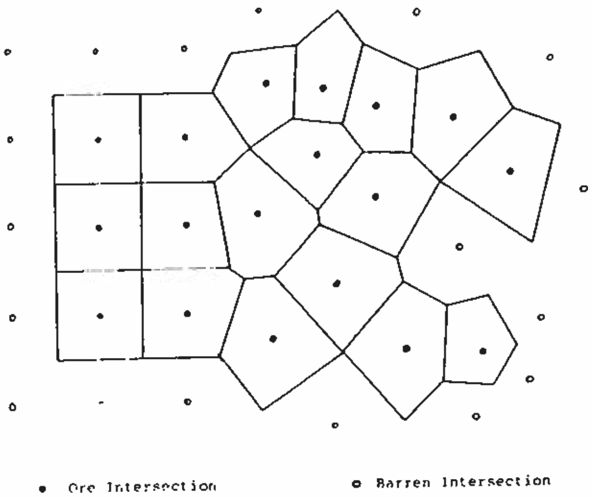


FIG. 5—Polygonal method.

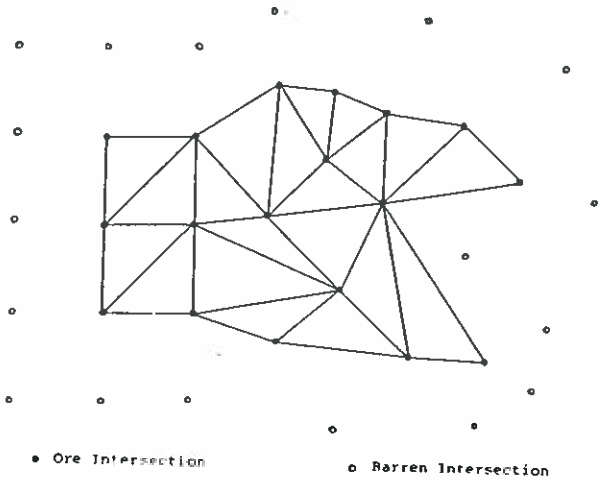


FIG. 6 – Triangular method.

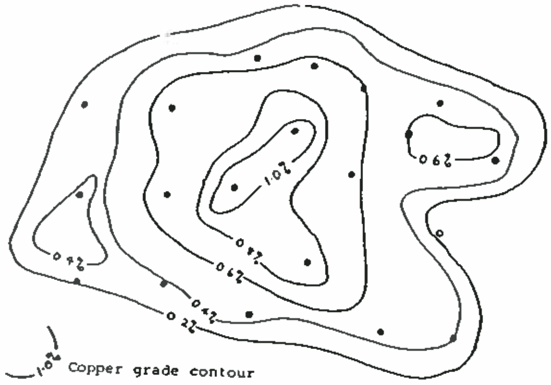


FIG. 8 – Contouring method.

ing a plan of grade distribution from vertical holes.

6. **A 'sphere of influence' method** (Fig. 9) in which the grade of a portion of an orebody is derived from samples within and surrounding the blocks (in two or three dimensions). The method gives, according to various formulae, greater weight to nearby samples and some lesser weight to distant samples. Here we have samples used repeatedly in a manner feasible only with a computer.
7. **Geostatistics** likewise uses surrounding samples to estimate grade of particular blocks, weighting being calculated on parameters obtained from a "variogram", representing a distance-value relationship between samples. As mentioned earlier, geostatistics can produce a measure of the confidence level of the estimate. Geostatistics, in common with the other estimation methods available, requires assumptions and judgements to be made involving both the techniques used and their applicability to the orebody.

