Practical interpretation of resource classification guidelines

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FIGURE CAPTIONS

TABLE CAPTIONS

INTRODUCTION

Mineral resource and ore reserve classification defines the risk associated with quoted resource tonnes and grades, allowing the interested party to make a judgement as to the 'worth' of the resource statement. The JORC Code and Guidelines (1992) are now well entrenched as the foundation upon which gold and base metal deposits in particular are publicly reported. There are three categories of resource, namely Measured, Indicated or Inferred reflecting decreasing levels of confidence. The ore reserve, that is the economically mineable part of the resource, is classified as Proven or Probable and can only be drawn from the Measured and Indicated resource categories.

As summarised by Stephenson (1995), resource/reserve classification has been an issue ever since the earliest days of mining in Australasia where, like elsewhere in the world, the industry, for a long time, lacked firm reporting guidelines. Those currently adopted in Australasia as the minimum standards for companies reporting to the Australian Stock Exchange (ASX) have been developed and revised since 1972 by the Australasian Institute of Mining and Metallurgy (AusIMM), the Australian Institute of Geoscientists (AIG) and Australian Mining Industry Council (AMIC). Debate is now underway in terms of adopting an international code.

The Code specifically does not attempt to regulate either the classification technique or the method of estimation of the resource/ore reserve, but rather places the responsibility for this task on a 'Competent Person' whose experience will decide the appropriate approach for a given commodity/orebody. The Competent Person must be a Corporate member of either the AusIMM or AIG with 5 years experience 'relevant to the style of mineralisation' under consideration.

The Guidelines (JORC, 1992) advise that the Competent Person is required to judge an Inferred resource to have identified mineralisation based on some sampling, with low confidence in geological interpretation, and no established continuity. An Indicated resource should have, in contrast, a confident interpretation of the geological framework and sufficient sampling to establish continuity of mineralisation. For a Measured resource, the sampling should leave no reasonable doubt of the tonnage and grade and should provide a close estimation of reality. There should be a firm understanding of geological controls.

The Code is qualitative in how it sets up the terminology and allows freedom of experience in choice of methodology. However, in other respects, there are fairly stringent underlying constraints. The resource must have a reasonable probability of being mineable at some future date, which implies that it should be quoted at a cutoff related to anticipated mining restraints likely to enable economic exploitation. The ore reserve must be economic at some realistic specified cost/price structure and must take into account mining recovery factors, environmental and other considerations. It is implicit that before an ore reserve can be quoted the deposit needs to have been studied to the feasibility stage or at least to pre-feasibility level.

Resource and ore reserve estimation techniques vary widely from traditional methods such as two dimensional sectional interpretations through to block modelling using weighting techniques such as inverse distance or kriging. Conditional simulation is a modern technique which gives not only the estimate of the grade but also the conditional variability of the grade for each block in the deposit.

Regardless of estimation technique, confidence classification should take into account practical considerations such as drillhole spacing, mineralisation continuity, sample representativity and potential mining method. In addition to these, there are quantitative geostatistical tools such as variography, kriging variance (which is a measure of data configuration), average sample distance from block and number of samples within search, which can be used for geostatistically generated models. Conditional simulation allows the presentation of risk in terms of the likelihood of occurrence of certain outcomes (probability map), for example the probability of exceeding cutoff.

PRACTICAL CONSIDERATIONS

Data Quality

The quality of assay data should be taken into account when there are different generations of drilling and sampling. For example different drilling and sampling methods can give rise to bias which would need to be taken into account when assessing the data prior to resource estimation. Corrections for low core recovery should also be considered.

The integrity of geological information such as drillhole logging, lithological and structural interpretation is the foundation of a high quality resource estimate. The geological model relies on accuracy of sample co-ordinates which demands high standards of surveying of both drillhole collars and downhole samples. The samples themselves are dependent on drilling technique as well as sample preparation and assaying procedures. In addition, the measurement and interpretation of bulk densities also affects resource calculation.

Drillhole spacing

The most obvious factor affecting classification is that of drillhole spacing. Most companies strive, for obvious economic reasons, to obtain the maximum benefit at minimum cost, meaning that the number of drillholes must be just sufficient to ensure continuity, without costing more than necessary.

The inevitable question that arises is - “what is the optimum drillhole spacing?”. The answer is “it depends!”. The level of risk that management is willing to accept determines how rigorous data collection will be at the start of a project as well as during subsequent mine development. The cost of gathering information has to be weighed up against the potential cost of uncertainty.

