# COMMON SENSE AND GOOD COMMUNICATION IN MINERAL RESOURCE AND ORE RESERVE ESTIMATION

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## ABSTRACT

Mineral Resource and Ore Reserve estimation is a challenging and demanding field, requiring application of professional knowledge, skill and experience of the highest order. If the many potential pitfalls are to be avoided, however, there are two other requirements which are of equal, if not greater, importance:

- Good communication
- Common sense

Estimation of Mineral Resources and particularly of Ore Reserves is almost always a team effort, involving a number of disciplines. Good teamwork requires good communication, both between team members and between the team and other parties having an interest in the process. Breakdown in these lines of communication can have far reaching effects on the project under consideration.

The need to use common sense during a Resource or Reserve estimation exercise would seem to be self-evident. It is surprising, however, how often rigid adherence to procedures and methods prevails at the expense of clear thinking, usually with adverse and sometimes fatal effects on the project under consideration. This has become increasingly true as computerised methods have assumed a central role in Resource/Reserve estimation. The critical question that estimators should ask themselves at all stages of the process is: “Is what is being done sensible given the data available, what is known of this deposit and the purpose of the exercise?”

## INTRODUCTION

Considerable emphasis is placed these days on techniques employed in the estimation of Mineral Resources and Ore Reserves, with discussion tending to concentrate on the comparative merits of alternative computational approaches. While this subject is important and fully deserves its wide public airing, it is only part of the story, being concerned primarily with the tools employed in arriving at an estimate of Resources and Reserves. Of more fundamental importance is the way in which those tools are applied, and in particular, whether they are used sensibly and in full consultation with all those involved.

This paper discusses a number of issues relating to both estimation techniques and to the application of those techniques, with emphasis on the need for both common sense and good communication. In so doing, there is a slight risk of appearing to state the obvious; however it is surprising how often the obvious is ignored or is swamped by undue attention to technical detail.

The paper is largely an updated and expanded version of a paper written by one of the authors and published in 1990 (Stephenson, 1990).

## COMMON SENSE

The Macquarie Encyclopedic Dictionary defines common sense as "sound, practical perception or understanding", and it is in this sense that the expression is used in this paper. It is essential that common sense, as thus defined, be applied at all stages of a Resource or Reserve estimation exercise.

### Geology

The single most important factor in Resource/Reserve estimation is **an understanding of the geology of the deposit**. This cannot be emphasised too strongly. Without a sound geological understanding, and a sensible application of that understanding, an estimation exercise becomes merely a mathematical treatment of sample results with no practical value. More seriously, any result which does not take sufficient account of geology is almost certain to give a seriously misleading impression of the value of the deposit.

It is axiomatic, therefore, that the most important function of the geologist is to interpret the geology of the deposit to the best of his or her ability, and to communicate that interpretation (and the implications of that interpretation) to other members of the team involved in the estimation process and to potential users of the end result. The geologist must also make a prudent assessment of the quantity and quality of the data (geological, sampling, etc.) upon which the interpretation is based and convey to other involved parties an appreciation of any uncertainties attached to the data. This is critical for both the selection of the estimation method and for Resource/Reserve classification at a later stage.

Since geological understanding is central to the whole estimation process, the earlier that some feel for the geology and detailed mineralisation controls can be gained, the better. This is advisable not only for the purpose of governing the estimation exercise, but also to guide the orientation, spacing and type of drilling required and to minimise the risk of drilling holes sub-parallel to mineralisation controls.

It has become more common over the past decade or so to implement some early, close-spaced drilling to allow application of the geostatistical technique of variography (Journel and Huijbregts, 1978; Vann and Humphreys, 1994). Variograms quantify spatial continuity of a variable, and so can provide an important early assessment of short-scale continuity of mineralisation. Such an assessment is complementary to geological assessment, and also allows a judgement to be made as to the adequacy of existing drilling spacing.

Potentially open-pittable, hard-rock deposits are often drilled primarily by reverse circulation percussion ("RC") holes, which provide little detailed structural geological information. In such situations, drilling one or more diamond drill ("DDH") holes as soon as there is a suspicion of a potentially economic deposit is a wise precaution and a sensible investment. In the authors' experience, the quality and value of lithological and alteration logging of RC samples is greatly augmented by logging of nearby DDH cores. In addition to the benefits in terms of geological control, early diamond coring enables a very preliminary feel for mining conditions and for mineralogical/metallurgical characteristics. A word of warning however: at this stage, there is a chance that cored samples may not be representative of material that will eventually be mined, and too much should not be made of preliminary mining and treatment observations.

