MINERAL RESOURCE MODELLING AND GRADE ESTIMATION

24 OCTOBER 2025

PRESENTER:

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INTRODUCTION

1. The presentation summarises the things many practitioners know already but may give lesser or more importance to some steps than others in the process.
2. It should be clear by the end of the presentation the strong connection and overlap between mineral resource modelling and grade estimation.
3. In my experience the weaker the connection between the field geologist and Geostatistician the higher the risk of a final grade model with a disconnect to reality, the most prevalent being the linking of intersections across a barren zone, thereby falsely boosting mineral resource estimates.

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HISTORICAL ESTIMATION OVERVIEW

1. **Manual Methods** (includes use of spreadsheets):

(a) Section or plan view simple or weighted averages

(b) Polygonal methods based on a notion of range of influence as midway between drill intersections

(c) Inverse distance (usually Power 1) - usually used to estimate blocks that do not have an sampling data in them or at the boundaries

2. **Software Methods** (made for purpose software):

(a) Kriging (most popular) - Simple, Ordinary, Indicator

(b) Inverse Distance (power 1 and power 2)

(c) Simulation - usually conditional to try to estimate proportion and distribution of grades above chosen cut offs

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HISTORICAL ESTIMATION OVERVIEW

1. In the manual method the exploration/mine geologist drew their own plans and sections by hand before handing them over to a draughtsman, and then signing off. In that sense ownership of the model and estimation remained with the originator.

2. The advent of geological modelling and estimation software brought in a new position, "computer geologist", who became focused on using the software as the next step after receiving sampling (usually drill hole data). Mistake number 1.

   Drilling on sections was thought to be unnecessary as the software would capture the correct position in space rather than projection to a section line in the manual case. Mistake Number 2, though not as serious as Mistake Number 1.

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RESETTING THE PROCESS

THE 8 RIGHTS FOR CREDIBLE MINERAL RESOURCE ESTIMATION

1. Get the Geology and Structure Right
2. Get the Sampling right
3. Get the Assays and Densities right
4. Get the Mineralisation Pattern(s) right
5. Get the handover to a resource modelling and grade estimation specialist right
6. Get the mineralisation spatial behaviour model block model definition right
7. Get the block model definition right
8. Get the mineral resource classification right

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GEOLOGY AND STRUCTURE

This is Geology 101. Geological and structural mapping The deposit has a geological setting . It is important that this is well understood as a major constraining factor.

Structures are also important whether there are disruptive (e.g. fault displacement) or enhancers (mineralisation emplaced in shear zones).

A 3D geological model can be built at this stage. The construction of geological or resource model is the best demonstration of knowledge of the geological setting. In this regard it should worth celebrating that among us there are at least two who have contributed to the understanding of PGM mineralisation and structure on the Great Dyke: Tony Martin who ushered in narrower sampling of the MSZ and spreadsheet estimation alignment based on base of the Pt peak which coincide with sulphides becoming finer from the hanngingwall and Andrew du Toit who came up with Circles Model to mimic the continuously deceasing dip from both flanks to the axis of the dyke.

In parallel with this geological modelling, should be the collection of density information for the different rock types and alteration or oxidation zones

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DENSITY SAMPLING

- One often overlooked parameter during sampling is DENSITY. Quite often it is done as an afterthought when the time to estimate tonnage has comes.
- But density is critical because grades are given in terms of mass (% or g/t). Hence modelled volumes must be converted to tonnages to have an estimate of mineral content.
- It is trite that for the same volume and grade, resource tonnage and in situ mineral content is directly and positively correlated with density. Therefore its is critical to have sufficient number of density measurements for each rock type (oxide, intermediate and sulphide/fresh, alteration as may be applicable).
- Because density does tend to have a mean value , a minimum of 30 samples are required for each sample type. Preferably, density determinations must be exhaustive over the sampled interval. If not then periodic determinations (annually) must be done to check for any changes.

The PGM miners are foremost because they determine density for each sample across the zone of interest, such that density estimation can be done in the same manner as grade.

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SAMPLING FOR GRADE

It is critical that sample integrity is preserved from the field until the results are out of the laboratory.

1. Field QAQC - documented procedures followed in the field to ensure that samples are correctly located (X,Y,Z), representative, the correct size, there are no undue losses, there is no cross-contamination and they are correctly labelled.

2. Laboratory QAQC - the documented measures a geologist must put in place to assess the accuracy of laboratory results:

(i) **Use of CRMs (standards)** - rejection/acceptance

(ii) **Use of duplicates** - usually for characterisation of the deposit

(iii) **Use of coarse blanks** - for checking laboratory preparation contamination checks

(iv) **Use of pulp blanks** - for in-process contamination checks

(v) **Use of repeats** - pulp rejects re-assayed to check repeatability of assays

(vi) **Use of umpire laboratories** - check for systemic errors like bias

The aim is to arrive at the conclusion that the assay data are fit for use in mineral resource modelling, grade estimation and other business use.