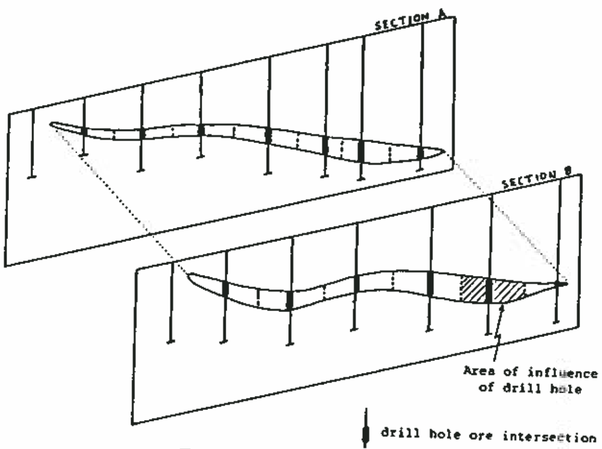
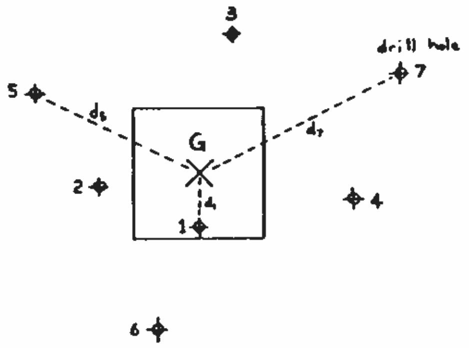


FIG. 7 – Sectional method.

In this progression from the very simple to the most sophisticated procedures so far one can see four important elements. The first is to subdue the influence of the frequency distribution by deriving a grade for a particular portion of a deposit from more samples than one; in effect down-grading high assays and up-grading low asays and thereby moving the assigned grade closer to the average of the deposit.

The second is that the simple, but obvious even if over-simple, assumptions of the earlier procedures become, in the later, so wrapped up in mathematics and computer print-outs that the assumptions can be lost sight of. For example, in the sphere of influence method, one of the formulae that we have met is weighting of a peripheral sample by the inverse square of its distance from the central sample. Now the inverse square relationship is valid for light and for gravity but so far as we know it has no place in ore geology. At best, the inverse square weighting is a severe discounting of the influence of peripheral samples. At worst, it suggests a scientific basis that it does not possess.

The third element in the progression is the trend toward a greater role for mathematics and the computer. As will be said later, we think this is desirable and in some instances essential but there is a danger that these may be used as a substitute for geology. When ore reserves were being estimated in underground mines, the questions of ore continuity had usually already been settled by actual opening up. Now that most testing is by drilling, continuity is less well known and more dependent on inference or assumption. In the course of the study we have met two instances where the ore reserves were estimated purely as numbers. In both of them ore continuity (or the ore-waste relationship) between drill holes is geologically complex. In such cases the between-hole interpretation (and here we might refer again to the second paragraph of this section) has been handed over, overtly or tacitly, to a formula and to the computer.



$$G = \frac{\sum_{i=1}^{n} g_i \times \frac{1}{d_i}}{\sum_{i=1}^{n} \frac{1}{d_i}}, \text{ or } G = \frac{(g_1 \times \frac{1}{d_1}) + (g_2 \times \frac{1}{d_2}) + \ldots\ldots}{(\frac{1}{d_1}) + (\frac{1}{d_2}) + \ldots\ldots}$$

g_i = grade of drill hole i

d_i = distance of drill hole i to centre of block

FIG. 9—Sphere of influence method.

The fourth element is the persistence, even in the most sophisticated procedures, of subjective factors. We have learned of one high calibre estimation system in which any overlarge polygon is broken up, and any unusually good intersection is diluted, by "artificial" drill holes with widths and grades judged to be appropriate.[1] In another high calibre system employing a sphere of influence method, the resulting block grades are scanned by the geologists and any thought to be abnormal are arbitrarily replaced by a more acceptable figure.[2] These adjustments (of which incidentally we approve in their particular contexts) emphasize that the result is an estimate and not a calculation.

At this stage it becomes necessary to digress from the general theme to examine more closely the last of the procedures previously mentioned. Geostatistics is based upon the concept that the distribution of mineralisation within most orebodies is not random and therefore simple or classical statistics is not applicable.

