PRACTICAL INTERPRETATION OF MINERAL RESOURCE AND ORE RESERVE CLASSIFICATION GUIDELINES

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Mineral Resource and Ore Reserve Estimation

The AusIMM Guide to Good Practice (Monograph 23)

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INTRODUCTION

The Australasian Code for reporting of Mineral Resources and Ore Reserves (JORC Code) was updated in 1999 (JORC 1999). This paper has been written as an update of Snowden (1996 and 1997) to recognise the large amount of experience with the use of the JORC Code gained by industry over the last four years, and describes the latest developments in technology and toolkits for risk classification.

The JORC Code provides a system for classification of tonnage and grade estimates according to geological confidence and technical/economic considerations. The Code describes the criteria which apply to the reporting of exploration results, Mineral Resources, Ore Reserves, Coal Resources and Reserves and mineralised stope fill, stockpiles, remnants, pillars, low grade mineralisation and tailings.

Stephenson (1995) summarises the history of development of the JORC Code by the Joint Ore Reserves Committee, comprising members of the Australasian Institute of Mining and Metallurgy (AusIMM), the Minerals Council of Australia (MCA) and the Australian Institute of Geoscientists (AIG). The committee also has representation from the Australian Stock Exchange (ASX), Securities Institute of Australia (SIA) and Mineral Industry Consultants Association (MICA).

The Code represents the mandatory reporting standards for AusIMM and AIG members. It is considered by MCA and SIA to represent best practice and forms the minimum standard for public reporting of exploration results, Mineral Resources and Ore Reserves according to Australian Stock Exchange (ASX) and New Zealand Stock Exchange (NZSX) listing rule requirements.

The ASX requires that any public report should accurately reflect the CP’s report of the classified Mineral Resources and Ore Reserves and should name the CP, who must give consent in writing to inclusion of his/her information in the public report in the form and context in which it appears.

The JORC Code 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' (CP), whose experience will decide the appropriate approach for a given commodity/orebody. The CP must be a Fellow or Member of the AusIMM or AIG with 5 years experience 'relevant to the style of mineralisation and type of deposit and to the activity which that person is undertaking'. ASX listing rules require the CP to be named and, as such, the CP is subject to industry, regulatory and peer exposure. ASX listing rule 5.13 and Clause 8 of the JORC Code require that the CP gives consent in writing to inclusion of his/her information in the public report in the form and context in which it appears.

JORC is involved in international negotiations on reciprocity of reporting definitions and standards which have been underway for some years and are still ongoing. Meanwhile, ASX listing rules now define a "recognised mining professional" in similar terms to a CP in the JORC Code, except that the person must have "membership of a recognised overseas professional body that has agreed to sanction the person if the person does not comply with Appendix 5A" (the JORC Code).

The principles of the JORC Code are threefold. A public report should be presented clearly and unambiguously (ie transparency), it should include all the information reasonably required and expected (ie materiality) and it should be based on work undertaken by a CP (ie competence).

The Code requires that a Mineral Resource should have "reasonable prospects for eventual economic extraction", which implies that it should be quoted at a cut-off related to the anticipated mining method likely to enable economic exploitation. The Ore Reserve is the "economically mineable part of a Measured or Indicated Mineral Resource". Appropriate assessments ("which may include feasibility studies") must therefore be undertaken at some realistic specified cost/price structure and must take into account mining recovery factors, environmental and other considerations in order to "demonstrate at the time of reporting that extraction could reasonably be justified".

There are three categories of Mineral Resources, namely Measured, Indicated or Inferred Resources, reflecting decreasing levels of geological confidence. A Measured Resource is generally converted to a Proved Reserve and an Indicated Resource to a Probable Reserve but, in circumstances where mining or other technical/economic conversion factors may be of lower confidence, a Measured Resource could be converted to a Probable Reserve at the discretion of the CP.