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Handling of Other Quality Control Results

1. Duplicates characterise the mineralisation rather than to be used as a tool for acceptance or rejection. However, for evenly disseminated mineralisation the Duplicate ≈ Original
2. The reject from the final (homogenised) pulp that gets analysed is a repeat i.e., it can be used to test repeatability and, indirectly, the level of achieved homogenisation (CRM-like).
3. Being part of the sample stream and accepted because of passed CRMs, Duplicates and Repeats cannot be used as CRMs for acceptance/rejection decisions.

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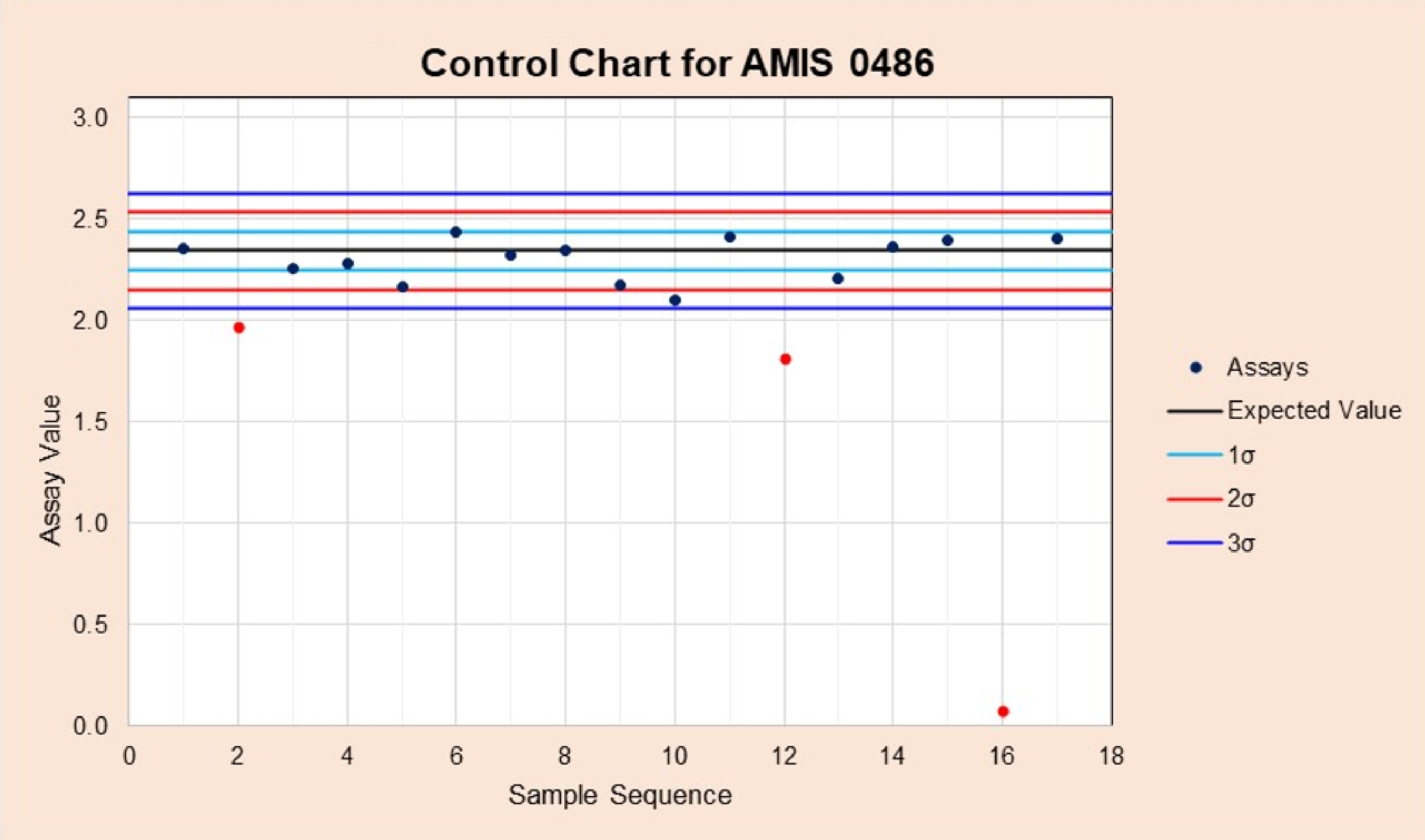
Control Chart CRM



1. Check that the failed values shown as red points are real failures (e.g. that they are not CRM swaps) before requesting reanalysis. Point 16 seems definitely a CRM swap.
2. The low failure outside 2 but within 3 (point number 10) may be considered marginal failure because it is a possible outcome from the homogenised CRM pulp. The Competent Person needs to make this call after noticing that such outcomes occasionally arise.

