Exploration and sampling techniques for conglomerate gold in the Pilbara region

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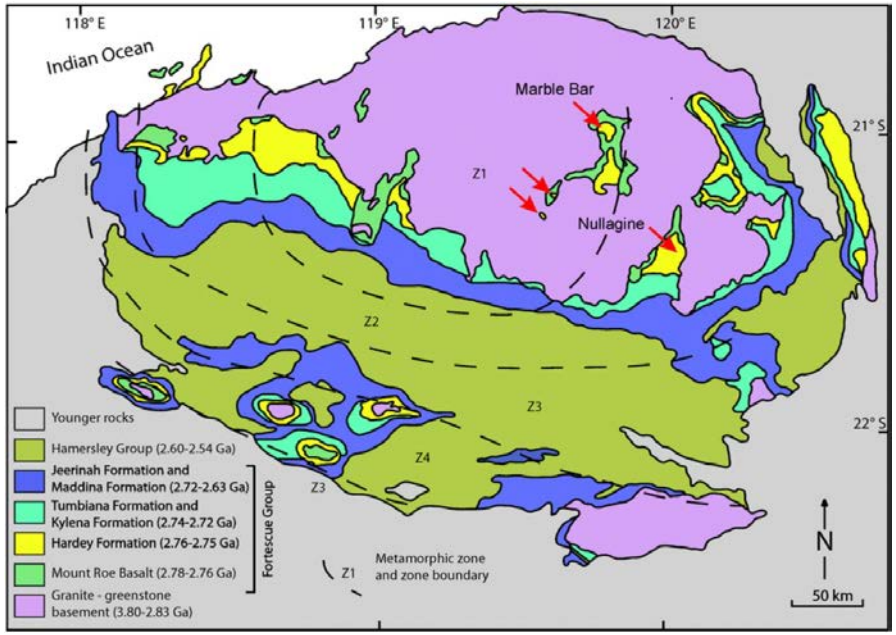
Outline of presentation

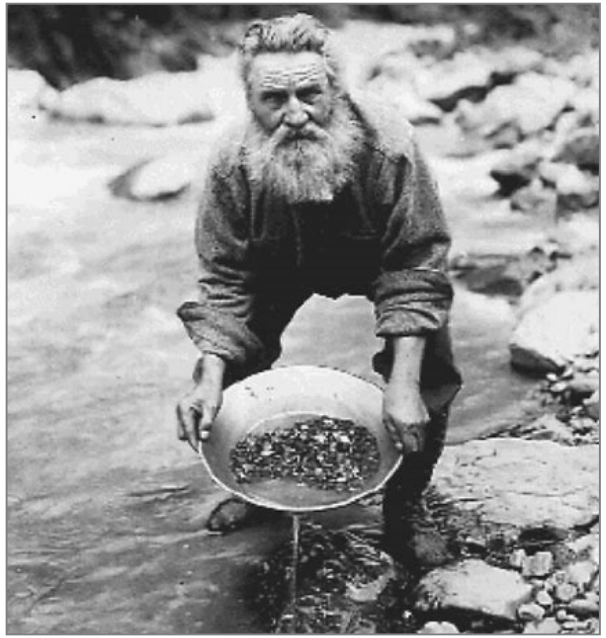
- Exploring for conglomerate gold
  - Current Knowledge
  - Pilbara examples
  - Similarities and differences with Witswatersrand style
  - Model for gold deposition
  - Conglomerates – what do they look like?

- 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

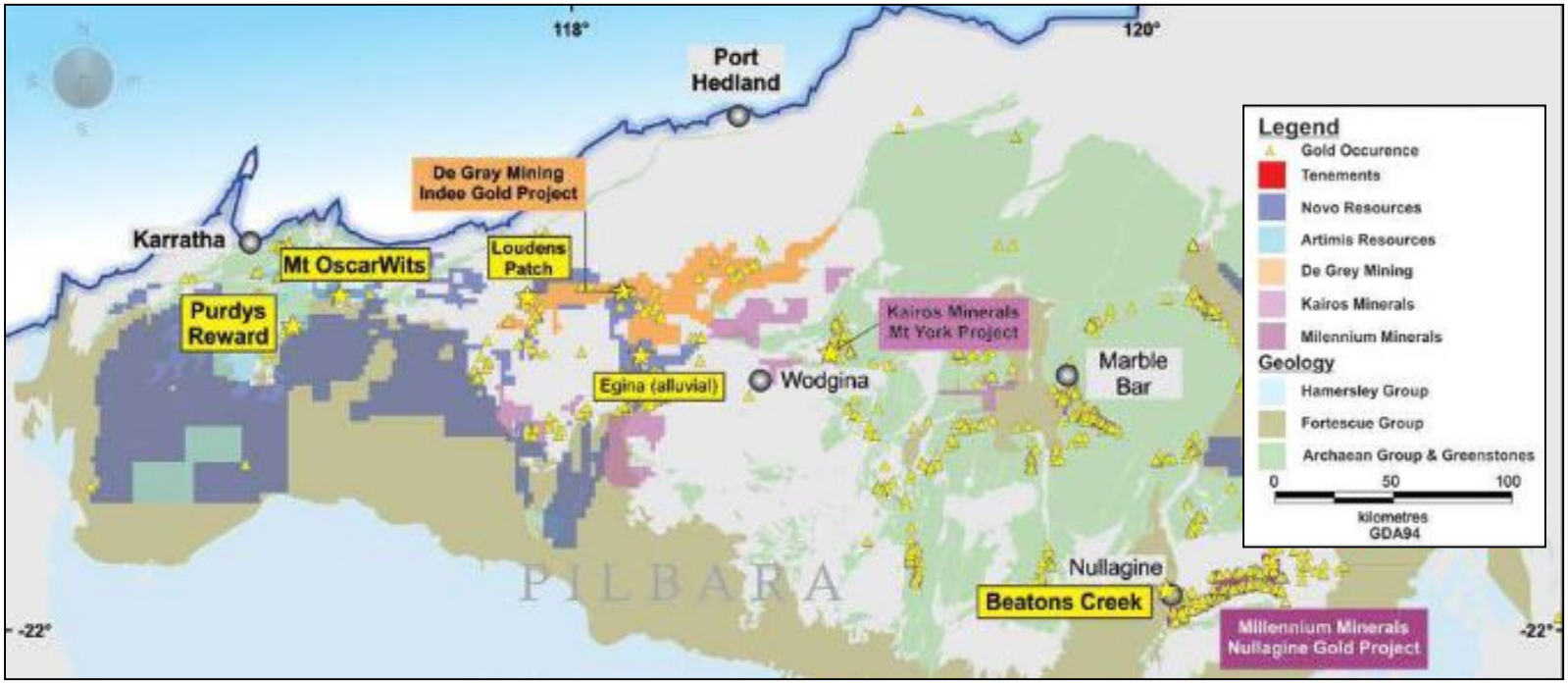
- Historic mining of conglomerate-hosted gold at Nullagine & Marble Bar
- Recent discoveries of conglomerate-hosted gold in the Pilbara at
  - Beatons Creek (Novo Resources)
  - Purdy's Reward / Comet Well (Artemis Resources JV)
  - Louden's Patch / Jarret Well / Steel Well (De Grey Mining)





