Mining Seminar
Geology and Resource Estimation
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March 2014
Geology, Resources And Mining Topics

1. Introduction
2. Geological Settings and Mineralisation
3. Reporting Codes – JORC, NI43-101
4. Resource Estimation
5. Technical Due Diligence
1. INTRODUCTION
Role of a Resource Geologist

- Concerned with earth materials that can be utilized for economic and/or industrial purposes;
- Computerised geologic resource modelling is a specialized skill, which is part science, part art;
- The assumptions (and errors) of a resource model will propagate all the way through the economic analysis of a mining operation;
- Therefore, geologists, engineers, metallurgists, investors, CFOs and CEOs all the rest have a vested interest in resource modelling.
Tools of the Trade

► Wide range of very powerful data processing tools available;
► It is possible for a single individual to achieve what would have taken whole team weeks, and with greater flexibility;
► Use these tools with skill and application;
► Examine tools available to the practitioner, their uses, strengths and weaknesses, and then look at some examples of how they are applied in practise;
► Both manual and computer based skills should be used, along with a large dose of Common Sense.
Resource Estimation Cycle

1. Raw Geological Data
2. Capturing Data
3. Validate Data
4. Know Your Data
   - 3D Geological Model Interpretation
   - Geostatistics
     - Basic Statistics
     - Constrained Raw Data
     - Domaining
   - Volume Modeling
     - Variograms
     - Variogram Parameters
     - KNA Study
   - Block Modeling
     - Estimation
     - Model Validation
5. RESOURCE
6. Reporting
Resource Modelling Cycle

1. Basic understanding of how these types of models are constructed and of their purpose

2. The Resource Model is an interpretation of the location, size, shape, and grade of a deposit and the surrounding waste material
   - based on information derived from mapping and drillhole logging such as geologic contacts, rock types, structures, assays, geophysical logs, and density measurements.

3. A three dimensional interpretation will constrain zones representing different rock types, different zones of alteration, structures and mineralization etc
   - topographic data will be used to divide the 3-D space into an above ground (air) zone and a below ground (rock) zone
Resource Modelling Cycle

4. Created boundaries of these zones are typically a series of polygons or 3D triangulated surfaces (wireframes)

5. Generate statistics
   - Basic Statistics, e.g. mean, mode, max, min, SD and CV
   - Statistical Plots, e.g. histograms and log probability plots

6. Generate Variograms

7. Develop a Block Model
   - A Block model is a 3D gridded model representing variability in rock type, density and grade;
   - Block dimensions, model size and the number of attributes can vary between models;
   - Confidence levels can also be assigned to the block model. (resource classification as described by JORC as measured.)
“Know Your Data”

- A clear understanding of the style of mineralisation.
- The model will be revised and amended many times during its life as more data becomes available, each being a “snap shot” of an unknown reality at various stages of the process from exploration to mine closure.
- The accuracy of this interpretation depends on the quantity and quality of the input data, the ability of the tools being used to model reality and the skill of the practitioner.
Let us consider a set of drilling intersections
A very conservative geologist’s interpretation.
A conservative geologist’s interpretation.
An optimistic geologist’s interpretation.
A very optimistic geologist’s interpretation.
An extremely optimistic geologist’s interpretation.
A geophysicist’s interpretation.
The mining engineers interpretation.
2. GEOLOGICAL SETTINGS AND MINERALISATION
The process of determining the mineralisation style appropriate for your deposit is the very first step.

Deposits can be divided into 3 main groups for the purposes of modelling:
- Layered, Vein and Disseminated styles.

The changing nature of the underlying deposit geology and mining requirements, however, leads to a different emphasis in the use of tools with each style.

The table below examines these differences in emphasis using three groups of deposit styles.