It may help some readers to know that the reaction to geostatistics of two of the authors has changed considerably over the period of the study. After a recommendation that the potential of the geostatistical technique should be carefully evaluated a feeling developed that its proponents seemed to be saying 'If you don't understand this, you're an idiot; and if you don't use it, you're a fool'. This was accompanied by serious misgivings about the validity of some of the fundamental assumptions. It was later realized that our difficulties were more with the misuse rather than proper use of the technique. And so we arrived at the present position of seeing geostatistics as a potentially valuable adjunct at the calculation stage of estimation.

Very broadly, a geostatistical grade estimate could be said to be based upon the following.

1. A mathematical representation of the spatial distribution of the mineralisation of an orebody based upon the assay difference between pairs of samples the same distance apart.
2. Surrounding assays should be used on a weighted basis to estimate the grade at a given point. Parameters obtained from graphing the differences between groups of pairs of assays at various distances apart (a variogram), as noted above, are used to calculate the weighting factors for surrounding assays in estimating the grade at a given point.
3. Computer techniques are used to determine the grade at numerous points within an ore reserve block on the basis of the above procedure. The

---

[1] White, G. H. and Gee, C. E., 1977. Computerised geological and mining ore reserve systems at Western Mining's Kambalda Nickel Operations, in APCOM 77, pp. 263-274 (Australasian Institute of Mining and Metallurgy: Melbourne).

[2] Stoker, P. T., 1979. Ore reserve estimation for copper-orebodies at Mt. Isa Mines Ltd. in *Estimation and Statement of Mineral Reserves* p. 231 (Australasian Institute of Mining and Metallurgy: Melbourne).

grade at these points is used to estimate the grade of the block.

4. A measure is obtained of the statistical confidence level that the resulting estimate will fall within a given range of values.

The reasons for being specially interested in geostatistics are,

1. there is a need for refinement of estimation procedures to achieve greater accuracy and confidence in prediction,
2. the study had led us to think that one principal direction of improvement is via statistics in a form which can be grafted onto geology,
3. geostatistics seems to offer a better estimate of block grades and, in addition, a measure of the accuracy of the estimates,
4. the concepts that these improvements may come through a study of the distribution of values in the deposit itself is one that we find most appealing, and
5. the wide advocation and teaching of geostatistics.

In passing, let us note that wide use by the industry is not among the reasons. In addition, the discipline demanded by geostatistics in assembling and presenting the data is probably, in some cases, a significant factor in itself in a geostatistical estimate being more acceptable than an estimate obtained using a traditional method.

Conversely, the application to a traditional estimation method of the discipline discussed in this guide could well upgrade the estimate obtained.

The study has however led slowly to the development of a preference for geostatistics as it is understood and presented by such people as Professor Michel David,[1] rather than as it seems to be often mis-used or mispresented by some of its proponents. For example, certain applications appear to overlook or ignore the need to examine the geological validity of the comparisons inherent in the variogram. This perceived misuse or mispresentation relates to viewing geostatistics as a complete ore reserve estimation method, rather than the calculation component of a much broader ore reserve estimate. Such an estimate includes sample data, sample preparation and analysis, geological interpretation, the establishment of relevant mining and metallurgical parameters, as well as a calculation method.

One aim of this study has been to identify, through better understanding, the directions of improved estimation. Considered as one such direction, our view on geostatistics is that,

1. geostatistics is of real potential if it is reconciled with the geology of the deposit,
2. statistics and other forms of calculation should not be involved in ore reserve estimation until all other factors such as geological continuity and contacts, lost core, representativeness, sampling and assay errors have been identified, examined and assessed,
3. geostatistics is not an alternative to a rigorous examination of the data, judgement, and assumption by an experienced estimation team containing at least a mining engineer, geologist and statistician. It is but one component in the total estimate, and
4. if used by an estimation team containing at least a geologist, mining engineer and statistician, and seen as but one component in the estimate, geostatistics must have an increasing potential in ore estimation.