Core logging is now largely carried out on coded sheets (more recently, by bar-coding systems) with a minimum of descriptive content. This is good practice and is recommended when the project is at an advanced stage or once mining has commenced, as it provides a checklist, minimises data transcription errors and assists in maintaining consistency in logging. However, at the early exploration stage, there is a danger that strict adherence to a coded form of logging can result in important overall geological characteristics and mineralisation controls being either missed or going unrecorded (the "forest for the trees" syndrome). A major problem is that, although many coding systems allow descriptive content, this content is rarely accessed.

At early stages in the investigation of a deposit, the authors suggest that geologists should focus at least equally, if not preferentially, on descriptive and graphical core logging (which of course can be computerised later if the project advances). They should be encouraged to record thoughts and ideas on what has been learned from each hole, and logging procedures should facilitate such recording. In fact, early application of more free-form, descriptive and graphical logging is an essential preliminary phase in the setting up of appropriate computerised logging systems.

A point often overlooked when considering the reliability of a Resource/Reserve estimate for a new deposit is the fact that the geological model, upon which the estimate is wholly dependent, is based almost entirely on interpretation from drill samples which themselves represent only a tiny fraction of the mineralised body (often less than 0.001%). This must necessarily impose a constraint on the reliability of the estimate. In the final analysis, confirmation of the geological model can only be gained once mining has provided sufficient exposure to enable geological mapping.

Commonly the potential errors associated with an incorrect or inappropriate geological interpretation are orders of magnitude larger than the potential errors associated with grade estimation. Changes in the fundamental understanding of the geological controls on mineralisation can dramatically alter an assessment of tonnage.

These days, more and more use is made in Resource/Reserve estimation of computer-based grade interpolation techniques, both geostatistical and non-geostatistical. Such techniques constitute major advances in our ability to make maximum use of large amounts of data. However, there is a risk that in the blind application of technology, common sense will be ignored. Any interpretation of grade distribution must be consistent with the geologist's interpretation of the deposit and quantified spatial grade distribution (which can be modelled through variograms), although the requirement for consistency does not imply that directions of grade continuity will always coincide with those of geological/lithological continuity. Geological interpretation must not, of course, be considered sacrosanct and immune from change; indeed, reinterpretation must be an ongoing activity. In the end, however, grade interpolation must be governed by observation of the deposit geology and character, not vice versa.

One final point on geology. Old geological plans, especially on old mining properties, should **never** be ignored. They can usually be used with sensible caution and with appreciation for the fact that many geologists of yesteryear were much better observers and mappers than modern-day geologists (they probably spent more time "down the hole" and less time staring at screens…).

**Database**

The database comprises the raw observations and measurements upon which the Resource/Reserve estimate is based. It is not within the scope of this paper to discuss all of the items in detail (for a recent discussion on the topic, interested readers are referred to the Proceedings of "The Resource Database Towards 2000, Towards 2000 AusIMM Minerals Resources and Ore Reserves Estimation Seminars, May 1997"), but it is important to stress, in relation to a common sense approach, the need to **check the data**. This applies at all stages from sampling, assaying, surveying etc to final presentation.

Sampling and assaying are of critical importance, and should be subject to a rigorous system of checks for representativity, accuracy and precision. There is little point, however, in expending considerable time and effort at these stages if the data are then plotted incorrectly on final plans. Transposing from one scale to another may result in misplotting which is sometimes not easy to detect, and it is always advisable to have plans, cross sections, longitudinal sections etc at the same scale. Where both manually-plotted and computer-generated plans exist for the same data, the two should always be compared and any differences resolved. An excellent use for computerised systems is their application in 3D visualisation, which usually makes spotting locational data errors easier and quicker.