Adapted from Duke & Hanna 1997.
## Deposit Styles

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Layered</th>
<th>Vein</th>
<th>Disseminated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geology Model</td>
<td>- Much smaller extent in one direction (generally Z)</td>
<td>- Much smaller extent in one direction (generally width)</td>
<td>- Equidimensional</td>
</tr>
<tr>
<td></td>
<td>- Sharp boundaries between layers</td>
<td>- Sharp external but difficult internal boundaries</td>
<td>- Diffuse boundaries</td>
</tr>
<tr>
<td></td>
<td>- Rock is the ore, single phase</td>
<td>- Open space fill is the ore (minor alteration halo), consecutive phases</td>
<td>- Alteration overprint is the ore, multi phase with complex overprints</td>
</tr>
<tr>
<td>Data Characteristics</td>
<td>- Sampling by layer</td>
<td>- Sample within vein only</td>
<td>- Continuous sampling with long intercepts</td>
</tr>
<tr>
<td></td>
<td>- Holes vertical &amp; wide spaced 400-500 m</td>
<td>- Holes closer (10’s m) but erratic, survey important</td>
<td>- Holes wide (100’s m) but various orientations</td>
</tr>
<tr>
<td></td>
<td>- Limited surface data</td>
<td>- Assays highly variable</td>
<td>- Good surface data</td>
</tr>
<tr>
<td></td>
<td>- Often have geophysics</td>
<td>- Low concentration of valuable element (ppm)</td>
<td>- Moderate concentrations of valuable elements (fractions of %)</td>
</tr>
<tr>
<td></td>
<td>- High concentration of valuable element (%)</td>
<td>- Skewed &amp; mixed populations</td>
<td>- Normal populations</td>
</tr>
<tr>
<td></td>
<td>- Single population</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Deposit Styles

### Criteria

<table>
<thead>
<tr>
<th>Data Continuity Variography</th>
<th>Layered</th>
<th>Vein</th>
<th>Disseminated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good continuity along layers (typically 100’s m)</td>
<td>Moderate continuity of mineralisation down dip and along strike</td>
<td>Good continuity, particularly vertically.</td>
<td></td>
</tr>
</tbody>
</table>

### Domaining

- Sharp roof and floor boundaries
- Gridded models with contacts and thickness
- Flat to shallow dips (10°)
- May be small scale faults
- Lateral facies changes
- Sharp external boundaries but complex internal mixing of ore and waste
- Vein outlines, vein splits, faulting
- Diffuse definition of concentric domains based on cut-off grade and geology
- Barren late intrusive phases and high grade sheeted vein areas.

### Interpretation Focus

- Fault definition – often aided by “soft” data – magnetic, landsat, air photos
- Facies pinch outs
- Weathering profiles
- Erosion, younger units (e.g. intrusives)
- Grade and thickness variations
- Very high grade “shoots”
- Extreme grade outliers
- Structural control of shoots
- Definition of cut-off zones
- Higher grade areas
- Characterising grade distribution in the higher grade sheeted veins
### Deposit Styles Continue

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Layered</th>
<th>Vein</th>
<th>Disseminated</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grade Modelling</strong></td>
<td>▪ Major elements, impurities, moisture, density</td>
<td>▪ Mixed populations</td>
<td>▪ Extreme values, often use top cuts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Extreme values, often use top cuts</td>
<td>▪ Use soft boundaries with data overlap</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Shoots</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Density</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Problems, eg arsenic</td>
<td></td>
</tr>
<tr>
<td><strong>Density</strong></td>
<td>▪ Uniform</td>
<td>▪ Local variations, particularly if high grade is associated with sulphides</td>
<td>▪ Uniform</td>
</tr>
<tr>
<td></td>
<td>▪ Low (coal, laterites)</td>
<td>▪ Average (2.7 to 2.8)</td>
<td>▪ Average (2.6 to 2.7)</td>
</tr>
<tr>
<td></td>
<td>▪ High (iron ore, base metals)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mining</strong></td>
<td>▪ Geotech</td>
<td>▪ Minimum mining width</td>
<td>▪ Very large tonnages but low grades susceptible to metal price variations</td>
</tr>
<tr>
<td></td>
<td>▪ Ground water</td>
<td>▪ Internal &amp; external dilution</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ Small scale faults</td>
<td>▪ Wall rock behaviour</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Faulting</td>
<td></td>
</tr>
</tbody>
</table>
Deposit Styles Continue

The style selected should be based on an understanding of these key points:
- The regional geological setting
- The overall alteration and structural patterns
- Detailed surface mapping of lithology, structure & alteration
- Evidence from drill samples
- A thorough Research of similar better known deposits.
Deposit Styles – Physical Dimensions

- The selection of a particular style for your deposit will imply that a range of physical dimensions is to be expected, based on experience from other similar deposits.