It is only with respect to coal that the JORC provides guidance on specific drillhole spacing and this is because of the general lack of depositional complexity of coal deposits.

Mineralisation continuity and uniformity

The more continuous and uniform the mineralisation, the fewer the number of samples needed for a given level of confidence. Geological controls may or may not be related to mineralisation continuity. It is thus important to establish the relevant geological controls which affect mineralisation in order to quantify spatial continuity within meaningful geological domains.

Continuity and uniformity of mineralisation may differ within geological domains. Visual recognition of continuity is obtained by examination of plans and sections showing geology and assays. Drillhole spacing needs to be designed with the style of mineralisation in mind.

Potential mining method

There are significant differences in resource confidence between open pit and underground mining and for different commodities. The risk is related not only to drillhole spacing and the nature of the mineralisation but also to the style of mining.

It is rare for an underground mine to go into feasibility with any of the resource Measured. The cost of implementing a close enough drillhole spacing from surface is usually prohibitive. Only after development progresses and underground fan drilling or development sampling is underway, can any of the resource be classified Measured. It becomes imperative, in such cases, to rely on geology and the mineralisation model more than sampling for decision making. It is also necessary to understand that there is, of necessity, a higher level of risk attached to underground mining.

Resource tonnage and grade cannot be quoted independent of the mining method selected. Additionally, at the ore reserve calculation stage, mining recoveries must be taken into account in any quantified estimates. The cut-off grade for interpretation and/or reporting needs to be considered with respect to the continuity of mineralisation which controls the degree of mining selectivity possible for a given mining method.

Cut-off

If mineralisation is unlikely to be mineable at some future date, then it cannot be classified as a resource. This indicates that economic potential must be considered within the reporting methodology for a resource prior to the evaluation of mine economics. Thus, the cut-off at which the resource is reported needs to relate to the likely mining scenario and should be consistent with economic exploitation. The Competent Person should assess the cut-off for resource reporting.

The grade/tonnage relationship varies with selectivity, and the resource estimate for a given cut-off depends on block size. It is necessary to take note of the nugget effect and the capability to mine selectively when considering the confidence classification of the resource at a given cut-off.

Estimation technique

Confidence in a resource estimate depends on the resource estimation technique employed. For example the level of risk depends on the geological mineralisation model used, the limits or constraints applied, the mathematical modelling procedure (2D vs 3D, sectional vs block model, weighting technique, top grade cut vs uncut) and the specific parameters employed. No single method is appropriate for all orebodies. It is up to the Competent Person to define the level of comfort appropriate in a given situation.

QUANTITATIVE GEOSTATISTICAL TOOLS

Semivariogram

The semivariogram (Figure 1) is a graph relating the degree of similarity between sample grades or other relevant parameters to the distance between them along any given orientation. The experimental semivariogram values calculated for a given sample separation at a given distance separation, are mathematically modelled using, in the case illustrated, a spherical model. The graph levels off at a value equal to the population variance. The distance at which it levels off is called the range of influence. The grades of samples separated by distances greater than the range of influence are uncorrelated, that is they are random in grade with respect to both their spatial separation and orientation. The nugget effect is the inherent variability plus sampling variability at zero separation distance.

The semivariogram allows the anisotropy of the mineralisation to be measured mathematically. Confidence classification depends on the drillhole spacing relative to the range of influence both along strike and down dip.

Semivariogram visualisation

Modern techniques in semivariogram visualisation, as described by Coombes (1995) in these proceedings, present the geologist with an extremely powerful tool for determining, not only individual ranges of influence for particular orientations, but also graphical displays of deposit anisotropy for given grade ranges. These displays assist in interpreting spatial continuity and in defining appropriate drillhole patterns to achieve various levels of confidence in resource classification.

For example, continuity will not be demonstrated where drillholes are further apart than the range of influence, beyond which the resource is Inferred. It is more subjective defining the drillhole spacing at which the division between Measured and Indicated resources is made, for example, as a rule of thumb, taking a distance equivalent to 2/3 of the total variability. More stringent controls must be applied in the case of extrapolation of grades beyond drillholes compared with interpolating between drillholes.