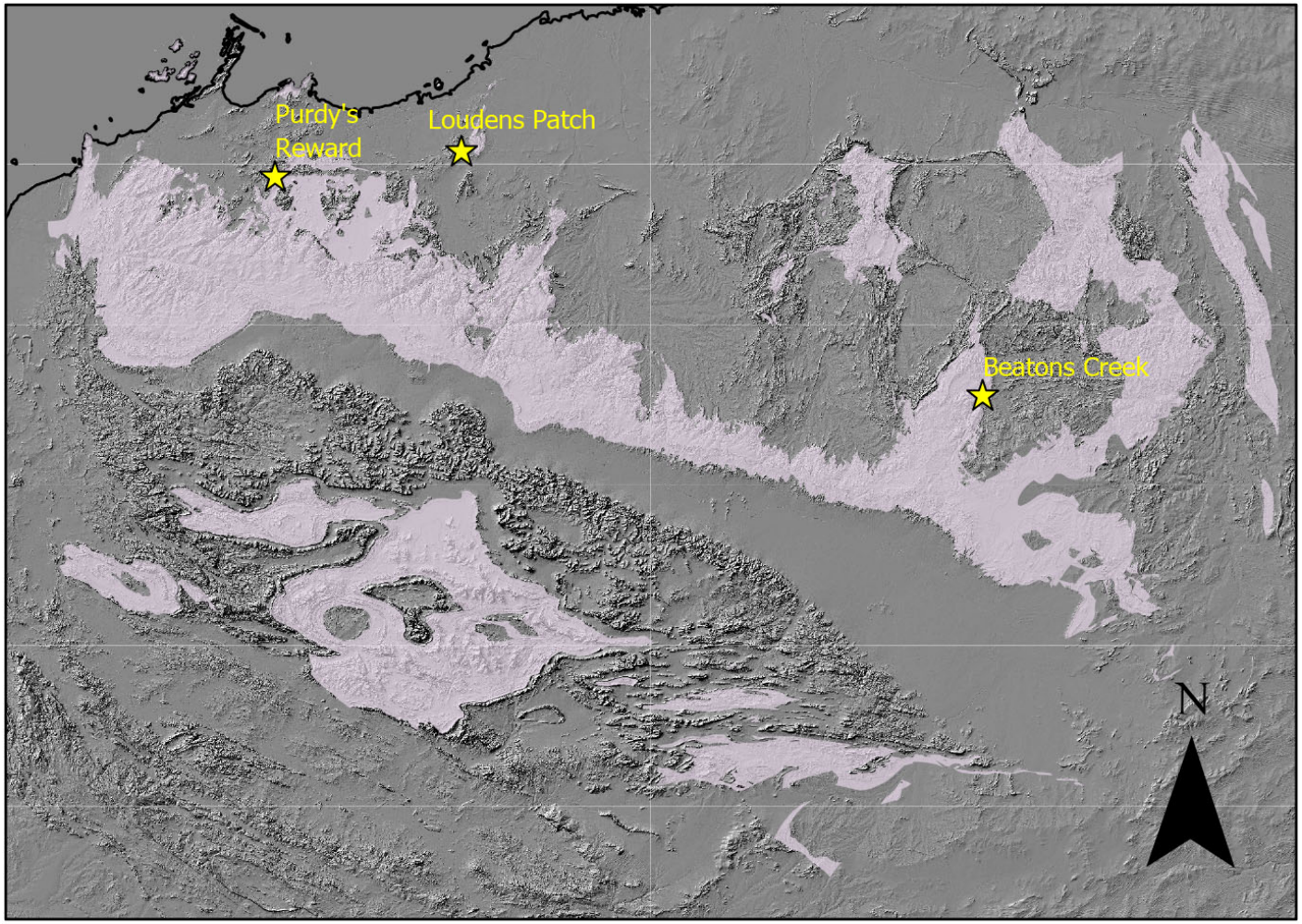
Current Knowledge

- 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.