Lastly, of three recent texts on ore reserve estimation which deserve notice, the first two are from the 1971-76 Amdel study already mentioned (p. 4) entitled "Ore Reserve Procedures".[1] It is apparent from the reports that the sponsors as well as the consultants regarded the problem as mainly computational. Thus the conclusion was reached that "the solution" was "to hire mathematically oriented staff and to hire computer time".

The third is "Some Aspects of Ore Reserve Estimation", by F. Mendelsohn.[2] The authors received a copy of this in January 1981 and commend the work to anyone involved in ore reserve estimation.

In addition, there are texts which could leave the reader with the impression that mathematical procedures were now available for resolving unaided all problems connected with resource evaluation, including mine planning. This comfortable conclusion has been denied us and not we think because it has escaped us but because the study has made clear that the problems are not only mathematical.

This guide therefore is unconventional in stressing the shortcomings of ore reserve estimation, the inherent imprecision of ore reserve calculations, and in presenting the calculations as only one part, and not necessarily the most important part, of an ore reserve estimate.

In lieu of easy (and not generally understandable) solutions, we see an increasing challenge from low grade prospects to refine all three phases of ore reserve estimation, pre-calculation judgement and assumption, calculation procedures and post-calculation adjustments, most of all in those aspects that are not readily expressed as numbers. We are impressed by the knowledge that an Arizona porphyry copper mine achieved satisfactory ore reserve prediction only after 20 years of study and trial; that it took a large Australian nickel mine 6 years to develop their computerized polygonal procedures to the point of yielding a "planned

---

[1] Director, Institut de Recherche en Exploration Minerale, Montreal, Canada.

[1] 1973. Ore reserve procedures, Australian Mineral Development Laboratories rpt No. 922.
1976. Ore reserve procedures, Australian Mineral Development Laboratories rpt No. 1145.

[2] Mendelsohn, F., 1980. Some aspects of ore reserve estimation, University of Witwatersrand, Johannesburg, Economic Geology Unit, Information Circular No. 147

mining reserve";[1] that Bougainville is still seeking a better estimation procedure after a decade of estimates; that ZC/NBHC has up to now been using on the lower grade zinc lodes the estimation procedures developed for the high grade lead lodes which may not be good enough for low grade ores. The latter do not have the economic margin to live with variances in sampling, assaying, dilution and tonnage measurements collectively affecting the result, adversely, by as much as 15 per cent (see Fig. 1).

We must also have in mind that the ultimate result of an ore reserve estimate is a recommendation to a Board of Directors. At this stage it is essential that the person responsible should have confidence (i.e. more than statistical confidence) in the conclusion. We feel that understanding is a major factor in this confidence. It is for this reason that simpler procedures retain their appeal. Within their known even serious imperfections they are trusted not to mislead.

Therefore at this stage, our feelings about procedures (as distinct from estimation as a whole) run as follow.

1. All estimates should have the best possible geological input combined with well-thought-out statistical (or geostatistical) treatment. No purely mathematical estimate should be accepted.
2. Important estimates, especially for new ventures, should be made by more than one method, one of which should be a simple conventional method. Even though the other may be the preferred method, it may contain, to the extent that it is mathematical, a factor which is not fully understood. As noted above, a simple procedure is safe on this score and will point to the need to identify the reasons for any important differences.
3. The long-term aim should be to develop procedures with special suitability for the major types of deposits, stratiform (e.g. lead-zinc-copper), disseminated (e.g. porphyry coppers), veins (e.g. gold-quartz), bauxite,.etc.