PRACTICAL CONSIDERATIONS

Mineral Resource confidence classification should take into account practical considerations such as drilling, sampling and assay integrity, drill hole spacing, geological control and continuity, grade continuity, estimation method and block size, potential mining method and reporting period. Ore Reserve confidence classification should take into account the confidence classification of the Mineral Resource and should not include Inferred Resources. Cut-off grades, mining and metallurgical factors or assumptions, cost and revenue factors, market assessment (where appropriate) and other risk factors such as environmental, social or political should be considered by the CP in terms of their impact on confidence in the Ore Reserve estimate.

Data Quality

JORC assessment and reporting criteria requires comment on “quality of assay data and laboratory tests” and “whether acceptable levels of accuracy and precision have been established”. This means that quality checks should be made, for example assessing drilling and sampling procedures and laboratory quality control. Good data management, data flow and database integrity are critical aspects of data quality.

Geological information such as drillhole logging, lithological and structural interpretation is the foundation of a high quality resource estimate. It is necessary to consider “the nature of data and assumptions made”, “effective alternative interpretations”, “the use of geology in guiding and controlling Mineral Resource estimation” and “factors affecting continuity of grade and geology”. The geological model relies on accuracy of sample coordinates, which demands high standards of surveying of both drillhole collars and downhole samples. In addition, the measurement and interpretation of bulk densities also affects resource estimation.

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.

Inferred Resources are estimated “from geological evidence and assumed, but not verified, geological and/or grade continuity”. Sample data for Indicated Resources must be “spaced closely enough for geological and/or grade continuity to be assumed”. Measured Resources are based on data “spaced closely enough to confirm geological and/or grade continuity”.

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. Drillhole spacing needs to be designed with the style of mineralisation in mind.

Mineralisation continuity and uniformity

The optimal drillhole spacing is that which satisfies an acceptable risk profile at any given stage of a project for the minimum cost. The CP needs to decide whether sampling is close enough for an accurate measure of continuity to be made. If this is the case, a numerical evaluation of the spatial correlation can be made within the context of the geological setting in order to establish the relationship between samples and hence to evaluate the cost/benefit of infill drilling.

Potential mining method

JORC requirements are that the Mineral Resource must have "reasonable prospects for eventual economic extraction" and should consider "approximate mining parameters" and "likely mining dimensions". In other words, the Mineral Resource must be reported to a realistic degree of selectivity. The Ore Reserve "includes diluting materials and allowances for losses".

There are significant differences in Mineral Resource and Ore Reserve confidence between open pit and underground mining scenarios and for different commodities. The risk is related not only to drillhole spacing and the nature and grade of the mineralisation, but also to the cut-off grade dictated by the relevant costs. The confidence level at any given cut-off grade used for reporting a Mineral Resource and/or Ore Reserve needs to be considered with respect to the continuity of mineralisation which controls the degree of mining selectivity possible for a given mining method.

Reporting period

Conceptual or long term mine planning relies on the accuracy of global estimates. However, short term planning or grade control requires accuracy of block by block estimates. Confidence in the Ore Reserve estimate will depend on factors such as mining throughput, bench height, equipment selection and the ability of the model to represent the mining selectivity. The degree of confidence depends on mining approach (open pit versus underground, bulk versus selective, high or low cut-off) and the reporting period (daily, monthly, annual or life of mine). Current definitions in the JORC Code do not cater for specific reporting periods, but are interpreted to be geared towards reporting of the global estimates.

Cut-off grade

If mineralisation is unlikely to be mineable at some future date, then it cannot be classified as a Mineral 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 grade at which the resource is reported needs to relate to the likely mining scenario and should be consistent with economic exploitation. The CP should assess the appropriate cut-off to use for Mineral 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

JORC assessment and reporting criteria require comment on “the nature and appropriateness of the estimation technique(s) applied”. The estimation method must be able to reflect the appropriate grade/tonnage relationship for a given mining scenario and should take into account whether a change of support is required to reflect the volume variance relationship. The optimum size of the block used for modelling is related to the continuity of mineralisation as well as the data available and accessed (Krige 1996).

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 versus block model, sample search procedure, weighting technique, recognition of skewed or mixed distributions) and the specific parameters employed. No single method is appropriate for all orebodies. It is up to the CP to define the level of comfort appropriate in a given situation.