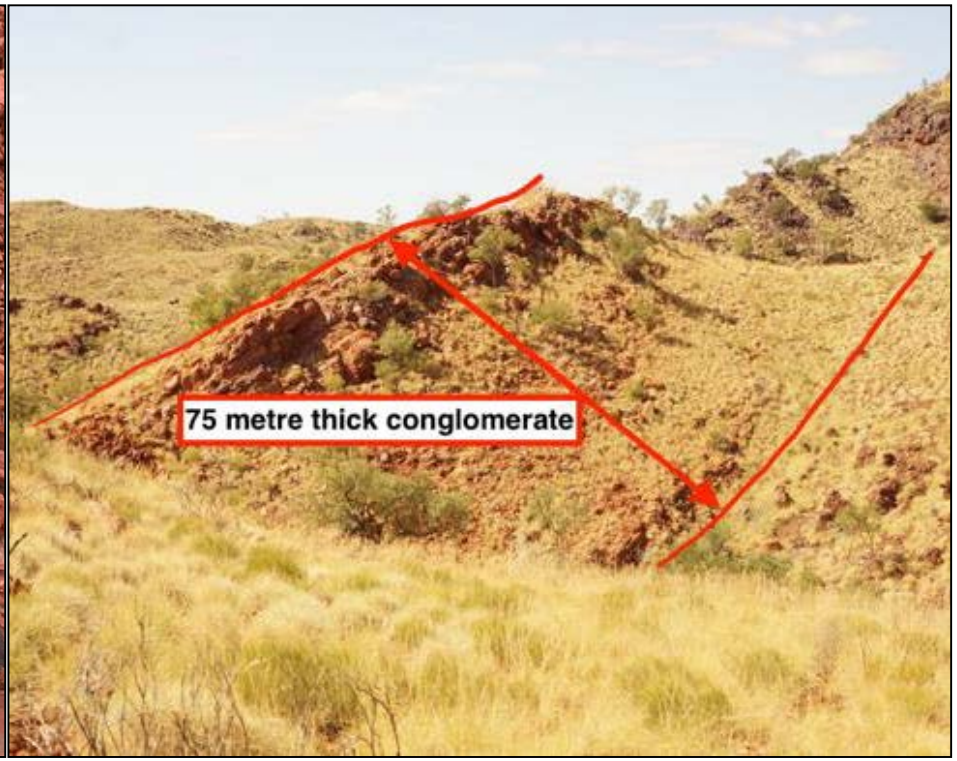
Distribution of Fortescue Group

Significant under-explored prospective stratigraphy



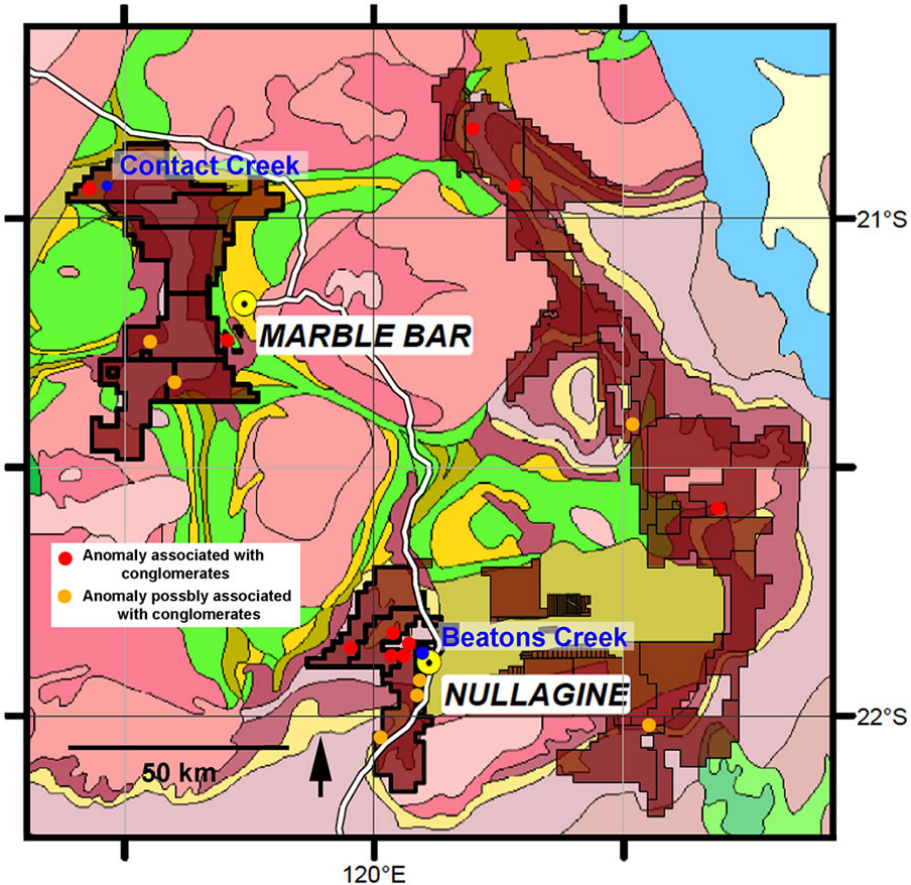
Conglomerate gold – Purdy's Reward

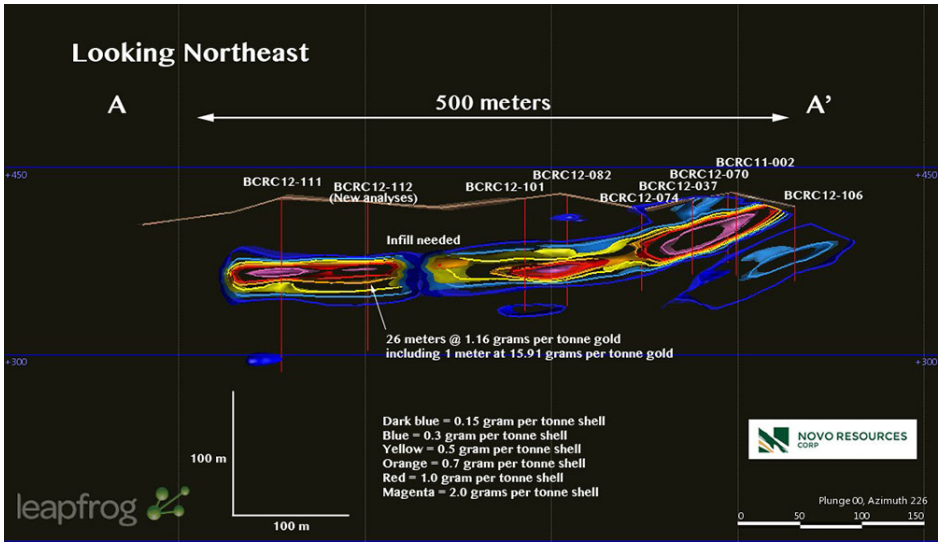
- Recent discovery of pebble conglomerate-hosted gold at Purdy's Reward
- Association with basal conglomerates in Mount Roe Basalt at base of Fortescue Group
- (Modified) palaeoplacer with abundant gold nuggets

