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)
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/56d987d21bbe076a4c0be7f/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 = \[\text{NE+FE+GSE+QE1+QE2}+\text{DE+EE+WE+PE+AE}\]
Gy’s Formula – Reminder!

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

Sample grade

Mineralogical factor:
\[ c = \left[ \frac{(1 - t_i)}{t_i} \right] \cdot M \cdot G \cdot L \]

Liberation factor: \( d_N \), \( d_i \), etc...

Shape factor

Granulometric factor

Sample Mass:
\[ \left( \frac{1}{M_S} - \frac{1}{M_L} \right) \]

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 Geol, 10*
• 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
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

- Nb Samples: 23154
- Draw in Log Scale
- Shift Log: 0.000
- Minimum: 0.005
- Maximum: 354.000
- Mean: 0.840
- Std. Dev.: 2.968
Conglomerate gold – RC drilling
Conglomerate gold – Diamond Drilling & RC drilling
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
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