A Resource or Reserve estimate depends on how representative the samples are of the mineralised body, and for this reason both the size and the spacing of the samples are of critical importance. As a general rule, the bigger the sample the better. If criteria such as depth, structural complexity, ground conditions and the presence of water allow, it may be preferable for the main drilling method to be RC rather than diamond core, since a typical 1m long RC sample is approximately 10-15 times the volume of a 1m halved HQ core sample. However, since percussion samples provide virtually no useful information on structural aspects and may suffer from down-hole contamination or smearing, it is very important that sufficient twinning of percussion intercepts with diamond core holes is carried out to provide confidence in the geological interpretation and to ensure that down-hole contamination is not a significant problem. Note that the different sample volumes of core and RC will be reflected in the statistical behaviour of assays from these two different “supports”. In particular, larger supports are expected to have less variable grades (lower variance). This is the “support effect”, well known to geostatisticians.

Gy’s formulae (François-Bongarçon, 1992; Pitard, 1993), which give guidance as to appropriate sample volumes, were developed for the sampling of particulate materials, that is to material once it has been crushed or pulverised or otherwise disaggregated, at which point any spatial relationship between mineralised particles has been destroyed (a necessary prerequisite to the application of Gy’s formulae). In sampling particulate materials, increasing sample size by 100% will normally result in a substantial relative improvement in sample representativity and thus precision. The same is not true at the in-situ sampling (drilling) stage, and these formulae are sometimes mis-applied and used as justification for doubling sample size by taking whole core rather than half core for assay in, for example, high-nugget gold deposits. While the theoretical merits for this procedure may be debated, the authors are, in any case, strongly of the belief that sampling of whole core is very unwise at the early exploration stage. This is because it is essential that the opportunity to re-log and re-sample core, and to carry out metallurgical and geotechnical studies on samples of core, is maintained.

There are rare situations where whole core sampling may be justified at a later stage of exploration, for example, at the drill-out phase. Any decision to introduce the procedure must be based on comprehensive geological, geostatistical and sampling justification, and the alternative of over-size core or of non-core sampling must be eliminated as a possibility.

In the event that whole core is taken at any stage of exploration, high-quality and detailed core photography is essential and the authors suggest that such photography should be duplicated and stored off-site.

More and more companies are becoming aware of the importance of introducing and maintaining quality control (“QC”) procedures on sampling and assaying, particularly for exploring and evaluating precious metal deposits. Common strategies include routinely inserting duplicate and replicate samples, assay standards and blanks, check assaying using alternative methods, and participating in inter-laboratory or round-robin check programmes. However, it is disturbing how often such good practices are not accompanied by routine evaluation of the **results** of the QC data. No company wants to learn at the financing or final commitment stage of a project that a large part of its Resource/Reserve database is invalid or of suspect quality, yet it happens all too often. It should be company policy that no QC programme is set up without a well-formulated and high-quality supporting evaluation procedure.

Optimum sample (or drillhole) spacing is dependent on geology, grade continuity (both manually interpreted and as quantified by variograms), and on the stage of exploration, but can also be dependent on the cut-off grade considered likely to be applicable. For example a drill hole programme may be designed to sample a deposit on the assumption that a low (say 0.5%) cut-off grade would apply. The same drillhole spacing may be inappropriate if the cut-off grade is later raised to (say) 2.0%, since it would almost certainly fail to adequately sample the smaller high grade zones which are to be selectively mined. In this situation, it may be necessary to close down the drillhole spacing in spite of the additional cost. It is possible to assess the effects of changing drill spacing using a geostatistical approach (either by calculation of estimation variance or by utilising conditional simulation).

One of the raw measurements which is often given too little attention is the bulk density or tonnage factor. A small change in this factor can have a large effect on the estimation of tonnage and contained metal. A number of situations have occurred in the industry where incorrect tonnage factors applied, particularly in the early stages of new open cut operations, have resulted in under-budget tonnes produced, and a consequent shortfall in early cash flow. It is important to measure tonnage factors inclusive of voids which will still be intact when the rock is mined and delivered to the treatment plant. Diamond core is preferable to percussion chips for this purpose, since it can be sealed to preserve voids prior to measurement of volume. In addition, if bulk density varies significantly from sample to sample, then this variable must be incorporated into the Resource estimation if biased grade estimation is to be avoided.

One final point on the database. As with old geological plans, there is a temptation to reject old drilling and sampling plans as being out of date or “too difficult” to use. The temptation should be resisted. The plans may be suspect or of uncertain quality; however, it is often possible to make constructive use of them by examining old records in detail, and by consulting previous workers who are usually only too happy to assist. Even if, after expert assessment, assays are considered unusable as absolute figures, they may provide a valuable insight into grade trends in areas now inaccessible.