The 2σ guideline is not a straight jacket. It should be followed within reason.

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HANDOVER FOR MINERALISATION MODELLING

- The best way to handover data from the exploration or project geologist to the in-house or outsourced mineral resource modelling speclialist is to ensure an overlap rather than a baton handover.
- Geostatisticians are not necessarily good at interpreting the data in light of the geology and structure. A typical geostatistician is quick to look at assays and possible intersection correlation based on a superficial understanding of strike and dip.
- With experience a geostatistician soon learns that the statistical, and spatial analysis comes after complette understanding of the geology and mineralisation model. The project geologists must handover these models in the best format possible, even if it means handrawn plans and section and must validate the model before estimation

Function	Field work	Geogical Modelling Sampling	Resource Modelling	Geostatistical Modelling	Classification
Project Geologist(s)					
Resource Modeller/Geostatistician					

MINERALISATION MODELLING

The best way to deal with this is to formalise the modelling with a with a standard task procedure (or a Modelling Rules Statement). It helps to maintain consistency and objective approach.

1. Cut-off Grades
2. Minimum width
3. Handling of internal waste intervals
4. Lateral extrapolation after the last drill lines
5. Down-dip extrapolation - to a common datum or uneven base
6. State any assumptions

MINERALISATION MODELLING

The Main Issues are:

1. Cut-off Grades
2. Minimum width
3. Handling of internal waste intervals
4. Lateral extrapolation after the last drill lines
5. Down-dip extrapolation - to a common datum or uneven base
6. Conditioning of strings for wireframing purposes
7. Formalise how to deal with soft boundaries, if only at a later stage.
8. Handling of topograhy

VARIOGRAPHY

1. Variography is an intuitively popular method of characterising spatial behaviour along 3 mutually perpendicular directions which are usually but not always along strike, down dip (perpendicular to strike) and across strike (perpendicular to both strike and dip). It is an objective method of asigning weights to samples that participate in an estimate according to both distance and direction.

2. Very short range variablity is captured in the nugget component of total variance i.e. this quantifies the fact that as the distance between adjacent samples approaches zero, there is necessarily no convergence in the grades. Nugget variance is therefore non-direction, unlike spatial variance.

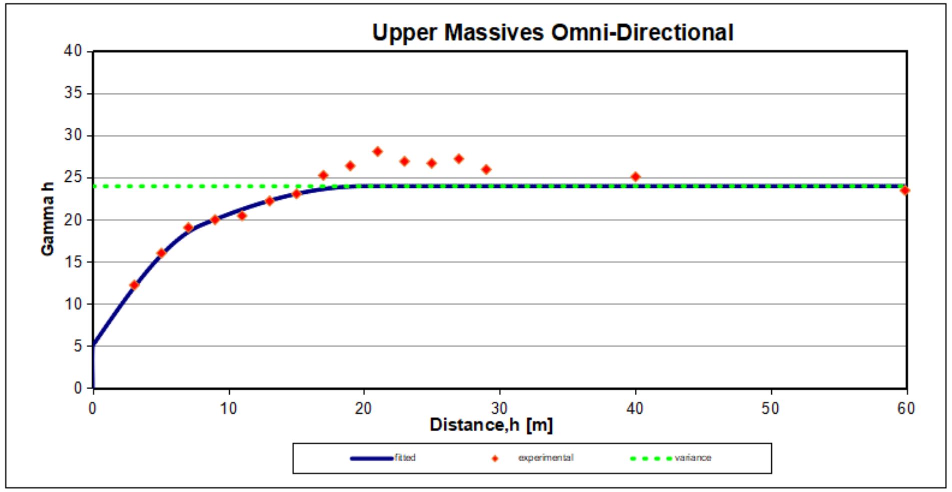
3. Isotropy - exists if the **range** is the same irrespective of direction i.e. the weigths assigned to samples that participate in an estimate are the same for the same distance irrespective of direction. (***Range** = the distance at which sample grades are no longer correlated)