TOOLKIT AND TECHNOLOGY

Traditional classification of resources based on sectional interpretations is limited to the resolution of the section spacing and relies on a qualitative assessment of the continuity of the mineralisation with respect to the drill hole spacing along and between section lines. A more quantitative assessment of confidence in numerical estimates can be achieved using geostatistical tools, which allow one to measure:

- Spatial continuity;
- relative uncertainty as a function of data configuration; and
- absolute risk.

Spatial continuity

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 can be assessed according to the drillhole spacing relative to the range of influence both along strike and down dip.

Semivariogram visualisation described by Coombes (1995) is used to determine the ranges of influence for particular orientations and provides graphical displays of deposit anisotropy for given indicator grade ranges. These displays assist in interpreting spatial continuity and in defining appropriate drillhole patterns to achieve various levels of confidence in Mineral Resource classification.

Nugget Effect

Confidence in classifying a Mineral 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. In practice, the nugget effect is the level of variability at dimensions less than the minimum sample spacing. 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 Mineral 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.

Measures of relative uncertainty

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.

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 estimation, 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.

Kriging variance 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 Mineral 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 Mineral 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.

Conditional bias

Krige (1996) presents a practical analysis of the effects of spatial continuity and the available data within the search ellipse as it affects measures of conditional bias. The two parameters he suggests using to investigate whether the block size used for grade estimation is appropriate are kriging efficiency (KE%) and regression slope (R) which can also be used to calibrate the confidence in block estimates and are given as follows:

$$KE = (BV-KV)/BV$$

$$R = \frac{BV-KV+|\mu|}{BV - KV + |2\mu|}$$

Where:

BV = theoretical variance of blocks within domain;

KV = variance between kriged grade and true (unknown) grade, ie kriging variance;

μ = LaGrange multiplier

Perfect estimation would give values of KV = 0, KE = 100% and R=1.

Distribution of measures of relative uncertainty

Many methods of classification based on kriging variances, kriging efficiency or regression slope have been observed. Not all of them are valid, as pointed out by Glacken (1996) and it may be worth noting a few poor practices. For example, there is often a tendency to consider the distribution of, say, kriging variances and set an arbitrary distribution percentile for distinguishing Mineral 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 and to the overall integrity of the input data and security of the interpretation of the geological controls on mineralisation. Confidence in the geological framework is all-important and generally takes precedence over any mathematical indicator of confidence.

Measurement of absolute risk

Conditional simulation

Confidence classification can also be facilitated using conditional simulation, which provides an objective measurement of grade or tonnage risk (Thomas et al 1998). 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 achieveing the grade of any block can be expressed as a probability map (a plot of the probability of the block grade being above a cut-off), 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 misclassification of ore as waste or vice versa (Journel, *pers. comm.* 1995). These plots are grade 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 Mineral Resource and Ore Reserve classification. Practical examples of the uses of conditional simulation for risk analysis are given by Coombes et al (1998, 1999 and 2000).

Risk assessment using conditional simulation

The range of outcomes for each location simulated in a model can be summarised in terms of an average, minimum, maximum, or any other statistic of the distribution. A confidence interval can be presented to communicate the degree of risk at each point location, or by block, or indeed, by any given reporting period. High confidence blocks, for example where the 90% confidence limit is less than, say, plus or minus10% of the average simulated grade (for a given location, block or period), can be identified for Measured Resources and lower confidence blocks for Indicated and Inferred Resources.

A method of demonstrating grade risk is illustrated in Figure 3, which shows the average grade of the minimum, maximum and median simulations by scheduled annual increments and also gives the kriged model grade for comparison. The scheduled grade for years 3 and 7 is well outside the range of simulated outcomes, highlighting potential high risk periods for further investigation. The magnitude of the risk in grade is generally of the order of +/- 0.5 g/t to 1 g/t for each of the periods scheduled.

Conditional simulation-based resource categories have the advantage of objectivity, in that the degree of risk can be expressed quantitatively, and take into account grade variability as well as location of data. It must be stressed, however, that data integrity, geological continuity and mining assumptions must always be considered, regardless of the technology applied, and it is the CP who needs to decide on the final classification, taking all relevant factors into account.