**Estimation parameters**

Cut-off grade theory is a subject of considerable complexity, and it is beyond the scope of this paper to discuss it in detail. The interested reader is referred, for example, to Lane (1988) for a study of the topic. The point to make in the present context is that cut-off grades for Mineral Resource estimates must be based on some, albeit very preliminary, estimate of economic viability. This can, of course be difficult, particularly at the early stages of exploration, when data are often sparse. However, from a practical point of view, there is little merit in producing an estimate based on a cut-off grade well below any likely to be applied in practice. Indeed, such an estimate would not meet the JORC Code requirement that Mineral Resources have “reasonable prospects for eventual economic extraction”.

A sensible approach to the problem of selecting cut-off grades at the Mineral Resource stage is to produce, if possible, estimates at a number of cut-off grades and to summarise the results graphically. Geostatisticians refer to this approach as "parameterisation of Reserves." A word of caution though. Computers can be of great assistance in multiple cut-off grade exercises; however, it is essential that a high degree of geological and mining interaction takes place with the estimates at all the cut-off grades, otherwise the results will tend to be unachievable in practice. This is particularly true at higher cut-off grades where, in the absence of manual intervention, a computer will often "pick the eyes" out of a deposit, producing an estimate based on isolated grades which can never be mined in practice without massive dilution. This approach is compounded if "small block linear interpolation" is used as an estimation method (see below).

Other parameters which are of fundamental importance are a minimum "ore" width, a maximum thickness of included waste and (if applicable) an estimation block size. These factors require some judgement about the eventual mining method, and should be derived in consultation with a mining engineer. The two principal conversion factors by which Mineral Resources are modified to produce Ore Reserves are mining dilution and mining recovery. Small variations in these factors can have large effects on Ore Reserves, and it is essential that the same careful consideration is given to dilution and recovery factors as is given to the rest of the exercise. If the Reserve is being estimated for an operating mine, then the factors should be based on historical mining figures, and this is one of the reasons why it should be standard practice in operating mines to keep stope by stope or bench by bench reconciliations between ore predicted from Ore Reserves, material actually mined and mill products.

**Estimation methods**

There are many estimation methods to choose from, and new variations are continually appearing, particularly in the geostatistical field. The main points to consider in selecting a method are that it must be appropriate to the geology of the deposit and to the available data (bearing in mind both the spacing of drillholes and the quality of the data), and that it should also take some account, if possible, of the probable mining method. For example, there is little point in applying a mathematically complex block modelling technique using small blocks to a poorly drilled, gold deposit characterised by an erratic gold distribution, because such deposits can generally only be globally estimated, ie assigned an overall tonnage and grade. Selection of the estimation method is a critical step: use of an inappropriate method may produce completely misleading results with disastrous effects on the project or operation, and on the credibility of the estimator.

Computers are of tremendous value in enabling more to be done more rapidly with available data than is possible by manual means. It does not necessarily follow, though, that all computer-derived estimates are better estimates. Indeed, often the person trying to assess how good the estimate really is, is overwhelmed by the sheer volume of the data produced. The trick is not to be blinded by the way in which the results are presented, but to delve deep into the methods and techniques used so as to fully understand how the results were derived. A certain bulldog-like tenacity is useful in this regard! For the modern mining professional involved in Resource/Reserve estimation, a basic appreciation of current geostatistical approaches (including their inherent assumptions, pit falls and weaknesses) is compulsory.

Geostatistics has brought about a revolution in the field of Mineral Resource and Ore Reserve estimation. As with any method, of course, it is essential that geostatistical methods are applied taking proper cognisance of the geology and the available data. In fact, a main advantage of well-applied geostatistics is that it is, in a sense, **conditioned** to the data quality, via the nugget effect of the variograms. Nevertheless, there are many situations where geostatistical methods, when poorly understood and applied, are not only inferior to the more classical estimation methods, but may cause unnecessary confusion.