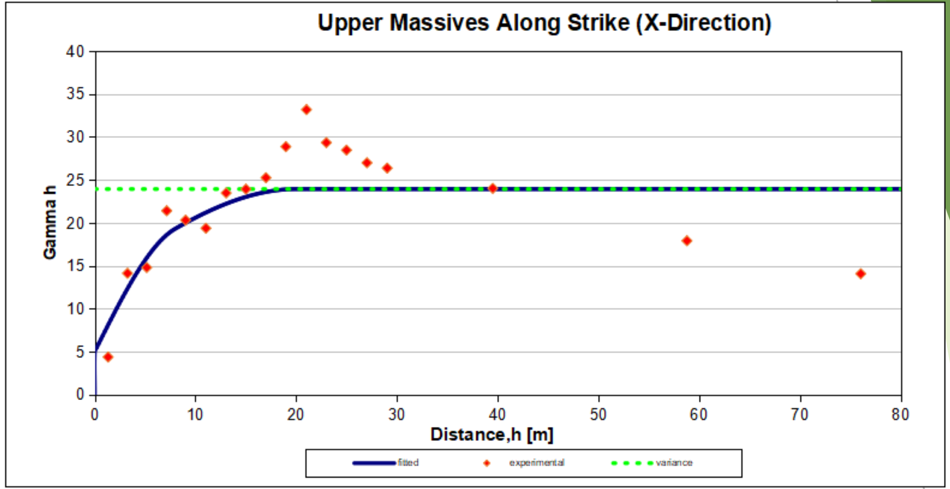
4. Anisotropy - exists if there is at least one direction with a different **range** i.e. the weigths assigned to samples that participate in an estimate are different for the same distance according to the direction

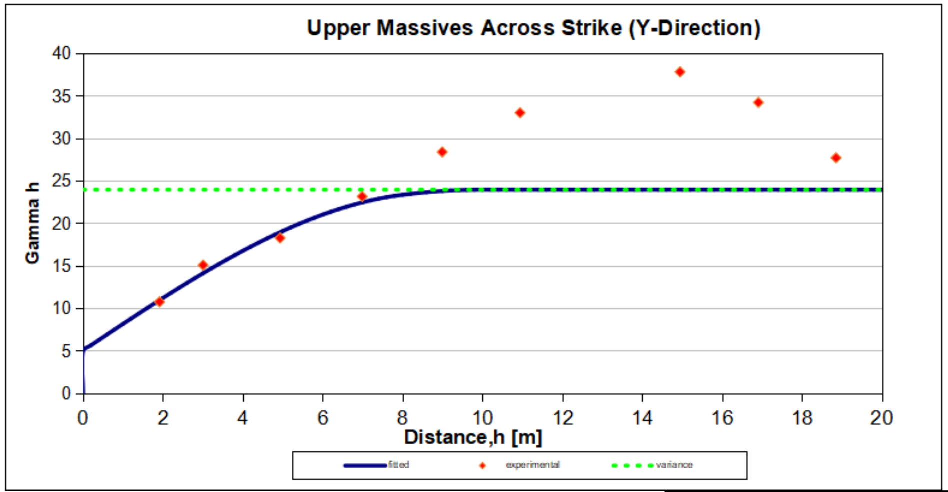
5. A variogram (semi-variogram, *sensu stricto*, $\gamma(h) = \frac{1}{2n} \sum_{i=n}^{n} [G(x_i) - G(x_i+h)]$) does not depend on the grades but differences in grade such that if you scale the grades (mulitiply/divide by a constant) the resulting semi-variogram will be the same: i.e. the ranges will remain the same even though the nugget and spatial variance will change accordingly.

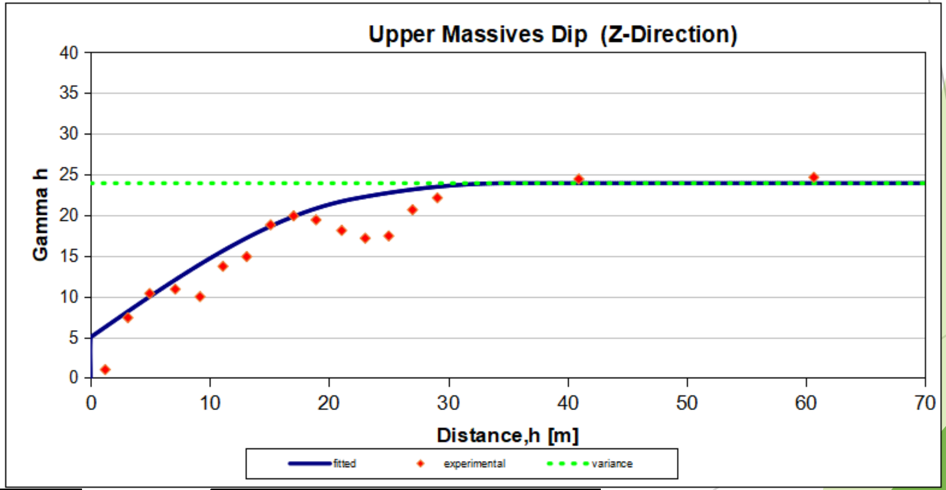
G = grade, h = separation distance and n = number f samples participacting in the estimate