EXAMPLE OF ASSESSMENT AND REPORTING CRITERIA

Table 1 is based on the JORC guidelines and gives an example of the various assessment criteria involved in determining the Mineral Resource and Ore Reserve confidence for a hypothetical 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.

In this example the Mineral Resource can be classified into Measured, Indicated and Inferred Resources and the Ore Reserve can be classified into Proved and Probable Ore Reserves based on the assessment and reporting criteria described in Table 1.

The sampling and assay results, in particular the underground channel sampling, have been independently checked and found to be reasonable. Due care and consideration has been exercised in preparing and validating the data entry. The database established and maintained is considered to be a good representation of the original sampling data with respect to location, grade and lithology parameters and is considered suitable for resource estimation. The classification is made in the context of the feasibility of a bulk open pit mining operation.

Resource blocks within the continuous and well-constrained Domain 1 have been defined as Measured Resources. Resource blocks within Domain 2 where there is less confidence in the geological model and poorer spatial continuity, have been separated into Indicated and Inferred Resources using relative kriging error for calibration according to drill spacing.

CONCLUSIONS

Modern geostatistical tools, which provide quantitative methods of describing risk, allow informed decisions to be made based on spatial continuity and probability, in addition to data quality and interpreted geology. It is clear that the 'Competent Person' is more likely to be the 'Competent Team' since the subject of Mineral Resource and Ore Reserve estimation addresses many disciplines including geology, geostatistics, mining and metallurgy.

Stakeholders such as resource/ore reserve practitioners, mining company management, the investment community and the financing community all rely on the JORC Code and capital market regulations. A well-constructed Mineral Resource and Ore Reserve classification system is transparent and discloses all material issues for the mutual benefit of all stakeholders. The increased use of more quantitative methods of determining and communicating uncertainty envelopes around Mineral Resource and Ore Reserve tonnes and grade will address a critical area missing from the current common practice of reporting.

It is likely that decision makers will use conditional simulation of grades in conjunction with other risk assessment tools such as the probability of pit slope failures and sensitivity to technical parameters and price/operating cost scenarios (as described by Morley et al (1999)), to evaluate up-side opportunities as well as risk of failure. Rather than being regulated by the reporting Code, it is more than likely that industry will embrace these tools once the bottom-line value of quantifying risk becomes more and more apparent.

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TABLE 1
EXAMPLE OF ASSESSMENT AND REPORTING CRITERIA FOR A HYPOTHETICAL STUDY

SAMPLING TECHNIQUES AND DATA	
CRITERIA	EXPLANATION
Drilling techniques.	HQ surface DDH. Original NQ underground diamond drilling. Recent NQ diamond drilling focussed below the last level of underground development
Logging.	Re-sampling confirmed high standard of original logging. No routine photographic record
Drill sample recovery.	Surface drill samples (10% of database) typically had recoveries of less than 75%, underground drilling typically better than 85%
Other sampling techniques.	Underground channel sampling
Sub-sampling techniques and sample preparation.	Whole sample generally crushed to –1mm before riffle splitting, followed by milling prior to pulp selection
Quality of assay data and laboratory tests.	Laboratory and check procedures are industry standard
Verification of sampling and assaying.	Independently resampled 10% of the underground samples and reassayed 10% of the reject and pulp samples. Checks confirm original results.
Location of data points.	Collars and all drillholes surveyed downhole using reliable technique.
Data density and distribution.	Underground development and crosscut sampling on development levels spaced 40m apart. Crosscuts spaced at 20m. Underground fan drilling at 20 m centres.
Audits or reviews.	Sampling protocol reviewed by independent consultant and found to be satisfactory.
ESTIMATION AND REPORTING OF MINERAL RESOURCES	
Database integrity.	Data capture included good validation procedure
Geological interpretation.	Domains are based on lithology, style of mineralisation and grade information. Good grade continuity in well constrained Domain 1. Domain 2 has less continuous peripheral mineralisation.
Estimation and modelling techniques.	Multiple Indicator Kriging within separate domains, estimated mean Au grades for 10m x 10m x 10m blocks.
Cut-off grades or parameters.	Resource modelled within geological boundaries, economic cut-off about 1 g/t Au
Mining factors or assumptions.	Open pit mining of primary consideration.
Metallurgical factors or assumptions.	No assumptions made
Tonnage factors (in situ bulk densities).	Measurements show little variability, average bulk density applied to all rock types.
Classification.	Calibrated using the relative kriging error with thresholds selected to reflect the demonstrated geological and grade continuity, resource classified on the basis of the bulk grades
Audits or reviews.	No previous audits.
ESTIMATION AND REPORTING OF ORE RESERVES	
Mineral Resource estimate for conversion to Ore Reserves.	Mineral Resource is inclusive of the Ore Reserve. Open pit optimisation of fully diluted bulk block model using Measured and Indicated Resources. Pit design and schedule based on 1.5 Mtpa throughput.
Cut-off grades or parameters.	1 g/t cutoff based on current spot gold price and current operating costs
Mining factors or assumptions.	Pit slopes based on independent geotechnical studies, no additional mining dilution.
Metallurgical factors or assumptions.	Recovery of 98% based on metallurgical testwork
Cost and revenue factors.	Operating cost parameters based on owner estimates, revenue parameters based on spot price. Government charges and royalty allowances made.
Market assessment.	Not applicable
Others.	No anticipated environmental, social, political or other risk factors
Classification.	Proved Ore Reserve derived from Measured Resource and Probable Ore Reserve derived from Indicated Resource.
Audits or reviews.	No audits.