Still on the subject of computers and geostatistics, lending organisations frequently like to see Resources and Reserves prepared by two methods, and have a distinct leaning towards computer-based methods. There is merit in running two Resource/Reserve estimates in parallel, especially if one of the methods is one of the more complicated geostatistical techniques. As long as they are both appropriate to the situation, then each acts as a check against the other, and provides a degree of comfort for the end-user. The authors have been involved in situations where this was a wise precaution. In one case, on the basis of the geostatistical results, a particular mining project would have been terminated or severely delayed, while on the basis of the parallel computer-assisted manual estimate, the project still had life. This was because the geostatistics had not taken proper account of geology, not because of inherent problems with the interpolation algorithm. Subsequent work on the geostatistical results brought them closely into line with the parallel estimate. On the other hand, contrary cases exist, where polygonal estimates, because of conditional bias, can be overly optimistic from an economic viewpoint (estimating fewer tonnes at significantly higher grade) and well-applied geostatistics gives a much more realistic appraisal of project feasibility.

Estimation of gold orebodies is particularly difficult due to the usually erratic nature of gold mineralisation ("high nugget"[1]). Although a number of methods have been proposed specifically for this type of mineralisation, there is, unfortunately, no single correct way of mathematically handling erratic gold grades. A simple technique which can be usefully applied in most situation is to composite grades to reduce variability. In many cases this adjustment is appropriate because the scale of mining selection will be significantly larger than that of uncomposited samples. The reduction in sample variance due to compositing may be sufficient to reduce the occurrence of extreme grade values to an acceptable frequency and to remove the need to impose grade cutting. Truly extreme grades may still require cutting, and the safest practice is to cut on the composites rather than the uncomposited data. Cutting of grades is itself a difficult field, and there is again no single technique which suits all orebodies. If there is doubt as to whether or by how much to cut grades, then a sensible approach is to prepare estimates using both cut and

[1] Note that "high nugget" does **not** always imply coarse or visible gold; it is a consequence of the erratic distribution of metal, and this can occur even with sub-micron gold grains when they are distributed in patchy clusters.

uncut grades. The resulting figures will provide some indication of the magnitude of the problem caused by the high grades and the sensitivity of the estimate to grade cutting approaches.

A serious difficulty with many applications of computerised block modelling is the tendency for uninformed practitioners to estimate **very small** blocks (in comparison to the spacing of available drilling). This is the “small block linear estimate problem” referred to previously. While it would be ideal to estimate blocks at the scale of the envisaged selective mining unit (“SMU”) dimensions at the stage of feasibility, this is rarely possible in practice. As block size decreases relative to drill spacing the precision of individual block estimates decreases, often sharply. The grade-tonnage curves implicit for such estimates will be distorted and conditionally biased (in other words, application of a cut-off grade greater than zero will inevitably result in an incorrect estimation of tonnage and grades), and as a consequence, mine planning based on these estimates (for example, pit optimisations) may be seriously economically misleading. This applies to both ordinary kriging and inverse distance weighting methods (Ravenscroft and Armstrong, 1990; Krige, 1997).

Since 1970, a number of advanced geostatistical techniques have been developed to get around this “small block” problem. These are called “recoverable resource estimators” by geostatisticians and rely on non-linear variants of kriging. This is a large subject in itself, and beyond the scope of this paper. Such methods are being increasingly adopted by major mining houses and have over a decade of track record in a number of large South African, Australian, North American and South American mines for a variety of commodities. While the benefits may be significant, the authors encourage the reader to understand such methods before using them and not to assume that they provide a panacea for all ills (Vann and Guibal (1998) provides an overview of the subject, and Rivoirard (1994) provides more technical detail). An important aspect of non-linear geostatistical estimates is that they are inherently capable of allowing for some components of mining dilution, although this must not be used as a substitute for a careful analysis of mining dilution when converting Mineral Resources to Ore Reserves.

Most operating mines have well established practices for estimating Mineral Resources and Ore Reserves. In many cases the method (taken in totality) is unique to the particular orebodies, and may be superior to other methods (for those orebodies). There should be no pressure to change for the sake of change. Operating mines should, however, take maximum advantage of the information gained from reconciling Ore Reserve prediction with mine production by using it in reviewing remaining Reserves, and if necessary, in adjusting estimation techniques or adopting new approaches. In particular, dilution and recovery factors should be constantly under review.

## Classification of results

One of the major judgements the Competent Person or Persons (as defined in the JORC Code (JORC, 1996)) has to make is how to classify the results (Stephenson and Stoker, in prep). In Australasia, the JORC Code provides definitions and guidelines; however, each situation is unique and needs to be dealt with on its own merits. An important point to bear in mind is that **there is nothing in the JORC Code which requires classification to be a complicated process** or to be based on a particular procedure such as the use of statistical data available from a block model estimation method (increasingly, industry appears to be becoming fixed on the latter as if it were somehow mandatory). As long as it is carried out by a Competent Person and takes into account *inter alia* confidence in continuity of geology and metal values in conjunction with the quality, quantity and distribution of the data on which the Resource estimate is based, the resulting classification should be in accordance with the JORC Code.