VARIOGRAPHY









		Range 1				Range 2		
C0	C1	X	Y	Z	C2	X	Y	Z
5.000	8.240	8	8	22	10.686	20	10	35
20.9%	34.4%				44.7%			

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VARIOGRAPHY

1. The thing to keep in mind is that the semi-variogram model fitted on the experimental data is an approximation of the underlying semi-variogram model. The sample data available just makes it possible for the modeller to have an idea what the underlying semi-variogram looks like.
2. This might suggest that diligent fitting of the model onto data (Nugget + several nested variograms) but this is not the case. There is such a thing as overfitting a model on experimetal data. It is sufficient that the fitted model be a good fit up to the sill (Nugget + C1 ± C2). As data sampling density increases it can bepected that the fitted moel will change but the changes should be minimal.
3. There are three common model semi-variograms to fit onto experimental model in the mineral resorce models

(i) Spherical model - honurs the fact that in any block the average will be bweeten the lowest and highest grades in the input

(ii) Exponential model - rarely used as it is applicable where the tjere is trend such that an absolute mean does not exist and so the variance is asymptotic. Despite this if an exponential model fits closeley with a spherical model, the results will be very close.

(ii) the Gaussian model - the role of this in estimating intermediate topographical points from point data has since been overtaken by drone surveys, However, it is still useful for estimating geotechnical and environmental (e.g. soil contamination) parameters because it is posiible to have estimates that are lower or higher that those in the input.

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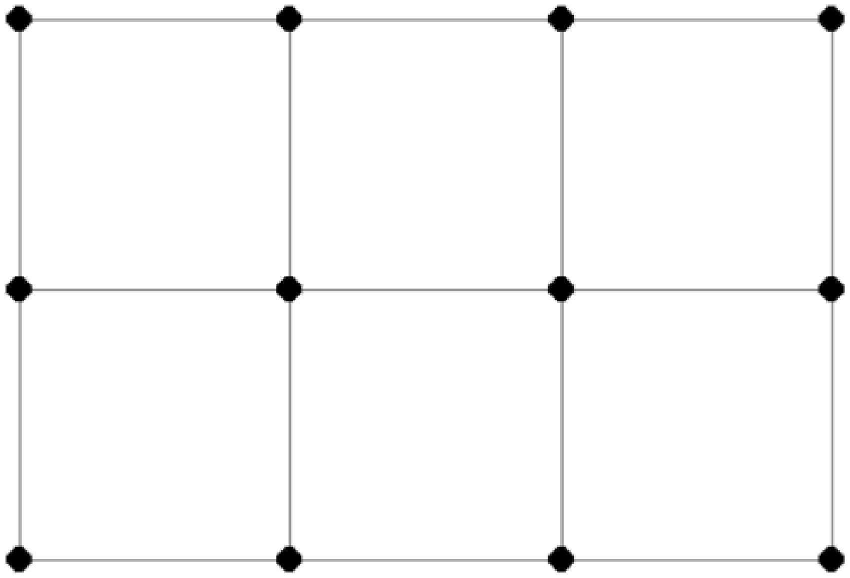
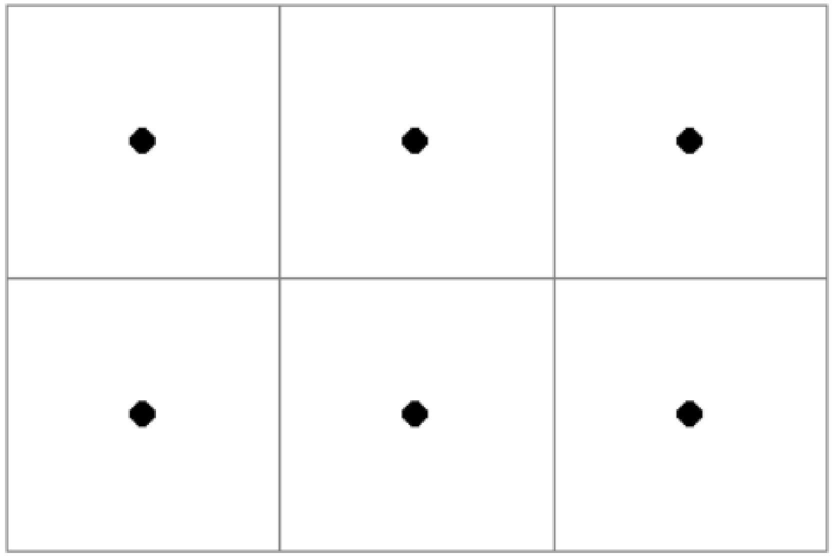
BLOCK MODELLING