Nugget Effect

Confidence in classifying a resource is affected by the nugget effect. This is a term used to describe how well sampling results can be reproduced by repeated sampling at the same location. It incorporates both the natural inherent variability of the deposit plus variability due to sample size, sample preparation and analysis. The more homogeneous the mineralisation, the lower the nugget effect. Finely disseminated mineralisation will tend to give easily reproducible results but heterogeneous mineralisation will be sensitive to the method of sampling and could give variable results from a single location.

How to measure the Nugget Effect

The nugget effect can be measured by examining the results of repeated sampling from the same or nearby locations. It can also be measured using the semivariogram. The intersection of the semivariogram on the Y axis is an estimate of the nugget effect, that is the level of variability at zero separation between samples. For gold, this is usually of the order of 30% to 50% of the total variability. Other, more regularly distributed commodities, such as iron ore, manganese and zinc have lower nugget effects. Some coarse gold deposits and alluvial deposits may display a random distribution with a nugget effect tending towards 100%. These are the most difficult deposits to evaluate because of the lack of spatial correlation.

Importance of the Nugget Effect in resource estimation and classification

Recognition of the level of the nugget effect is vital to resource estimation. The higher the nugget effect, the lower the likelihood of being able to achieve a high degree of selectivity during mining. This affects classification in that a high nugget effect resource quoted at a low cut-off may have a higher degree of resource confidence than if it were reported at a higher cut-off.

CLASSIFICATION TECHNIQUES

Traditional classification technique

Traditional classification of resources based on sectional interpretations are limited to the resolution of the section spacing. A polygon outlined on section is generally extended half way to the adjacent sections. Polygons extrapolated down dip or beyond end-sections are given a range of influence commensurate with the perceived continuity of the mineralisation. Polygons may be split between holes down-dip and given different levels of confidence. They are classified according to the perceived continuity of mineralisation with respect to the spacing along drillhole sections. It is unlikely for polygons to be split between sections on the basis of confidence although they may be ‘pinched out’ due to changes in grade.

The traditional method, being restricted by the 2-D approach, cannot take account of subtle changes in confidence criteria, such as could be incurred in situations of complex structural detail and anisotropy. Although based on geological appraisal, the traditional technique of resource classification is more qualitative than numerical.

Kriging variance

The variance of estimation can be calculated for any configuration of samples around a given block. In the case of a weighted grade estimate calculated by the kriging method of interpolation, this variance is known as the kriging variance and represents the expected value of the squared error between the actual grade and the estimated grade. It is dependent on a number of items including block size, internal block discretisation, sample numbers and layout and the semivariogram parameters but is independent of the actual grade. It can be used as an objective measure of the geostatistical confidence in a given block with respect to data configuration. Within a given geological domain, a map of kriging variance highlights the relative confidence from block to block and, apart from the obvious application to resource classification, is a drillhole targeting tool which exposes locations where infill drilling may be beneficial.

Kriging variance links the drillhole spacing and semivariogram ranges of influence and appropriate variances can be chosen to define resource confidence categories. The most effective way of doing this is to display the colour coded variances and drillholes in plan and section in order to define which variance most closely obeys the limits defined by the semivariogram ranges of influence. In applying the classification, there is an automatic distinction made between interpolated blocks (lower variance, more confidence) and extrapolated blocks (higher variance, less confidence). Figure 2 illustrates drillholes and blocks on section with kriging variance coded to distinguish between Measured and Indicated blocks. Any volume extrapolated beyond the range of influence is given no more than Inferred status, as there is no correlation between grades of samples at locations this far apart.

In situations of complex nested structures, small scale structures may account for most of the variability and should be given most weight in defining confidence. Thus, simply having a long range structure present may not be sufficient to infer a high confidence if, in addition, small scale structures are apparent.

Number of samples per block

Some classifications are based simply on the number of samples found within the search ellipse for a given block. This method is not particularly rigorous since it does not take into account the anisotropy nor the relative spatial location of the samples. This means a block with a cluster of data nearby could be classified equally with another where the same number of samples are evenly distributed.

The number of samples per block can, however, be useful in screening out blatantly unreliable areas based on very little data. An octagonal or quadrant search filter can be imposed in order to correct for clustered data (by restricting the maximum number of samples used within individual octagonal or quadrant search areas).