- Style of mineralisation will also provide:
  - Guidance of exploration for additional resources
  - An indication of further drilling at depth or along strike is warranted
  - Limits and dimensions for detailed modelling
Deposit Styles – Mineralisation Controls

- The geological processes involved in the formation of the deposit and how they acted locally.
- Controls will vary depending on the deposit style. These will include consideration of:
  - Structure
  - Host rocks
  - Alteration
  - Mineralisation
  - Weathering
- The timing of events is also important.
- It is likely a number of controlling surfaces can be modelled.
Refers to how the deposit is expected to behave between the controlling surfaces.

This is generally achieved by using a 3D grid of points with the value at each point estimated mathematically from a number of known points.

This estimation process needs to be related to a fundamental understanding of the geological processes.
3. REPORTING CODES – JORC, NI43-101
International Systems

- Australian JORC
- Australian Valmin Code
- Canadian NI43-101
- SAMREC
- CRIRSCO
- UN UNFC
- General agreement on Resources, Reserves and Competent Person
- US SEC Guide7 – Reserves only
JORC Code Requires

- Minimum for reporting Resources & Reserves
- Transparency
- Data and Assumptions
- Missing or inadequate data
- Resource has reasonable expectation of eventual economic exploitation
- Conversion of Resource to Reserves
- Personal responsibility - Competent Person
- Has some Limitations
ORC Code & Beyond

**Codes for Reporting of Resources and Reserves**

**Pre-Resource Mineralisation**

Estimates are Outside of the Code, but format for reporting of Exploration results are covered, as are definitions of Targets.

**Mineral Resources**

- Inferred
- Indicated
- Measured

Increasing level of geological knowledge and confidence

Consideration of mining, metallurgical, economic, marketing, legal, environmental, social and governmental factors

**Ore Reserves**

- Proved
- Probable

US SEC Only

**Grade Control & Blending**

OUTSIDE OF THE JORC/NI43-101 CODE

**Life of Mine Studies**
Estimation Issues

- A poor understanding of the geological controls will always lead to a poor resource estimate.
- Simple techniques such as a polygonal estimation may highlight the strength of underlying geology knowledge.
- The over-estimation of grade is worse for the project than under-estimation but both are bad in that neither truly reflect the actual cash-flows.
- Have multiple methods been used and compared.
Cut-off Grade

- Should be realistic and achievable
- The sensitivity of the estimates to changes
  - grade/tonnage curves
  - plans and sections of changes
- The Specialist will be required to comment whether the chosen mining method and costs reflect the chosen mining method.
Reserves with time

- Variation of the resources and reserves with time
- Major milestones of the project
- Use a time-line chart
  - major changes in all areas the project milieu
  - not just the hard technical issues of the mine production team.
Ore Feed vs time

ROM Feed by Quarter with Tonnage by Category and Grade

- Proved Reserve
- Probable Reserve
- Other Measured & Indicated Resource
- Inferred Resource
- Pre-Resource Mineralisation
- ROM Grade
4. RESOURCE ESTIMATION
Data

► Basis of any geological modelling or geostatistical analysis

► Raw data
  - Data Capturing
  - Data Validation
  - Data Formats
  - Data Quality
  - Compositing
Data Capturing

- Captured into a proper database which has integrity rules built-in as specified by the industry standards

- A few pitfalls when collecting data:
  - Numbering errors
  - Poor sampling at the source
  - Poor sample preparation
  - Poor analysis