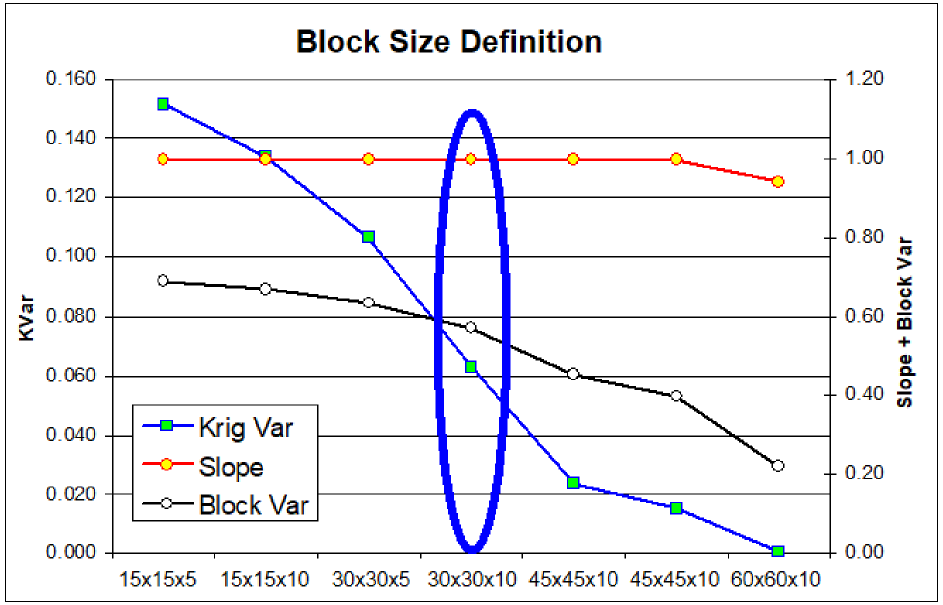
1. As the target of the estimation process, block model size and configuration is important and is important to run krig tests to optimise them.
2. Generally, the drilling drid determines the block size. Estimate into blocks smaller than the grid requires non-linear geostastitics This is true even if its is possible to get away with it in miuneral deposits with low variability over large distances e.g. Great Dyke chrome and PGMs

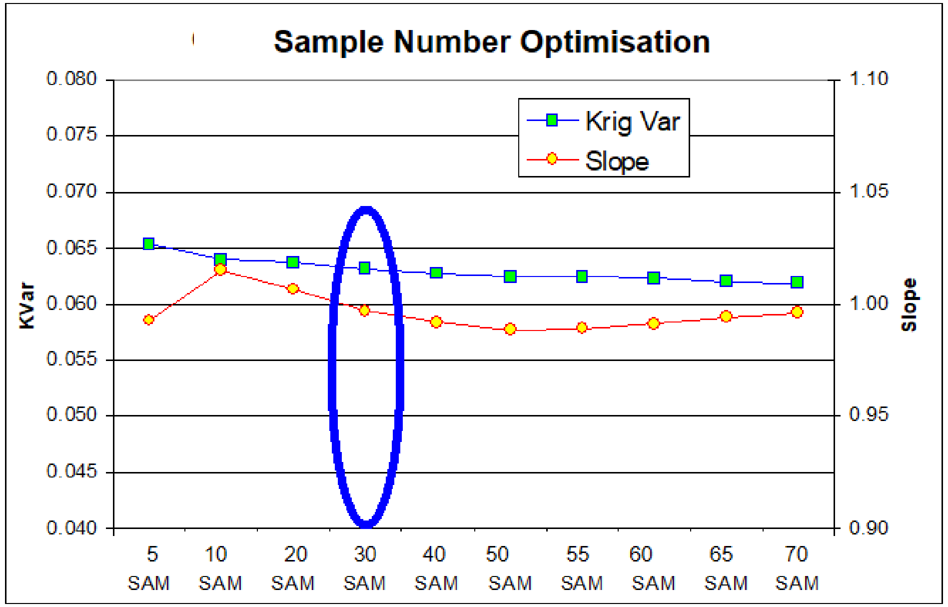




BLOCK MODELLING

1. The block size will determine the search volume and the optimum number of samples to achieve robust results.
2. Generally the drilling drid determines the block size. Estimate into blocks smaller than the grid requires non-linear geostastitics This is true even if its is possible to get away with it in miuneral deposits with low variability over large distances e.g. Great Dyke chrome and PGMs





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BLOCK MODELLING

1. Krig tests are necessary by testing the chosen block size at differently informed positions ; weel informed, moderately and sparsely informed.
2. The aim is to change start with a small search ellipsoid e.g. half the search range and gradually increase to twice the range percentage of samples with negative weights in the well informed area should not exceed 2%
3. Some software have the option of excluding samples with negative weights in the actual estimation process, but at the krig testing stage this option should not be considered because the idea is to understand the effect of incresing the search neighbourhood in a well informed block, when the samples are sparse but distant, and intermediate positions.