The Estimate

In the light of what has been said to this stage, we see an ore reserve estimate consisting ideally of a team effort in which

1. the basic data will be known to all concerned; e.g. drill core could, with advantage to the assessment, be logged by the mining engineer and the metallurgist as well as the geologist,
2. the in situ tonnage and grade will have been assessed by more than one computation method and some attempt made to measure or assess the statistical range,
3. the initial cut-off grade will have been established. This is a planning control insofar as it affects a decision to equip or not develop a deposit or a stope. It is an operating decision insofar as it may determine when a part of a deposit or a particular stope should be taken or left unmined,
4. adjustments will have been made to the in situ tonnage and grade to allow for percentage mineability, dilution, metallurgical factors and the effect of the learning curve, with experience yielding better results in perhaps the second and third years than in the first,
5. it will have been recognized that in different deposits and economic circumstances any one of geology/drilling, or sampling, or mining, or metallurgy or the nature of the sales contract may be individually the most important qualifying factor,
6. the possible influence of relative changes in metal prices on cut-off grade, mining and metallurgical targets will at least have been thought of,
7. the estimate will be as free as possible of the unavoidable bias in favour of a viable answer,
8. environmental factors will have been considered, e.g. its requirements may affect cut-off grade and in some situations a pyritic deposit or one requiring cyanidation may not be mineable and
9. it will have been appreciated that, though in reality "ore reserves" change with each change of metal prices, the need for operational planning and continuity transfer the variability to the financial result so that in practice it is the profits rather than the ore reserves which undergo short-term variations.

The last point to be made about the estimate is that for an established mining company the worst part of a disappointing result may not be the financial loss but the implication of incompetence, organizational and individual, that becomes attached to a failure. Since important ore reserve estimates occur only every few years at best, no time or trouble or high-level executive attention is too much in trying to ensure that the answer is the right one.

Who Should Make The Estimate?

The initiation of the ore reserve study in 1977 was overt recognition that ore reserve estimation was no longer simply a matter of sample lengths and assays being converted into tonnage and grade. Nor could it be delegated to an apparently highly sophisticated but in-

---

[1] White, G. H., 1979. Ore reserve estimation procedures used on high grade, complex nickel sulphide ores at Kambalda, Western Australia, in *Estimation and Statement of Mineral Reserves*, p. 181 (Australasian Institute of Mining and Metallurgy: Melbourne).

trinsically 'black box' approach. A principal result of this study has been the demonstration that, because of the many assumptions and judgements involved, an estimate on which important decisions depend, requires the efforts of the best team of say four or five that could be assembled, geologist, mining engineer, metallurgist, statistician and possibly also a financial adviser. For major ventures, the mining engineer should preferably have had experience of production tied to an ore reserve estimate.

However, even when this team approach has been accepted, a problem remains. Of necessity the estimate must be made largely by those engaged in the exploratory, developmental or investigational work that yields the basic data. Inevitably these are the people who, for one reason or another, would be disappointed with a negative result; who would, and quite properly, try to find a viable solution to a marginal situation. In the circumstances, objectivity is in danger.

There is another facet; people so involved can become too close to the problem. We believe we have seen it happen that attempts to refine an estimate can lead to such a concentration on the figures that broader more important factors, still within the data-base but not apparent in the figures, are overlooked. Such factors are the possibility of geological changes, adequacy of the testing, or potential and room for manoeuvre if required.

For these reasons, it is desirable to introduce into the estimation team, and whilst ideas are still fluid, one or more people not directly involved in the future of the project and of sufficient standing and experience to be able to contribute.

But safety should not be the only aim. The aim must also be not to miss an opportunity. And this puts the decision in the most difficult realm of whether a particular set of figures represents an opportunity or something that should be left alone.

Statement of Ore Reserves

The understanding that has been presented leads to some observations about ore reserve statements. These are, we should remember, the only way ore reserves become known to those outside the mining profession.

The practice of companies on statement of ore reserves in annual reports is spread over a wide range of

1. no statement,
2. declaration of a reserve equivalent to a few years production,
3. full statement of known reserves (in situ but not defined as such),
4. statement of in situ reserves even where an estimate of recoverable reserves is available,
5. statement of recoverable tonnage and grade,
6. statement of recoverable product.

The range is thus from saying nothing about the current ore position to making a long range forecast of total production.