- Errors can never be completely eliminated but the challenge is to minimise the errors produced
Data Validation

► Many errors and inconsistencies arise
► Errors can be identified through an audit of the database
► Specific criteria that should be assessed during a database audit include:
  - Drillholes and Field Surveys
  - Geological Data
  - Sampling
  - Sampling Preparation
  - Bulk Density and Specific Gravity
  - Data Entry
<table>
<thead>
<tr>
<th>Criteria</th>
<th>Original</th>
<th>Appropriate Form</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface mapping</td>
<td>Notes on plans, Traces key features</td>
<td>Point data, Lines</td>
<td>Interpretation of key units and mineralisation controls Domain boundaries</td>
</tr>
<tr>
<td>Surface data</td>
<td>Location and geology on maps, assays in database</td>
<td>Point data</td>
<td>Input to grade estimation</td>
</tr>
<tr>
<td>Drill logs</td>
<td>Down-hole geology, Down-hole geotech</td>
<td>Points, or intervals with point at each end</td>
<td>Domain boundaries</td>
</tr>
<tr>
<td>Drill assays</td>
<td>Lab results</td>
<td>Point data</td>
<td>Input to grade estimation</td>
</tr>
<tr>
<td>Drill probes</td>
<td>Digital Magsus, density, units, domains</td>
<td>Points</td>
<td>Domains</td>
</tr>
<tr>
<td>Airphoto/satellite</td>
<td>Traces key features</td>
<td>Lines</td>
<td>Domain boundaries</td>
</tr>
<tr>
<td>Geophysics</td>
<td>Interpreted units</td>
<td>Point or lines</td>
<td>Domain boundaries</td>
</tr>
<tr>
<td>Photographs</td>
<td>Prints</td>
<td>Digital</td>
<td>Interpretation Geotechnical</td>
</tr>
</tbody>
</table>
Data Quality

► The quality of the data needs to be accurate
► QA QC (Quality Assurance - Quality Control) must be addressed during the collection, recording and storage of any data
► QA QC include:
  - data verification
  - drill sample recovery
  - sample size
  - sample preparation
  - analytical methods
  - the use of duplicates/blanks/standards
The following assumptions need to be made before data analysis:
- single grade population (one domain)
- no bias and clustering

The objective of compositing is to obtain an even representation of sample grades (samples support)

There is no need to composite when all the sample lengths have the same length

Aim is to minimise the degree of sample splitting
Geological Modelling

► 3D geological modelling is the visual representation of what is in the ground

► 3D geological model consists of the following:
  - Drillholes in 3D space
  - A topographical surface
  - Any structural features e.g. faults
  - A volume of the ore body constructed from plans and sections
  - A block model with grades or other variables interpolated via geostatistics from the drillhole data.
  - Other volumes such as underground development, etc.

► Important to keep in consideration the uses of the geological model before attempting a model.
Block Modelling

- Based representation of a deposit
- Purpose of the block model (BM) is to associate grades with the volume model
- There are two main types of block models:
  - Report the volume of ore within the block
  - Divide the blocks into sub-blocks
- Ore grade from the drillholes or samples will be estimated into the blocks, the results in the block will have both volume and grade
- Common to make block size not less than one third of the sample/drill spacing
Volume Variance Relationship

- Defined as the relationship between the volume of a sample size (unit) and the expected variance of the grades when using such a sample size.
- The variance decrease as the sample size increases.
- Mining blocks have low variance, and diamond core have a high variance.
Estimation Techniques

- Geological Methods
- Polygonal
- Nearest Neighbour
- Inverse Distance
- Ordinary Kriging
- Log-Normal Kriging
- Indicator Kriging

- Concepts
  - Search Strategy
  - Discretisation
Geological Methods

- Generating a series of geological cross-sections & plans using a manual interpretation
- Volume = Area x section thickness
- Average grade obtained from the drillholes
Polygonal

- Area is divided into a series of polygons, centered upon an individual point.
- Average grade assigned to the polygon that is of the central sample.
Nearest Neighbour