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BLOCK MODELLING AND ESTIMATION

1. A parent prototype block model overlapping the extent of the resource wireframes
2. Some software have the ability to rotate blocks to align with the strike of the orebody but the inability to do so is not a barrier to credible estimates
3. The important thing is that the axes of the exllipsoids are aligned correctly e.g. along strike (or longest range) and downdip. The axis across dip will automatically be perperdicular to both.
4. Avoid estimating into subcells. Subcelling is designed to clip out portions of parent cells outside the resource wireframes or, conversely, to ensure that the portion withing the resource wireframes fits within the resource wireframe as closely as possible. Nevertheless, minimise the level of subcelling as it can make the model unneccesarily heavy.
5. Setting up of the estimation protocols may differ but most software have the ability to do multiple estimates in a single run. If in addition the primary kriging estmates, control estimates are also made using a clasical method like ID or ID2, it is better that the same search protocol is applied for credible comparison to be made.

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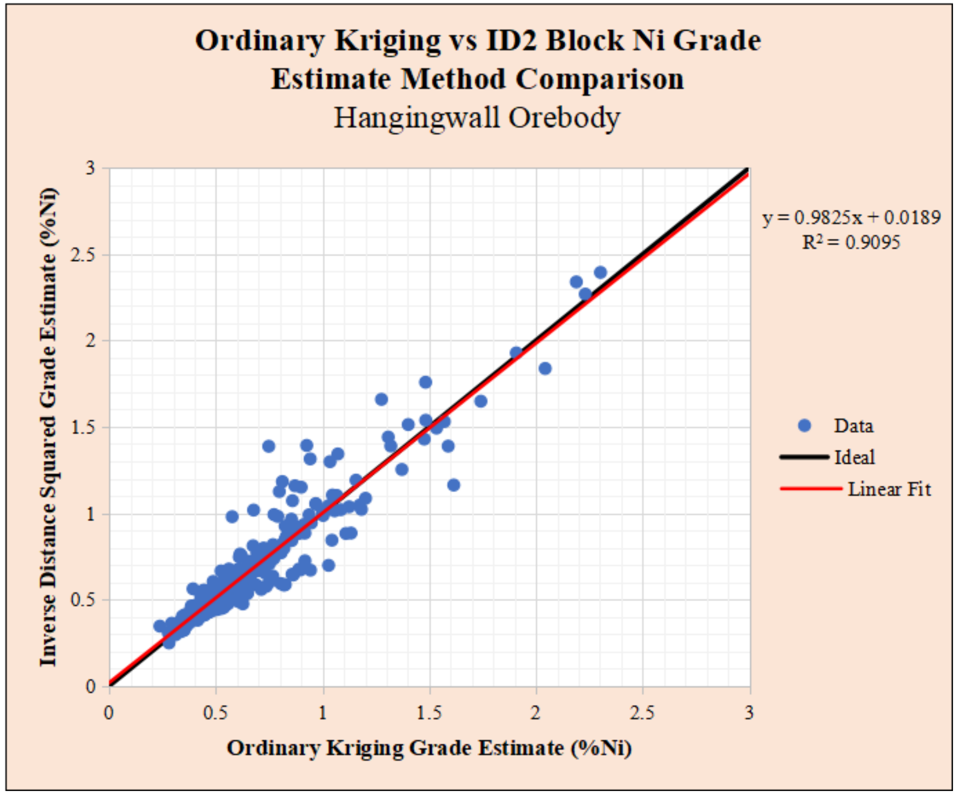
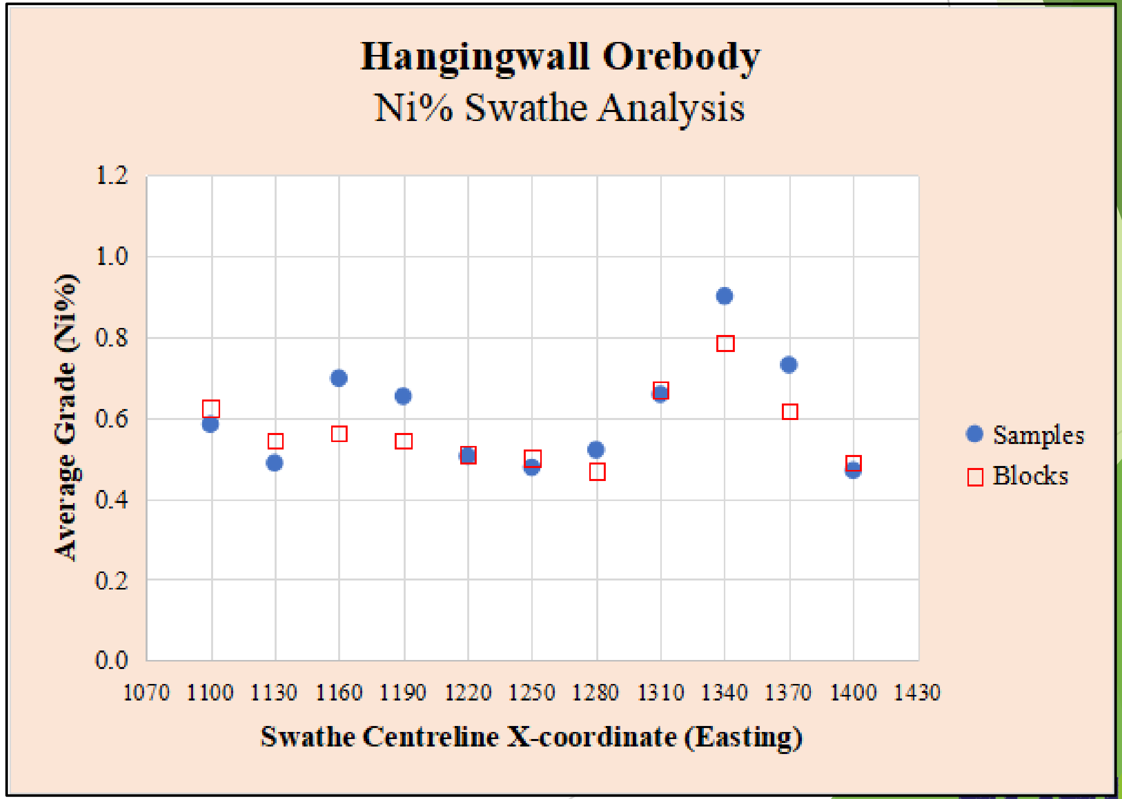
Estimation Validation