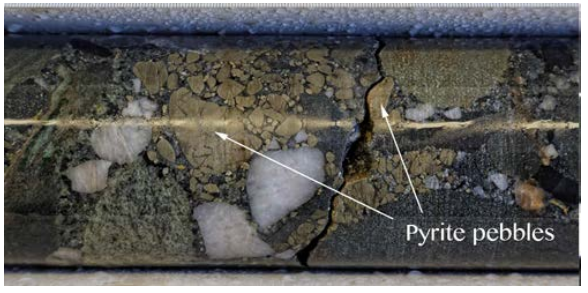


Conglomerate gold – Beatons Creek

- 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

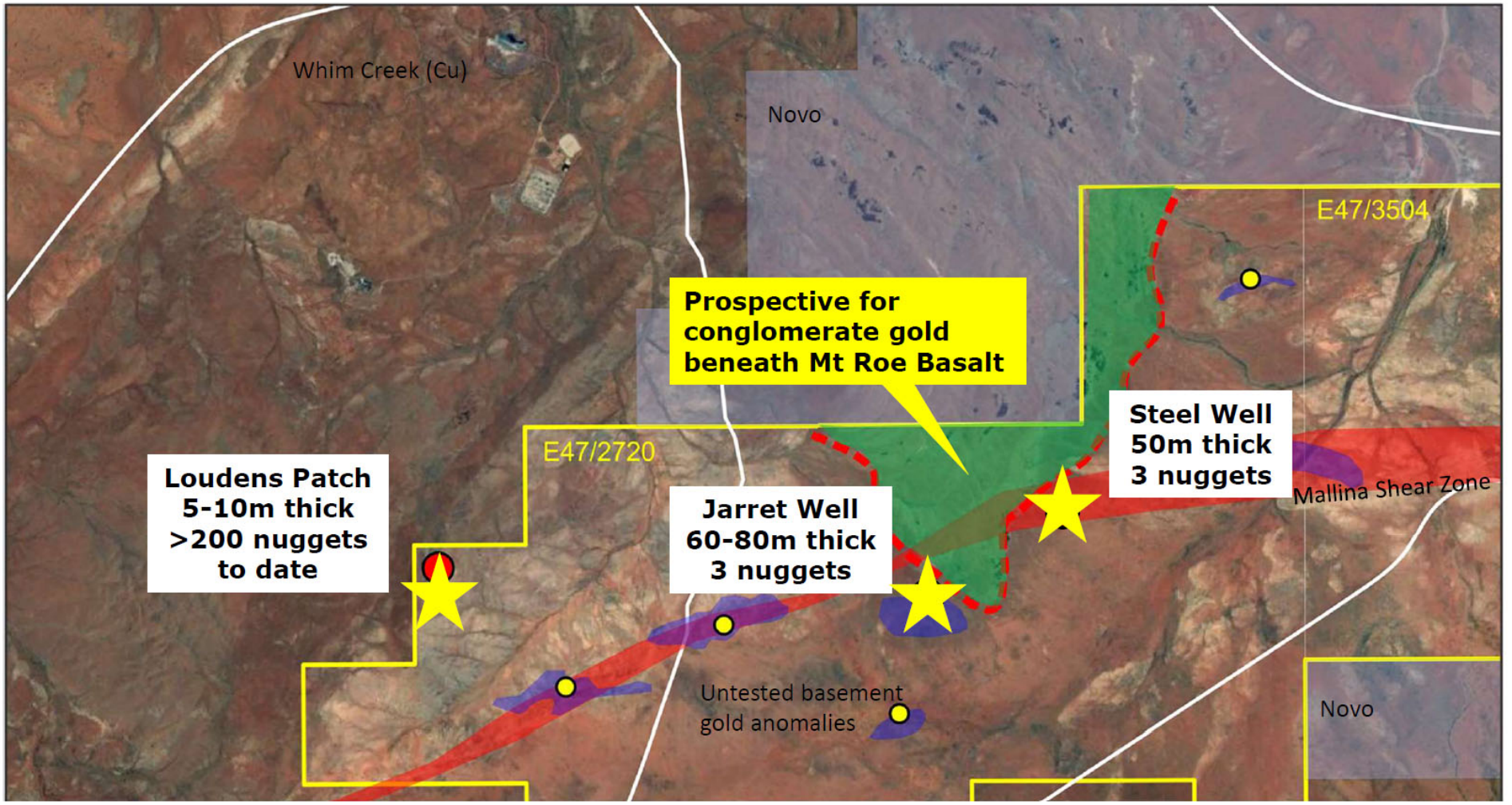






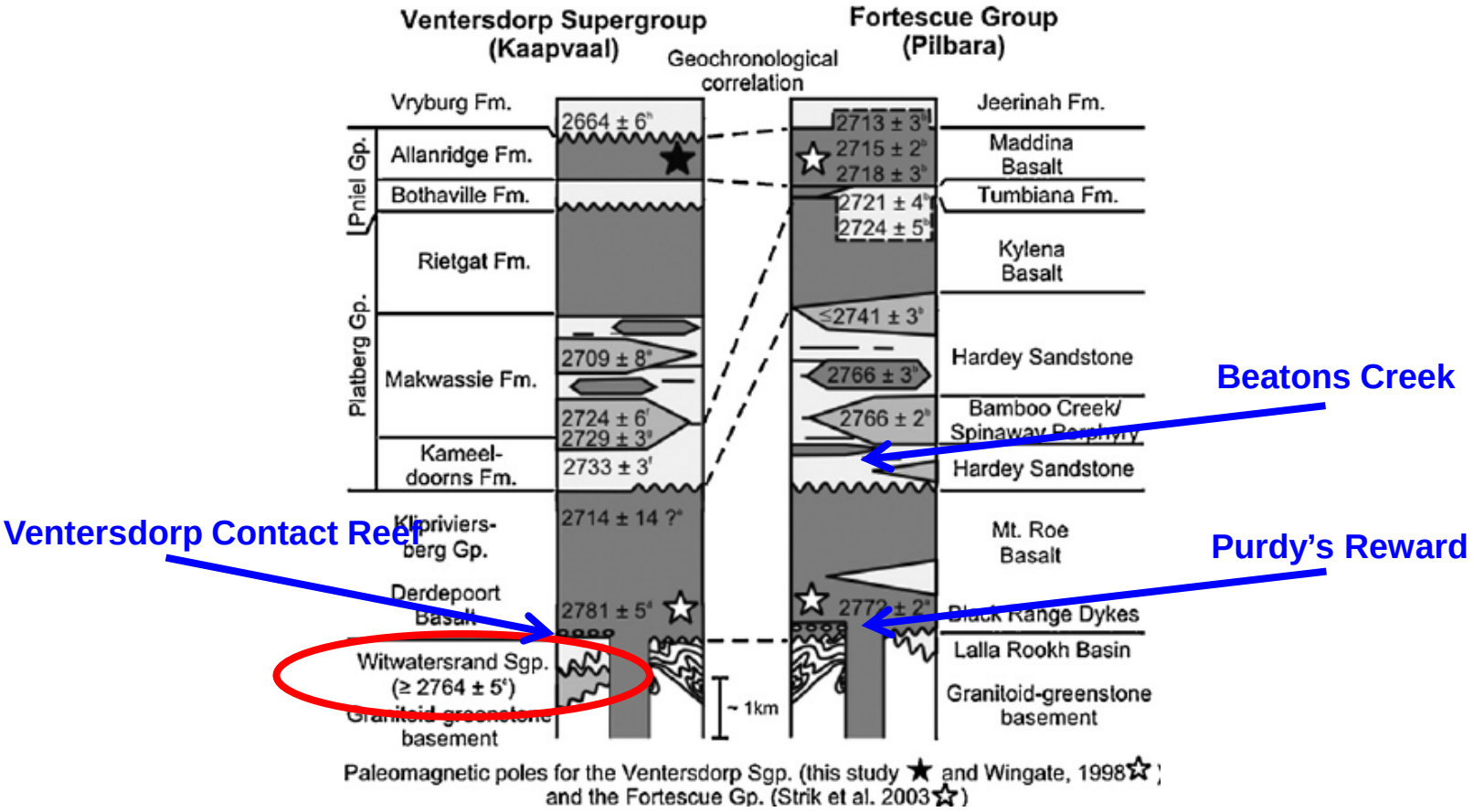
Conglomerate gold – De Grey Mining

- 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