Recommendations about the form of statement of ore reserves were drawn up in 1972 by a Joint Committee of The Australasian Institute of Mining and Metallurgy and the Australian Mining Industry Council.[1] The committee recommended restrictions on the use of "ore" and on the premature use of "ore reserves" but otherwise accepted a wide range of existing practice. These recommendations were reviewed two years later without modification.

In 1978, the Joint Committee commenced another review of the situation, with CRA contributing its experience to that time in its Ore Reserve Study. The discussions have led to two principal new recommendations.[2] Briefly they are that

1. tonnage and grade statements should be so expressed as to convey that the figures are estimates not precise calculations,
2. the statement should specify whether the figures refer to in situ or recoverable reserves.

Looking further ahead, our understanding prompts two technical and a number of general comments.

On the technical side, there is the preference for "proved", "probable" and "possible" as names for various categories of ore reserves. It may help to think of these as "best known", "not so well known" and "poorly known". The categorization had some meaning when "proved" ore meant "fully developed and ready for stoping", as it used to mean in Broken Hill, but since the three terms are geologically relative and organizationally subjective, one mine's "proved" may well be no better than another mine's "probable". The distinction retains some usefulness in assessing ore reserves for publication, e.g. "proved" would be included at calculated tonnage, "probable" at say 80%, as an allowance for uncertainty. Five categories of certainty are used in a 1978 Mesabi Range evaluation, 90% ("high expectation"), 75% ("some reservations"), 50% ("limited information"), 25% ("grade/economics questionable"), and 10% ("no tonnage assigned"). This classification is of interest since the lower categories reflect not only uncertainty of complete realization but also increasing uncertainty of how much of the tonnage will prove to be mineable. As the distinction disappears when two or more categories are added together, for the readers of ore reserve statements, looking at totals, the distinction is now (with one exception) meaningless and will probably gradually lapse.

[1] Report by Joint Committee on Ore Reserves April 1972. Published by The Aus.I.M.M.

[2] Reporting of Ore Reserves Report of the Joint Committee of The Aus.I.M.M. and AMIC March 1981. Published by The Aus.I.M.M. Reprinted Bulletin Australas. Inst. Min. Metall. No. 452 October 1981.

Th
"Earl
durin
the ie
word
confi
Th
statec
fifty
alreac
exam
the "
what
possit
kind,
elimir
ore re
On
of the
few li
of no
impor
the fa
a rece
two p
By i
ing co
interes
just lie
lesser
work
stages,
orebo
Fitzpa
extent
explor
In
rather
more
produ
hundre
difficul
iron o
prior t
the ev
sumed
can be
By c
sidered
decisio
Discus
ment i
may de
Ther
wider
Charte

¹ Davie
ingful d
(9), Apr

The exception is in the situation discussed under "Early Years". If the part of the ore deposit to be mined during the first few years is more rigorously tested than the remainder, then this is "proved" in both senses of the word, initially established, and subsequently tested and confirmed.

Then there is the definition of "ore". The definition restated by the Joint Committee in May 1981 is more than fifty years old and more rigid than modern usage, as already mentioned in the "Introduction". Some recent examples of statements about exploratory indications at the "pre-ore reserve" stage, are an attempt to convey what would be described in the industry as "ore possibilities" or "ore potential". A provision of this kind, for a wider use of the term "ore", might effectively eliminate the temptation to invent new terms for the pre-ore reserve stage.

On the general aspect, it is illogical that, as the basis of the enterprise, ore reserves should get at best only a few lines in annual reports and the accounts many pages of notes. In ore reserves, "contingencies" may be more important than in some financial transactions but as yet the factors affecting reserves seldom rate a mention. (In a recent annual report one major mining company gives two pages to ore reserves.)

By not discussing ore reserves in annual reports, mining companies are missing opportunities to inform those interested in the politics of resources that these do not just lie around waiting to be picked up. To a greater or lesser extent ore reserves are created by investigational work of various kinds, usually expensive and, in initial stages, involving risk capital. In the case of blind orebodies (e.g. Kambalda (in part), Norseman, Hilton, Fitzpatrick ore shoot) the "creation" is complete to the extent that the orebodies were discovered by subsurface exploration.