1. Visual inspection always works as a first line of validation. The block model coloured by grade should reflect the grade of the samples
2. Quatitatively, the block model average of the domains and globally should be practically the same as for the composites but the variance should be smaller.
3. Other Checks:





CLASSIFICATION

There are many classification approaches with a different degree of simplicity and complexity

1. **Search volume** (SVOL) based on sample grid spacing (1= Measured 2 = Indicated 3 = Inferred). This works well for brownfields projects where confidence based on the grid spacing has been established. Additional constrains are the number of samples and drillholes involved e.g, a block the edge may have all samples from the first search volume but they are very few and coming from only two drill holes and there fore cannot be classified as Measured.
2. **Slope of regression -** The Slope of Regression (SR) is a measure of the quality of the estimate, which is interpreted to be more robust when the slope of regression approaches 1. SR is based on the regression of the estimated value and the theoretical true value.
3. **Kriging Efficiency -** This is similar in application to the slope of Regression. The kriging efficiency is closely related to the Kriging Variance but is a scaled statistic, such that it never exceeds a value of 1. A way of getting this immediately is to use scaled semi-variogram parameters (Nugget + Spatial Variance =1.0).
4. **Determination from estimation variance of production panels -** estimated from idealised/theoretical true grade estimates and actual. e.g. for a gold mining entity differences less than 15% (i) up to 3 months are Measured, (ii) after 3 months up to 8 months are Indicated and (iii) beyond 8 months is Inferred. This tends to be specific to company specifications of risk and calibration on historical perfomance.

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SUMMARY ROAD MAP

	Parameter	Activity
Field Geology	**Geology and Structure**	Geological Modelling
	Assay and Density data	Sampling and Data Validation
Information Handover	**Modelling**	Geological Modelling
		Resource Modelling
Quantitative Resource Modelling	**Exploratory Data Analysis**	Statistics
		Histograms
		Correlation Graphs
	Domaining	Stationarity Analysis
		Mineralisation sub-zones
	Geostatistical Analysis	Spatial Continuity in 3 Orthogonal Directions
		Variography
Block Modelling	**Kriging Neighbourhood Analysis**	Block Size analysis
		Sample Number analysis
		Discretization
		Search Optimization
	Grade Estimation	Parameter Files
		Grade Estimation (OK vs ID/ID2)
	Model Validation	Statistical Comparison
		Swathe Analysis - Blocks vs Samples
		Alternative Method Comparison
	Classification	Kriging Efficiency
		Sample Spacing
		Search Volumes
		Geological Considerations

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END