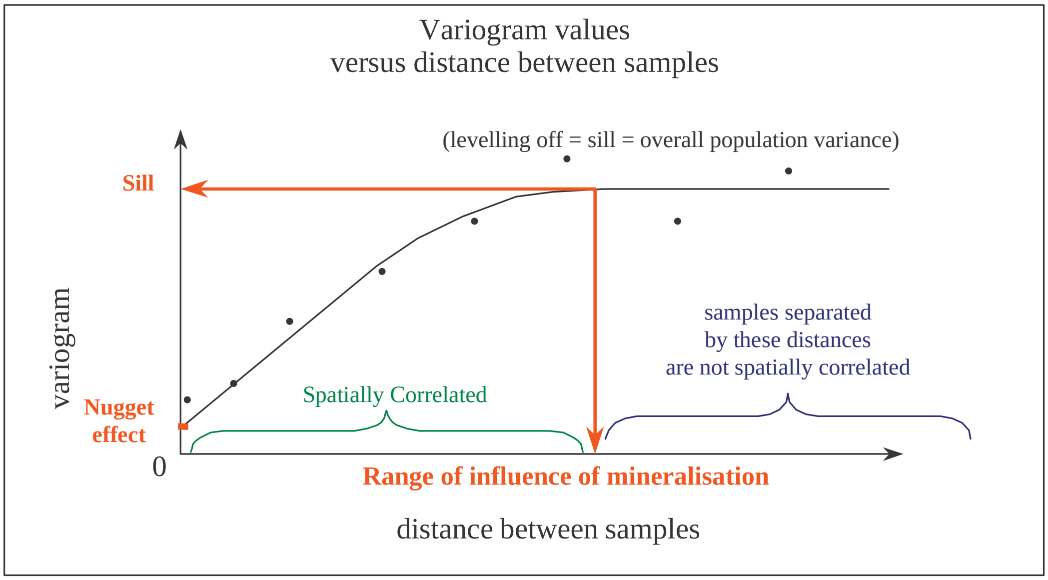

Figure 1 Experimental semivariogram and spherical model

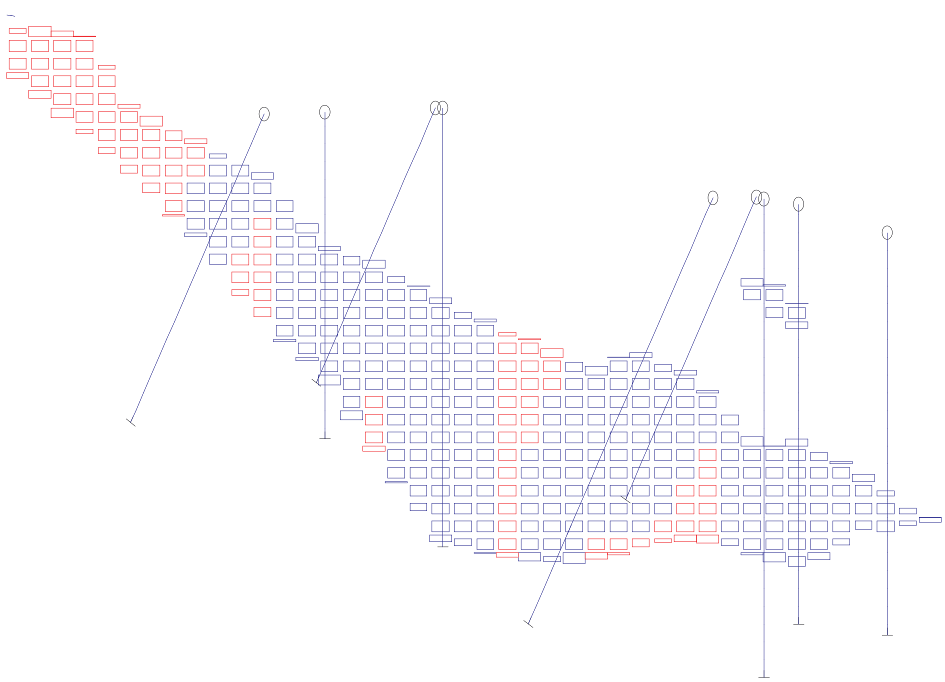

Figure 2 Drillhole section