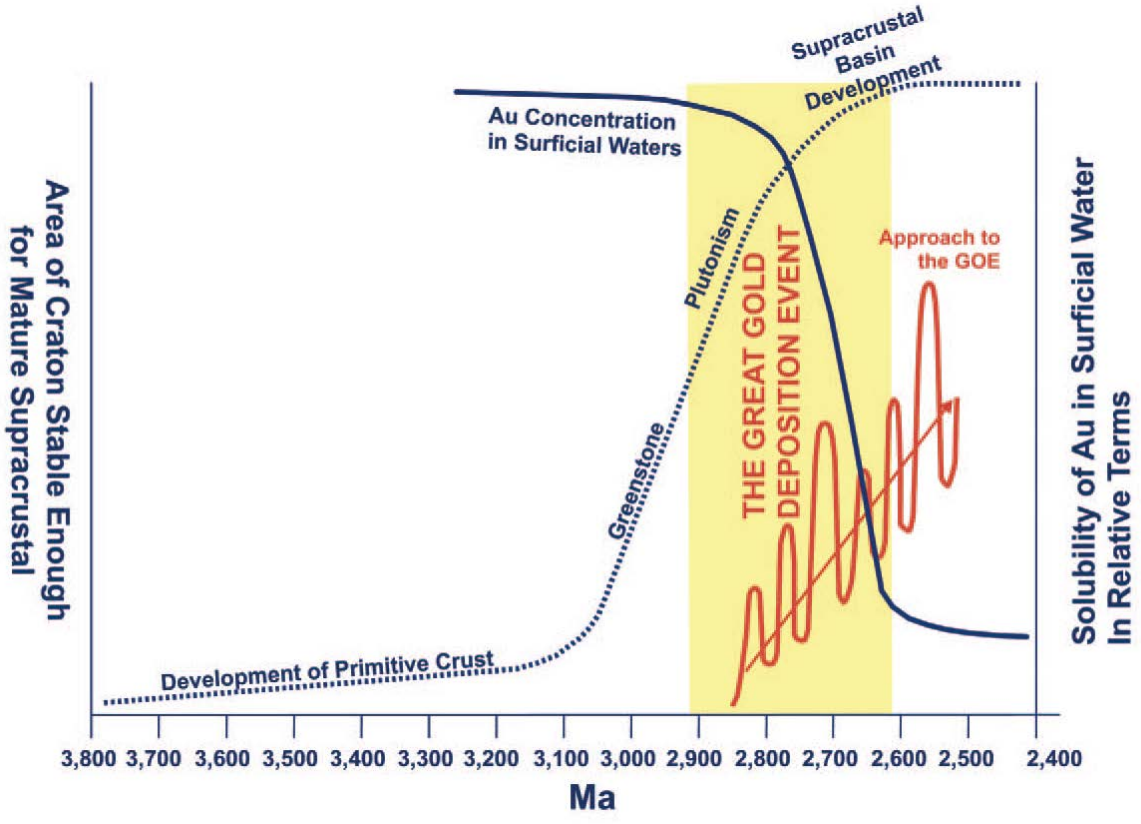


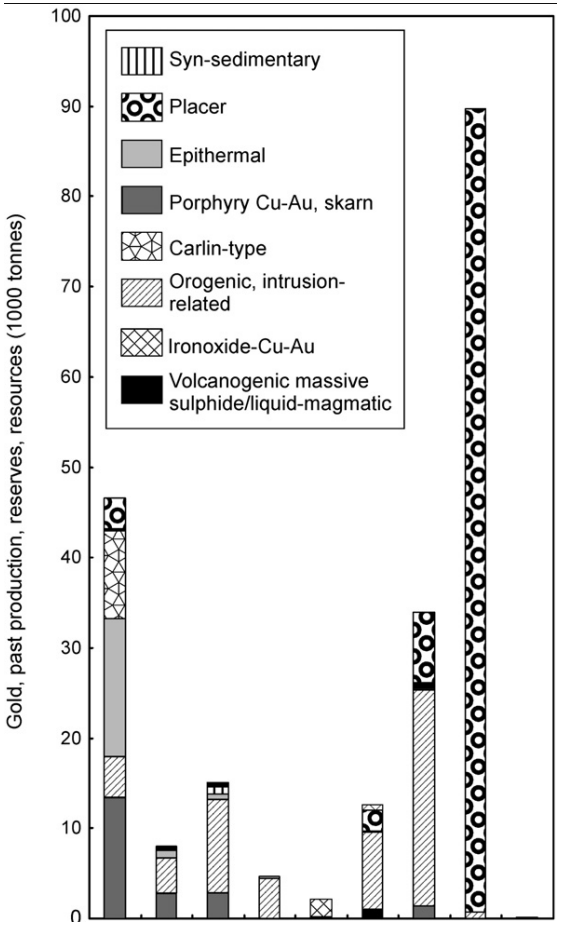
Wits Foreland Basin

- Gold occurs with graphitic carbon, detrital pyrite & uraninite and abundant carbonaceous matter (pyrobitumen, kerogen)
- Reefs are hosted by laterally extensive (10s– 100s of km^2) 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