It is also important to appreciate that the main reason for tonnage and grade estimates being classified is to provide company executives and others making mining investment decisions with a basis for assessing relative risk. It is useful, indeed essential, to bear this in mind when classifying Resources and Reserves.

Both Resource/Reserve estimators and users of Resource/Reserve estimates should appreciate that the category of Measured does not imply 100% knowledge of the Resource or 100% confidence in the estimate. It is a category for which, *inter alia*, "*.... any variation from the estimate would be such as not significantly to affect potential economic viability*" (JORC 1996). Likewise, the category of Indicated is one for which, *inter alia*, "*Confidence in the estimate would be such as to allow the application of technical and financial parameters and to enable an evaluation of economic viability*".

Classification can be a demanding task which requires the Competent Person(s) to consider many factors. A technique which one of the authors has found useful in focusing the mind when making classification decisions is to try to imagine the effect which additional sampling data (usually infill drilling) might have on the tonnage, grade, shape and location of the mineralised bodies (Stephenson, 1994). Geostatistical estimation variance studies can be a useful input to such a process, because the impact of additional drilling on confidence in grade estimation is then quantifiable (for a case study, see Humphreys and Srivastava, 1997).

As an example, if it is felt that closer drilling or sampling would not greatly affect the geological interpretation and/or confidence in grade distribution, or, even if it could affect the interpretation or grade distribution, would not result in a significantly different estimate of tonnage, grade, shape and location of the mineralised bodies, then (assuming that the quality of the data on which the estimate is based is acceptable) the particular section of the deposit under question may reasonably be classified as Measured.

A similar approach can be taken in deciding between Indicated Resources and Inferred Resources. If it is thought that additional drilling or sampling could significantly affect the shape and/or distribution of the mineralised zones, but not substantially affect the tonnage-grade estimate, then the portion of the deposit in question can probably be classified as Indicated. An even more basic approach can also be used. If the Competent Person has sufficient confidence in the Resource estimate for it to be used for definitive mine planning and investment decisions, then it probably meets the requirements for

Indicated Resources. If he or she does not have that sufficient confidence, it should probably be classified as Inferred.

One of the factors which can impact on classification but which is usually not adequately considered is the scale of classification (i.e. the volume of mineralisation that is being classified). Most Competent Persons would agree that they are not trying to classify a Resource or Reserve estimate at the scale of a block (especially when small blocks have been used relative to the sample spacing) even in situations where block parameters have been used as a basis. It would usually be accepted that the grades of individual blocks are subject to too great a degree of uncertainty. On the other hand, it would be most unusual for classification to be applied at the scale of the overall deposit. The normal situation lies somewhere in between, but the matter is very seldom given any attention in Resource or Reserve reports. One approach (Parker, 1998), possibly more easily applied at the advanced exploration or operating stage than at the early exploration stage, is to apply classification at a unit volume scale which represents expected mine production over a specified time period, for example over three, six or twelve months. In situations where mine production parameters are not yet known, a judgement could be made as to what would constitute a reasonably sized package of Resource blocks.

A final comment from a common sense point of view. Resource classification, by necessity, requires close familiarity with all issues which might affect confidence in Resource estimation, including quality of data, estimation method applied and geological interpretation. Yet sometimes estimators with little or only moderate familiarity with the deposit (as is usually the case with non-company consultants) are expected or required to classify their Resource estimates according to the JORC system. This can, and often does, result in classifications substantially at variance with the project geologists' view of the deposit, and can cause unnecessary doubts in the minds of company executives and other end-users of the estimates, to the possible detriment of the project.

The authors suggest that such situations could be largely avoided if project geologists always had an input into Resource classification decisions, regardless of who prepares the Resource estimate. Rather than requiring all Resource estimators to produce their own classifications, estimators without in-depth knowledge of the deposit and data could either be required to work closely with the project geologist to produce a classification acceptable to the geologist (the preferred approach) or be requested to subdivide their estimates into classes or zones representing different levels of confidence which could then be taken into account by the project geologist in arriving at an appropriate classification.