showing resource classification categories

Blue = Measured, Red = Indicated

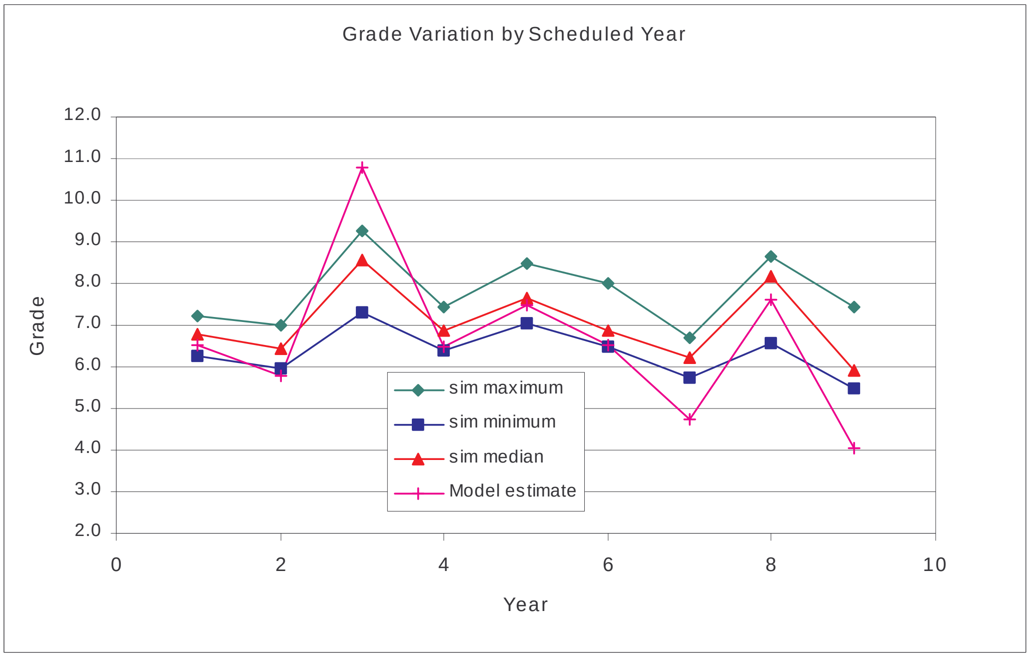

Figure 3 Grade risk illustrated by reporting period