Exploration and sampling techniques for conglomerate gold in the Pilbara region

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Outline of presentation

• Exploring for conglomerate gold
  – Current Knowledge
  – Pilbara examples
  – Similarities and differences with Witswatersrand style
  – Model for gold deposition
  – Conglomerates – what do they look like?

• Sampling conglomerate gold
  – Surface mapping, extents, type, character etc
  – Drilling, bulk sampling, grade continuity
  – Can Pierre Gy’s equation help us?
  – Domain modelling
  – Geostatistics
Current Knowledge

- Historic mining of conglomerate-hosted gold at Nullagine & Marble Bar
- Recent discoveries of conglomerate-hosted gold in the Pilbara at
  - Beatons Creek (Novo Resources)
  - Purdy’s Reward / Comet Well (Artemis Resources JV)
  - Louden’s Patch / Jarret Well / Steel Well (De Grey Mining)
Current Knowledge

- Conglomerates and pebbly sandstones deposited on and around the edges of the older granite greenstone terrain of the Pilbara Craton
- Mainly in the Hardey Formation above the Mount Roe Basalt, but also lower in the stratigraphy, e.g. Lalla Rookh Fm.
Distribution of Fortescue Group

Significant under-explored prospective stratigraphy
Conglomerate gold – Purdy’s Reward

• Recent discovery of pebble conglomerate-hosted gold at Purdy’s Reward

• Association with basal conglomerates in Mount Roe Basalt at base of Fortescue Group

• (Modified) palaeoplacer with abundant gold nuggets
Conglomerate gold – Beatons Creek

- Gold-bearing conglomerate horizons (reefs) within Beatons Creek member of the Hardey Formation
- Historic mining near the town of Nullagine in the late 19th century
Conglomerate gold – De Grey Mining

- Gold nuggets shed from polymict conglomerates at base of Mount Roe Basalt
Pilbara v Witwatersrand (Wits)

- Only Purdy’s Reward is an age-equivalent of the Ventersdorp Contact Reef (VCR) - Wits
Wits Foreland Basin

• Gold occurs with graphitic carbon, detrital pyrite & uraninite and abundant carbonaceous matter (pyrobitumen, kerogen)
• Reefs are hosted by laterally extensive (10s– 100s of km²) thin conglomerates/conglomeratic sandstones.
• Individual reefs typically consist of one or more auriferous horizon
• Most reefs are <2 m thick and payable portions of the beds are <10 cm and commonly <2 cm thick
Similarities between Wits & Pilbara

- Conglomerate-hosted
- (Modified) palaeoplacer
- Age restricted – Archaean to Palaeoproterozoic
Differences between Wits and Pilbara

• Provenance of conglomerates is different
  – Central Rand Group and VCR: quartzite & vein quartz
  – Pardo (Canada) and Pilbara dominated by mafic clasts
• Age difference (only Purdy’s Reward is age equivalent to main reefs in the Wits)
• Background gold levels in the Kaapvaal Craton are anomalously high. Is that the case for the Pilbara?
Conglomerate gold – Model

- Archaean to Palaeoproterozoic
- Anoxic, reduced environment – detrital uraninite, pyrite, gold, etc.
- Biogenic component – microbial gold fixation
- Great Oxidation Event (c.2.3 Ga) effectively ended ‘conglomerate gold’
Exploring for Conglomerate gold

- Archaean to Palaeoproterozoic stable cratons – gold-enriched source hinterland (mantle plume beneath evolving craton?)
- Deposition of basal conglomerates on undulating basement with topographic relief
- Formation of placers in fluvial to fluvio-deltaic environment – sediment re-working (to enrich placers) but in Wits also constant new supply (overall upward coarsening sequence)
- Evidence for redox-sensitive detrital grains – uraninite, pyrite, gold – anoxic conditions
- Evidence for biogenic component – pyrobitumen
- Preservation by overlying volcanism or sedimentation
Exploring for Conglomerate gold


- Palaeoproterozoic (>2.3 Ga)
Hardeys Formation - Conglomerate
Lalla Rookh Sandstone - Conglomerate
Steel Well- Conglomerate
Wits Conglomerate
The main (technical) challenges

1. Finding it
   • Which parts of stratigraphy/conglomerates carry the gold?
   • How many prospective conglomerates are we dealing with?
   • What controls the location of the gold bearing units?
   • Where can I find them near-surface?

2. Once found
   • How do we sample and quantify the mineralisation?
Finding them - Back to basics!

- Locate and characterise conglomerates, basement and structure
- Sedimentology: type, character, shape, and style of clasts, grading, maturity, imbrication and cross-bedding
- Mineralisation: alteration, sulphides, …nuggets!
- Basement, character, structure

- Use multi-element geochemistry to understand where you are in the stratigraphy (fingerprinting) and help vector towards mineralised patches
- Portable XRF, spectral instruments can play a role
Mapping is key!
Mapping is key!
Conglomerate gold – grade continuity

- The birth of geostatistics in the early 1950s, the result of the pioneering work done by Danie G. Krige when plotting distance-weighted average gold grades at Witwatersrand

- Krige sought to estimate the most likely distribution of gold based on samples from a few boreholes

- Krige used indicator minerals (pyrite and uraninite) to demonstrate continuity
Sampling Methodology

• What is the challenge of sampling conglomerates for gold?
• According to sample theory: the grade of the sample should be equal to the grade of the lot (i.e. non-biased)
• On a sample by sample basis, the squared difference between the grades of duplicated samples should be minimized (maximum precision)
• As the coarseness of the mineral phase increases, the inhomogeneity of grade distribution between particles increases
• This requires progressively larger samples to minimize sampling variance