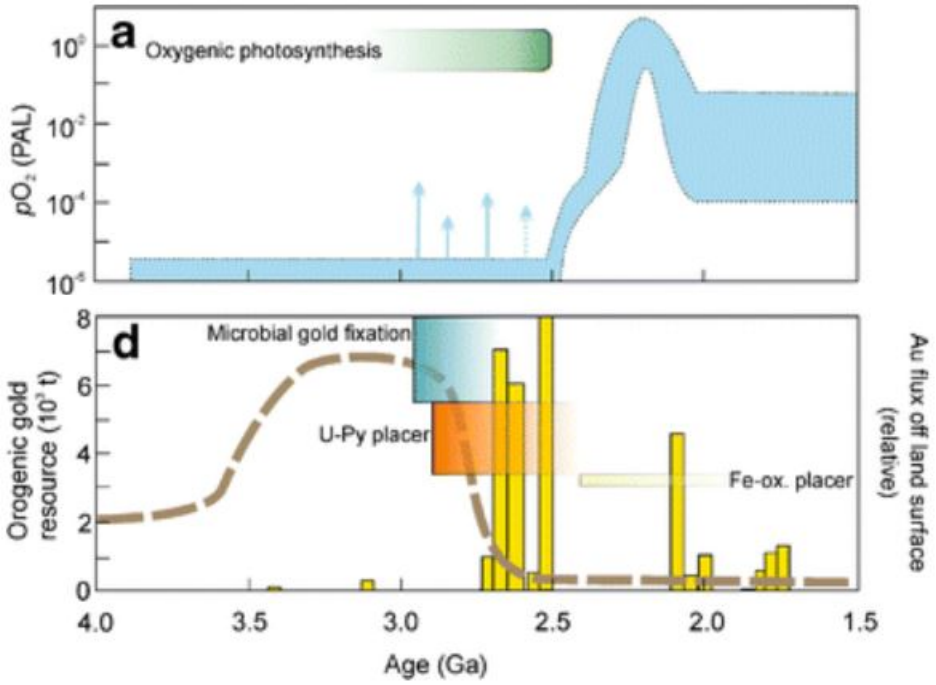


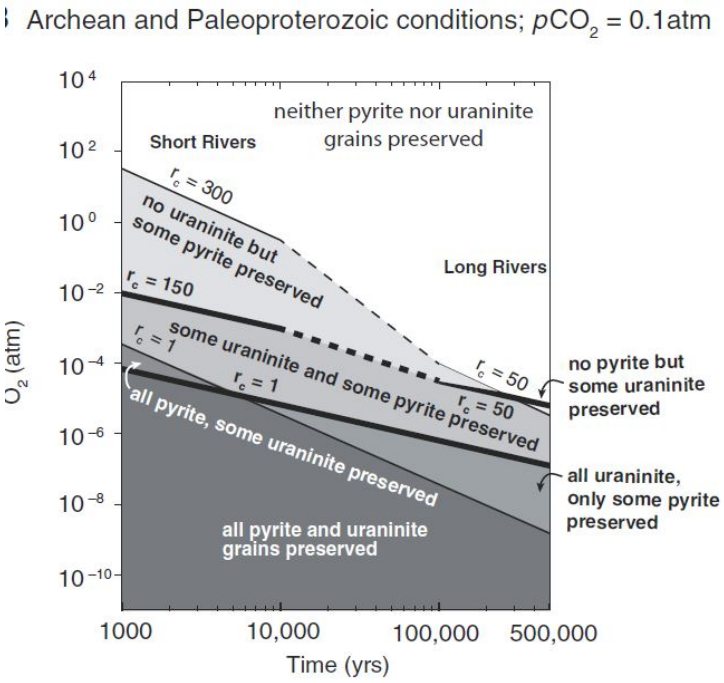
Differences between Wits and Pilbara

- 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’