In varying degrees, therefore, reserves are "made" rather than "acquired". It has always been so; at a guess, more than nine-tenths of the Victorian deep lead gold production was the result of investment of up to several hundred man-days of effort in shaft sinking under difficult conditions; even the best-exposed bauxite and iron ore deposits were not only economically unknown prior to their discovery forty to twenty years ago but, on the evidence of government decisions, had been assumed not to exist. It is only politically that these things can be regarded as being there for the taking.

By definition also, reserves are those which are considered to be economically workable at the time of the decision to mine, as discussed in the preceding section. Discussion of cut-off grades would reveal that government imposts on production raise cut-off grades and may destroy resources.

There is not much doubt that the trend is towards a wider interest in ore reserve statements. In The Chartered Accountant in Australia, April 1980,[1] Barry J. Davies presents an accounting view of ore reserve estimation and statement. The Australian publication "Search", June 1980,[1] discusses reserves. Against the background of a company representative saying to a meeting, "I'll be frank, we may have deposits and we may not . . .", the article quotes Coopers and Lybrand USA 1979, "Presentation of supplementary information about ore reserves is vital for an evaluation of the viability and worth of a mining entity. Disclosure of this information in the annual reports of mining companies has been very limited in much of the world until recently, but there are few countries that do not now make this disclosure. There is a current and growing trend in the industry to disclose more detailed statistical information about ore reserves", and also the Institute of Chartered Accountants UK 1978, reserves are "so fundamental to a proper appreciation of the results and potential of an oil company that estimates must be made and disclosed, especially of reserve quantities, even though there should be appropriate qualifications as to the necessary imprecision involved. Information, it is suggested, need not be precise to be useful". The latter is expecially interesting in its explicit appreciation of imprecision and in being applicable to any ore reserve.

From the industry, since the commencement of this study, we have the keynote address presented by Sir Frank Espie[2] at the Symposium on Estimation and Statement of Mineral Reserves organised by the Sydney Branch of The Aus.I.M.M. and a paper by N. Miskelly[3] on Ore Reserve Reporting Practices of Major Australian Mining Companies, presented at the 1981 Annual Conference of The Aus.I.M.M., which analyses the ore reserve reporting practices of fifteen leading Australian mining companies.

The widening interest in ore reserves and the limited response from the profession[4] or industry promises to create a vacuum likely to be filled from outside the profession and based on particular points of view. There is therefore a wider need for the understanding presented here to become the basis of an informed initiative by the industry and the profession to develop an appreciation of the nature of resources and reserves and of what can and cannot be "meaningful".

---

[1] Davies, Barry J., 1980. Practical problems preclude meaningful disclosure. The Chartered Accountant in Australia, 50 (9), April 1980: 19-25.

[1] Anon., 1980. Discussion—a too hard basket of Australian minerals, *Search* (ANZAAS) 11 (6): 170.

[2] Espie, Sir Frank, 1979. Keynote Address in *Estimation and Statement of Mineral Reserves*, pp. 1-5 (Australasian Institute of Mining and Metallurgy: Melbourne).

[3] Miskelly, N., 1981. Ore reserve reporting practices of major Australian mining companies, in *Sydney Conference, 1981* pp. 133-140 (Australasian Institute of Mining and Metallurgy). Reprinted 1981, Australasian Institute of Mining and Metallurgy Bulletin No. 457.

[4] In addition to the references mentioned in the "Introduction", the Presidential Address to the Institution of Mining and Metallurgy (Davis G. R., 1981, Geologists in the minerals industry, *Trans. Inst. Min. Met.*, 90: B93) lists papers by C. J. Dixon and J. O'Leary on geological aspects of feasibility studies/ore reserve estimation presented to the Mineral Deposits Studies Group of the Institution of Mining and Metallurgy, 19 March 1981.