Distance

The average distance of samples from the block in question is useful if the deposit is isotropic, otherwise, like sample numbers, distance does not reflect spatial relationships adequately. However, the calculation of an 'anisotropic distance' corrected for the ratios of the principal orientations of continuity is potentially useful. Inferred material can be screened out beyond the distance equal to the range of influence (where there is no spatial correlation). Measured and Indicated blocks could also be defined according to specified distances determined from the semivariogram.

Distribution of kriging variances

Many methods of dealing with kriging variances have been observed. Not all of them are valid and it may be worth noting a few poor practices. For example, there is often a tendency to consider the distribution of kriging variances and set an arbitrary distribution percentile for distinguishing resource categories, say > 2 standard deviations is Inferred, 1 - 2 standard deviations is Indicated and < 2 standard deviations is Measured.

Consider a very poorly drilled deposit, geologically no better than Indicated. If the distribution of kriging variances is used, some of the resource would automatically and erroneously be classified Measured. The kriging variance should thus not be used without reference as to how well the drillhole spacing addresses the geometry and spatial continuity of the deposit.

Conditional simulation

Conditional simulation is a process whereby the grade for any given block can be represented by a histogram defining a distribution of grades rather than a single average grade value. The risk associated with the grade of the block can be expressed as a probability map (a plot of the probability of the block grade being above a cutoff), a quantile map (a plot of the grade representing a given quantile of the grade distribution for each block) or isopleth maps representing the risk of misclassificatin of ore as waste or vice versa (Journel, *pers. comm.* 1995). These plots are data dependent, unlike the kriging variance which describes only data configuration.

The simulated grade distribution fully describes grade uncertainty at each location in a model. Journel (1992) describes conditional simulation as providing a tool for decision making with risk awareness. As such it provides a wealth of information which can be used for resource and ore reserve classification.

CLASSIFICATION LOG AND ASSESSMENT

Table 1 is based on the JORC guidelines and gives an example of the various assessment criteria involved in determining the resource confidence for a given deposit. The check list is used for both qualitative and quantitative observations, all of which are incorporated in the final decision as to the levels of confidence appropriate.

By stating the criteria used in this way, there is some degree of discipline/rigour introduced into a procedure which can otherwise be very subjective. It is possible for an interested party to review the information tabulated and reach an independent decision if necessary.

Modern geostatistical tools allow risk to be described more fully than previously. Informed decisions can be made based on spatial continuity and probability as well as interpreted geology. It is clear that the ‘Competent Person’ is more likely to be the ‘Competent Team’ since the subject of resource and ore reserve estimation addresses many disciplines including geology, geostatistics and mining. Decision makers need to understand and acknowledge that all estimates have an associated risk and they deserve to be given a measure of uncertainty which is based on a well constructed resource and ore reserve classification system. There would be merit in more quantitative risk assessment criteria being researched with a view to providing guidelines that could eventually be incorporated into the JORC code.

Table 1 Example of classification log and assessment

ASSESSMENT CRITERIA	COMMENT	≅ Inf	≅ Ind	≅ Meas	Inf	Ind	Meas
GEOLOGICAL CONTROL							
Geological Information	*Availability/ quality/ detail of logging, geological interpretation*						
DATA INTEGRITY							
Co-ordinates	*Survey quality, downhole surveys*						
Drilling Technique	*% RAB, % RC, % DDH*						
Assay Quality	*Sample interval, selective assaying or not, detection limits applied to intervals not sampled, type of analysis*						
MINERALISATION CONTINUITY							
Domaining	*Basis for domaining (oxidation, geology, mineralisation envelope)*						
Drillhole Spacing	*With respect to continuity of mineralisation*						
Estimation Technique	*Manual or geostatistical, method (eg. median indicator kriging with high grade search restriction), top cuts applied, base of drilling, geological, end constraints (essentially summarises the assumptions and decisions made with regard to the model)*						
Variogram Continuity	*Ranges, anisotropy, sample pair confidence, type of variogram used and ranges used for classification (eg. range corresponding to <2/3 sill => measured, range corresponding to >2/3 sill and < range of continuity => indicated, > range corresponding to sill => inferred, nugget as a % of sIll*						
Sample Numbers	*eg. 5 => measured, 2=> indicated, 1=> inferred*						
ECONOMIC SENSITIVITY							
Cutoff Grades used	*With respect to mining method*						
Mining Scenario	*Open pit/ underground, bulk/ selective*						
RESOURCE	*Allow for entry of actual grades and state whether acceptable in terms of JORC code and date*						

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