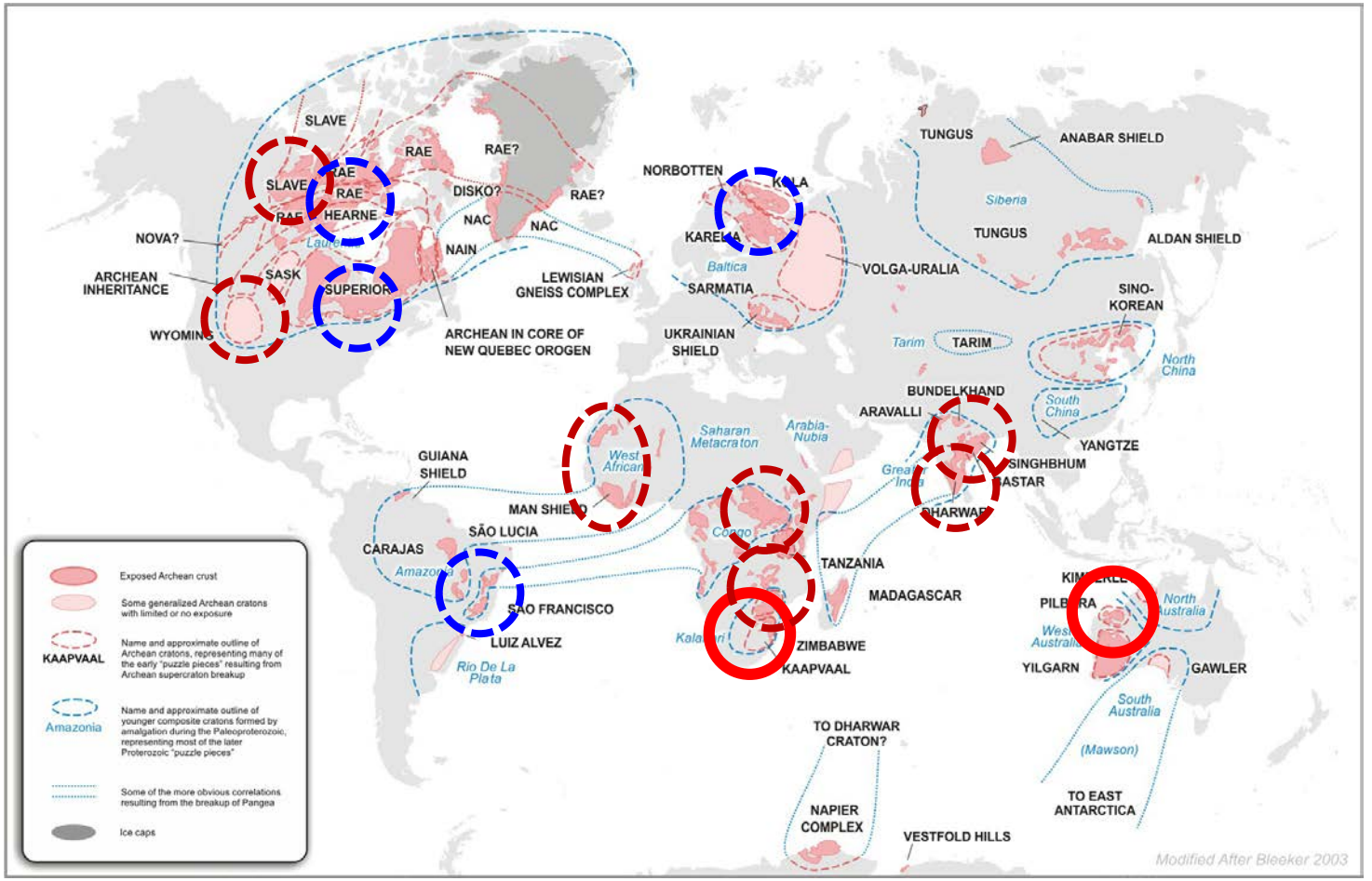


Exploring for Conglomerate gold

- 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

- Exposed Archaean –**Kaapvaal**, **Pilbara**, West Africa, Slave, Dharwar, Singhbhum, Wyoming, Zimbabwe, …
- Palaeoproterozoic (>2.3 Ga)