• Why is this important for conglomerate gold?
Sampling Methodology

- Conglomerate (palaeoplacer) gold is characterised by very irregular and patchy distribution

- This leads to large discrepancies between adjacent samples, a problem exacerbated by small sample sizes of typical samples from conventional drilling

- This in turn leads to a high level of uncertainty in generating grade estimates for blocks

- For potential investors this means lower confidence, higher risk

- Without Resources or Reserves, it is difficult to raise funding
Conglomerate gold – grade continuity

• Nugget effect for Pilbara conglomerate gold → difficult to define Mineral Resource estimates & encourage investors
  – Is bulk-sampling the answer? e.g. Pardo prospect (Inventus Mining Corp, TSX: IVS) trialing bulk-sampling & ore sorting

• 1,000 t Bulk Sample
• Completed Oct to Dec 2017
• Processed at McEwen Mining Black Fox Mill near Timmins
• Results released Jan 3, 2018
• Head Grade 4.2 g/t gold
• 89% Metallurgical Recovery
• Avg. Au Grade of 11 DDH 1.34 g/t
• Very Significant Results

https://static1.squarespace.com/static/56d987d21bbbee076a4c0be7f/t/5a4cc4a79140b791bb344688/1514980519550/Inventus_Jan3.pdf
Sampling Errors

• **In situ Nugget (NE)**
  • Fundamental sampling error (FE)
  • Grouping and segregation errors (GE)
  • Long-range heterogeneity (quality) fluctuation error (shifts / trends QE1)
  • Long-range periodic heterogeneity (quality) fluctuation error (cydes, QE2)
  • Increment delimitation error (DE)
  • Incremental extraction error (EE)
  • Weighing error (WE)
  • Preparation error (PE)
  • Analytical error (AE)

• Total Error = [NE+FE+GSE+QE1+QE2]+[DE+EE+WE+PE+AE]
Gy’s Formula – Reminder!

\[
\text{Rel. Var}(t_S) = c \ell f g d_N^3 / M_S
\]

**Sample grade**

**Mineralogical factor:**
\[
c = \left[ \left( 1 - t_L \right) / t_L \right] \cdot M \cdot G \cdot L
\]

**Liberation factor:**
\[d_N, d_L, \text{ etc...}\]

**Shape factor**

**Granulometric factor**

**Sample Mass:**
\[
(1/M_S - 1/M_L)
\]

**Nominal Size**
Nugget Effect (geostatistics)

• The degree of randomness within a body of mineralisation

• It is a quantitative geostatistical term describing the level of variability between samples at or very close to zero distance apart. It is defined from a semi-variogram as the percentage ratio of nugget variance to total variance

  – Low-nugget effect < 25%
  – Medium-nugget effect 25 to 50%
  – High-nugget effect 50 to 75%
  – Extreme-nugget effect >75%

Dominy et al., 2002, Classification and Reporting of Mineral Resources for High-Nugget Effect Gold Vein Deposits, Exploring Geology, 10
Sampling Tree - Nomogram

- Fundamental Sampling Error: due to the irregular distribution of mineralisation
- Pierre Gy’s model for the Fundamental Sampling Error
- Calculate $K$ and $\alpha$ parameters to substitute into Gy’s formula
- Determining sampling variance of the Fundamental Error

How do we determine these parameters?

- Sampling Tree Method (Francois-Bongarcon, 1995 & 1998)
Sampling Tree - Nomogram

- Record all sample weight
- Assay 30 samples for gold

For each nominal size ($d_N$) produced, apply binary splitting from one to thirty two

- Randomly select two samples for granulometric analysis
Sampling Tree - Nomogram

- Determine the variance of the 30 assays
- Ores at different calibrated comminution sizes
- Regression to derive best fit values for $K$ and $\alpha$
- Plot the curve on log scale
- Calculate the liberation size
- Compilation of sampling nomograms using calibrated constants for a particular ore

- Plot the nomogram (any sampling operation at each stage can be plotted on the chart as a path along a straight line of slope -1)
Example - Nomogram

Sampling Nomogram at 1 Au g/t

- 60 mesh
- 150 mesh
- 10 mesh

30% Safety
10% Design

F(M)

The posted precisions (in %) are for each sampling step. The overall precision without the primary sampling is 48% for this protocol.

M (g)  Comminution steps  Sampling steps
Geological Domains

- Model domains correctly
- Use diamond drilling to define domain boundaries
- Surface and trenching to obtain global estimates
Conglomerate gold – Diamond drilling

Grades measured on small support will be poorer than grades on larger support.
Conglomerate gold – RC drilling
Conglomerate gold – Diamond Drilling & RC drilling
Conglomerate gold – Gaussian Transform
Conclusions

• Mineral Resource must be appropriate to the geology of the deposit
• Use diamond drilling to define domain boundaries
• Mapping out subdomains on surface
• Surface and trenching to obtain global estimates
• Large drill diameter and close spacing to help overcome nugget-effect
• Bulk sampling – but restricted in scope and only appropriate to evaluate grade of a particular subdomain

• Competent Person has to use common-sense
Acknowledgements:

- Daniel Guibal, Danny Kentwell, Rod Brown, David Slater, Daryl Nunn, Hennie Theart
- Novo Resources, De Grey Mining, Agoratek International, Inventus Mining Corp