**Presentation of results**

Results should be presented clearly and concisely in a well thought out and logically structured report. This would seem to be an obvious point, but in the experience of both authors it is surprising how often a technically excellent piece of work is ruined by poor presentation. The aim of an estimation exercise is not only to produce Resource or Reserve figures, but also to communicate the result to those who need to use it. It is important, therefore, to keep the end-user in mind when writing the report. It is equally important to emphasise the qualitative nature of the estimate, and for this reason, the final result should always be referred to as an estimation, not a calculation.

The qualitative nature of the estimate is reinforced if final figures for tonnes and grade are rounded appropriately (rounding should not, of course, be applied **during** the computational process). As an example, a total Resource or Reserve figure of 10,563,942 tonnes @ 2.374g/t Au would be a ridiculously precise statement which would almost certainly bear no relation to the uncertainty surrounding the estimate. It would also be a misleading statement which could detract from the merits of any qualifying remarks, and could promote unrealistic expectations in the mind of a non-technical end-user. It is suggested that there are few metal deposits, apart from those with a long history of mining, which are well enough understood to justify grade statements to even the second decimal place.

## COMMUNICATION

Since Mineral Resource and more particularly Ore Reserve estimates are team efforts, it is essential that a high level of communication exists both within the team, and between the team and management and other users of the eventual result. This topic is discussed in relation to the various professions involved.

### The Geologist

As has already been stated, the most important function of the geologist is to interpret the geology of the deposit and to communicate that interpretation to all those who have an interest in the estimation process. If this is not done effectively, then no amount of computational wizardry will compensate for the lack of geological input.

### The Geostatistician

There is probably no area in Resource/Reserve estimation with more potential to be adversely affected by poor communication than the field of geostatistics. The view still held by some, that geostatistics is a “black box” approach, is largely due to a lack of understanding, which in turn is largely due to practitioners not explaining techniques clearly and in simple language. The requirement for good information flow occurs before, during and after the estimation process (the comments which follow assume that the geologist and geostatistician are not one and the same person, as is sometimes the case).

Before a Mineral Resource estimation exercise begins, three critical activities must take place:

- The geologist must explain fully the geological interpretation and the implications of that interpretation.

- The mining engineer must outline (if possible) the proposed mining method and requirements for mine design.
- The geostatistician must explain clearly the estimation method proposed, ensuring that the method is understood by the geologist and mining engineer, and convince them that it appropriately takes into account all the relevant geological and mining engineering aspects.

This last point is most important. There must be agreement that the method is suited both to the geology and to the nature, quantity, quality and distribution of the data. This decision requires a good understanding by all parties of the geological, mining and geostatistical characteristics of the project.

During the estimation process, a high degree of inter-disciplinary interaction must take place. Variography should always be checked for compatibility with geology by the project geologist, and adjusted if appropriate. Kriging parameters should be quantitatively tested to ensure minimisation of conditional bias. Results should be checked at all stages, not only on completion of the exercise. Frequent reference should be made to original data, and to comparable cross-sections, long-sections and level plans. Sensible use should be made of computerised 3D visualisation tools.

After the exercise is complete, the results of the geostatistical estimate must be presented in a manner which makes them easy to assimilate and understand. The technical knowledge of the eventual readers should be appreciated and documentation pitched at an appropriate level. If the final presentation is poor, it matters little that the exercise itself was of a high standard.

It is clear that over the past decade the use of geostatistics has grown steadily and that it is now one of the basic tools for Resource/Reserve estimation. The authors suggest that all professional mining engineers and geologists should be familiar with the concepts of geostatistics. If specialist, expert geostatisticians are included in the team, the other team members' familiarity with the subject will be particularly important. While geostatistics has much to offer, the application of kriging techniques without reasonable knowledge of the subject of geostatistics is fraught with dangers

**The Mining Engineer**

The mining engineer is a key member of the Ore Reserve estimating team, but should also be a member of the Mineral Resource estimating team. At both stages, there are a number of aspects where close communication and agreement between the geologist, geostatistician and mining engineer are required.

The estimation method and parameters should be discussed and agreed. It is particularly important that the mining engineer fully understands how the Mineral Resource estimate is arrived at and any limitations on its reliability. Cut-off grades, minimum "ore" widths, maximum included waste widths and (if applicable) estimation block sizes should also be discussed and agreed. These are likely to depend on the probable mining method.