- Assigns grade values to blocks from the nearest sample point to the block
  - 3D search ellipsoid
  - Maximum search distance
Inverse Distance

- Samples closer to the point of estimation are more likely to be similar in grade.
- Each sample is weighted according to the inverse of their separation.
- Samples closer gets a higher weighting than samples further away.
Ordinary Kriging

- Is an inverse distance weighting technique where weights are selected via the variogram according to the samples distance & direction (anisotropy)
Log-Normal Kriging

- Distribution is positively skewed with extreme values
- Log transform all the samples
- Apply ordinary kriging
- Back transform the log estimates
Indicator Kriging

- Used where there is mixed populations and skewed data
- Transforming data to indicators using a selected threshold and ordinary kriged
- Indicators are weighted according to their probabilities that the grade estimate is less than the

Probabilities create a cumulative distribution function (CDF)
## Estimation Techniques – Pros & Cons

<table>
<thead>
<tr>
<th>Technique</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inverse Distance</td>
<td>• Quick and easy to use</td>
<td>• Sensitive to data clustering</td>
</tr>
<tr>
<td></td>
<td>• Weight is directly related to distance, irrespective of the ranges of influence</td>
<td></td>
</tr>
<tr>
<td>Ordinary Kriging</td>
<td>• Built in declustering</td>
<td>• Time and effort to do variography</td>
</tr>
<tr>
<td></td>
<td>• Uses spatial relationship between samples to weight the samples</td>
<td>• Negative weights needs to be controlled</td>
</tr>
<tr>
<td>Indicator Kriging</td>
<td>• Can handle mixed populations</td>
<td>• Time and effort to do full indicator variography</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Order relation problems needs to be controlled</td>
</tr>
</tbody>
</table>
7. TECHNICAL DUE DILIGENCE
Margins in Mining – Where are they

- What is and is not included in C1 costs
- The real cost of Capital and how to hide it
- Overheads, R&D (incl. exploration) and core values
- Why high commodity prices do not equal high margins
- Value Waves
- Examples
Gold and Gold Miners 2000-2012

Total gold and major gold equities return (% 2000-12)

Note: Data indexed to 14th January 2000; index make up of 8 major gold producers’ total return indexes weighted by market capitalisation; Major gold producers defined as: AngloGold Ashanti, Barrick, Harmony, Kinross, Goldcorp, Gold Fields, Newmont and Newcrest.

Source: Bloomberg

From presentation by Nick Holland
CEO of Goldfields Limited
at Denver Gold Forum 11 September 2012
Costs are rising and grades falling

Operating cost per tonne

Average gold yield

Note: Cost per tonne is the weighted average of 8 major gold producers by total ore mined; average grade is the weighted average of 8 major gold producers by total ore mined. Major Gold producers defined as: AngloGold Ashanti, Barrick, Harmony, Kinross, Goldcorp, Gold Fields, Newmont and Newcrest.

Source: Gold Fields company data; annual reports
Widening gap between C1 and AllIn

**Notional cash expenditure for Major Gold Producers (2006-11, $/oz)**

- **Gold price**: CAGR (06 – 11) 21%
- **Total cash expenditure (NCE) incl. new mines**: CAGR (06 – 11) 21%
- **Operating cash costs (commonly quoted metric)**: 16%

**Note**: Major Gold producers defined as: AngloGold Ashanti, Barrick, Harmony, Kinross, Goldcorp, Gold Fields, Newmont and Newcrest. *Estimated NCE/oz based on total cash costs plus capex for existing operations, weight averaged by production (excludes new mine development capex).

**Source**: Bloomberg, Annual reports
Study level Definitions (CIM)

- **Preliminary Economic Assessment (Scoping Study)**
  - Scoping level assessment of options for forecast mine development, including capital and operating costs.

- **Preliminary Feasibility Study**
  - Minimum for Reserves.
  - Preferred mining method and mineral processing established.
  - Includes a financial analysis based on reasonable assumptions.