Dilution and mining recovery factors, while normally the province of the mining engineer, are largely dependent on geology and should be decided in consultation with the geologist. This is especially true for undeveloped deposits. Operating mines should be able to base these factors on detailed production reconciliation records.

Again in operating mines, decisions are usually required as to whether certain blocks of ground, such as pillars of various types, should be classified as Mineral Resources or Ore Reserves, or should be excluded from both of these categories. This should be decided by the mining engineer and geologist in consultation. However, the mining engineer must have the final say on when material has been "irretrievably sterilised", at which time it should be removed from both Resources and Reserves. Such decisions have the effect of reducing the company's assets and must be well documented.

**The Metallurgist**

Although the metallurgist is an important member of the technical team, he or she generally has a lesser role to play in the detailed estimation process than the geologist, geostatistician or mining engineer. It is more important to the value of the final result that the metallurgist has a close involvement at all stages of the drilling and sampling programmes upon which the estimate is based, in order that the necessary mineralogical and metallurgical investigations are carried out in a timely and logical fashion. There are three areas of the estimation exercise, however, where the metallurgist's contribution is essential for correct decisions to be made.

- The decision as to whether material is classified as Mineral Resources or Ore Reserves (or as neither) is, *inter alia*, dependent on metallurgical characteristics. Mineable mineralisation of attractive grade may have been identified, but if the metal is present in such a form as to make economic extraction impossible at present, then it cannot be classified as Ore Reserves. Whether it should be classified as Mineral Resources depends on whether economic extraction of the metal can be envisaged at some time in the future.
- In a similar fashion, division into ore types is often largely dependent on metallurgical characteristics. It is common, for example, to separate oxidised from non-oxidised material, and monometallic from polymetallic zones, because of the different treatment processes and responses involved.
- The decision as to which cut-off grade(s) to apply should only be made after consultation with the metallurgist. This is perhaps less important early in the project life, when often a number of notional cut-off grades will be applied; however it is critical at a final feasibility or mine production stage, where the cut-off grade must take account of metallurgical recovery and its effect on revenue.

**Technical Team and Management**

Although it is not always appreciated, one of the essential lines of communication is between the technical team and management.

Before the estimation exercise begins, there should be consultation and agreement on a number of matters: in particular, the purpose of the exercise, requirements of the end-users, form of presentation of the final result and any constraints on time and budgets.

During the exercise, management should be kept informed of progress. However, matters of a detailed technical nature would normally be passed on only if requested.

On completion of the exercise, there is a clear responsibility on the technical team to communicate to management not only the result, but also the data and assumptions upon which the results are based and the degree of confidence in the final figures. This should be achieved, as has already been suggested, by presenting a clearly written and logically structured report. It is recommended, however, that in addition to the report, a formal oral presentation should also be made, making use of visual aids such as overheads, slides, Powerpoint-type presentations etc. **The Mineral Resource or Ore Reserve estimate is the basis for the project. If management does not fully understand and have confidence in the estimate, then the project has a very shaky foundation**.

## SUMMARY

Given the nature of the theme of this paper, most of the points discussed are self-evident. That is the nature of common sense; it is obvious, but it is not always applied. The effect of a lack of clear thinking at any stage of a mining operation can have unfortunate consequences, but at the Mineral Resource or Ore Reserve estimation stage, it can spell disaster. The key points to bear in mind are to:

> **THINK** about whether what is being done during the exercise is **sensible**
>
> **COMMUNICATE** with other team members, management and end-users
>
> **STAND BACK** at regular intervals and avoid the "forest for the trees" trap.

If these guidelines are followed, correct decisions and judgements are not so difficult. After all:

> "*Science is nothing but trained and organised common sense*"
> (T H Huxley, *Collected Essays*).

to which may be added:

> *"…the problem with common sense is that it isn't…."*
> (Oscar Wilde).

## ACKNOWLEDGEMENTS

A number of colleagues offered ideas for, or reviewed the final draft of, the original paper on which this paper is largely based, and the author of that paper (PRS) gratefully acknowledges the assistance of Mr R Morland, Mr J Carswell, Mr C Moore, Mr R Knight, and Mr B Williams. Mr D Guibal and Mr T Wesson commented on the sections dealing with geostatistical subjects.


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