- **Feasibility Study**
  - Comprehensive technical and economic study of the selected development option for a mineral project that includes all factors.
  - Extraction is reasonably justified (economically mineable).
  - The results of the study may reasonably serve as the basis for a final decision by a proponent or financial institution to proceed.
Sensitivity and Risk

- Look at the likely range of outcomes rather than just state a single figure.
- The impact of variations to be tested, eg
  - impact of high values are dealt with (eg top-cutting)
  - grade tonnage curves
  - using different geological domains
  - changing the estimation methods
  - optimization of production plans
Cash Flow Sensitivity with Time

Project Cash Flow Sensitivity with Time

Net Cash Flow $M

-60.00  -40.00  -20.00  0.00  20.00  40.00  60.00  80.00


Years

Best Case
Worst Case
A range of likely outcomes

Distribution for NPV1 (10% dcf) after tax

Values in A$ Millions

PROBABILITY
Risk is OK

- The Financier is in the business of dealing with risk.
- The expression of a reserve in terms of an expected outcome with upper and lower limits is quite acceptable.
- The old practice of giving just one number will hide the risk factors.
- Risk is not bad, it just needs to be known.
- Limit the downside.

AS/NZS 4360:1999 Risk Matrix
## Risk Matrix

<table>
<thead>
<tr>
<th>#</th>
<th>Risk Event</th>
<th>Likelihood</th>
<th>Consequence</th>
<th>Risk</th>
<th>Comment and Possible Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Geology: Ore Body Interpretation</td>
<td>Possible</td>
<td>Moderate</td>
<td>High</td>
<td>Correlation of veins where there are no old underground workings, in particular California low grade open pit. Requires closer spaced drilling within open pit.</td>
</tr>
<tr>
<td>2</td>
<td>Lack of understanding of Geological Controls</td>
<td>Possible</td>
<td>Moderate</td>
<td>High</td>
<td>Understand the geological controls of the ore zone and its related mineralisation so that more accurate and precise modeling can be conducted. This can be done from detailed logging which will then feed into the resource estimate and ultimately mining targets and ground support regimes.</td>
</tr>
<tr>
<td>3</td>
<td>Mineralisation may not extend to depth</td>
<td>Likely</td>
<td>Moderate</td>
<td>High</td>
<td>Mineralisation may be restricted at depth with a sudden drop in intensity and grade once below the “boiling zone”. Caution needs to be exercised with projections at depth No RL limit is placed on the current resource estimates. MA would suggest a limit at 100m rl.</td>
</tr>
<tr>
<td>4</td>
<td>Grade Capping</td>
<td>Possible</td>
<td>Minor</td>
<td>Moderate</td>
<td>Grade capping applied to informing sample composites is too high in some domains, resulting in over-influence of high grade samples on estimation. Review caps</td>
</tr>
<tr>
<td>5</td>
<td>Incorrect Resource estimate methodology distorts the grade tonnage curve</td>
<td>Possible</td>
<td>Major</td>
<td>Extreme</td>
<td>Incorrect estimation methodology according to the geology and statistics can distort the grade/tonnage curve and ultimate resource numbers, hence affecting all subsequent activities leading on to mine development.</td>
</tr>
</tbody>
</table>

Based on AS/NZS 4360:1999
Clear Management Strategies

- Investors need to understand the company strategy and risk/reward drivers
- Exploration success
- Development value add
- Production efficiency
- Trading, Investment and Royalties
- Key people 100% dedicated to venture
- Evaluate as a whole
Value Waves

Value Waves

Value

Equity

Cost

Exploration Company

Development Company

Production Company

Time

Exploration  Discovery  PEA  Pre Feasibility  Feasibility  Construction  Production

MINING ASSOCIATES
In Summary

- Company clearly focused on stage of the value wave.
- Board and senior management with technical understanding of the company’s assets 100% committed.
- Quality advisers provide another view.
- Strategic planning for high potential projects; to reach long-term company objectives.
- Detailed analyses – key to successful project outcome; provides support and reassurance to investors.
- Transparency and materiality to investors.
Contact

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- www.miningassociates.com