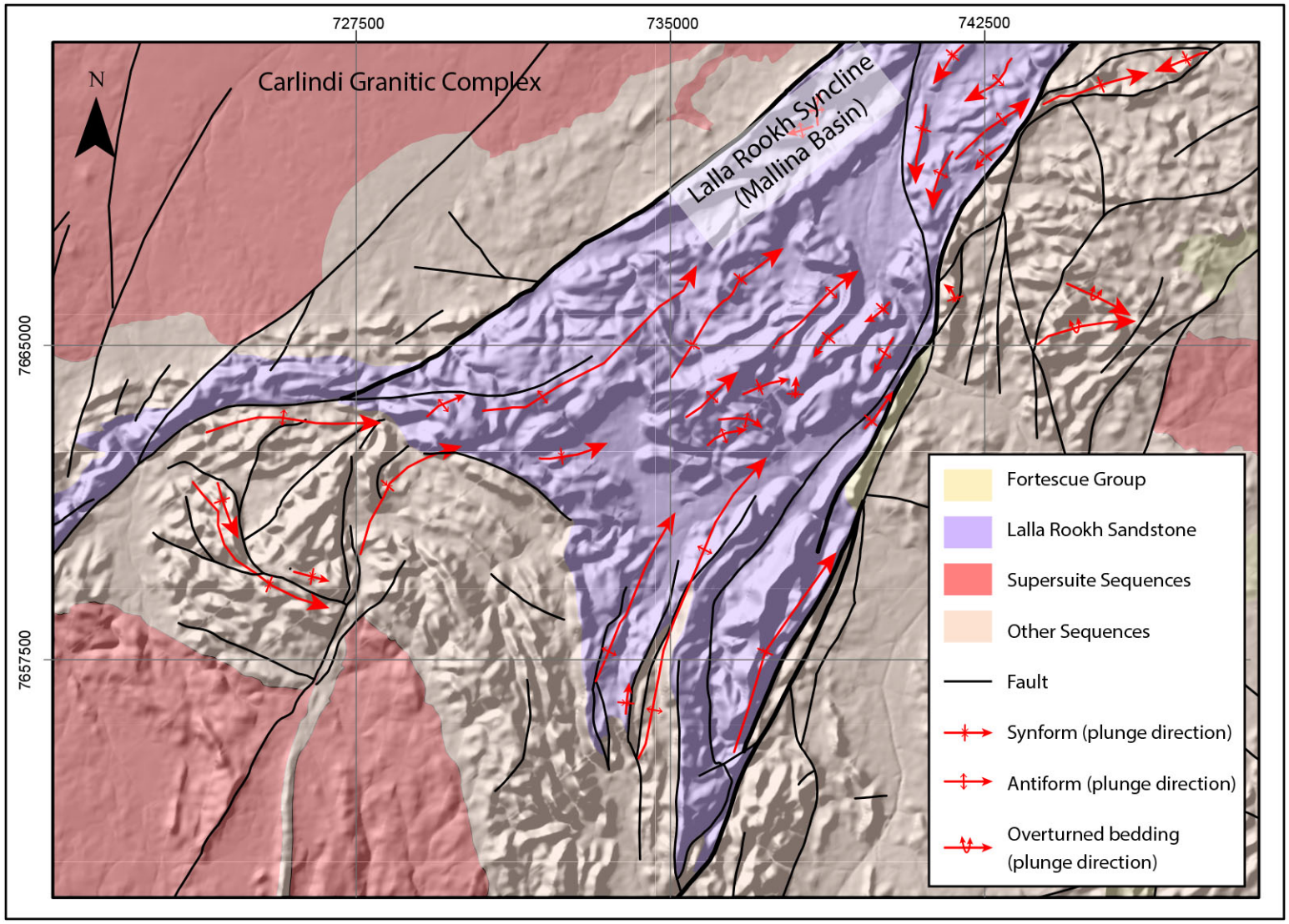
Hardeys Formation - Conglomerate

Lalla Rookh Sandstone - Conglomerate

Steel Well- Conglomerate

Wits Conglomerate

Lalla Rookh / Mallina Basin



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

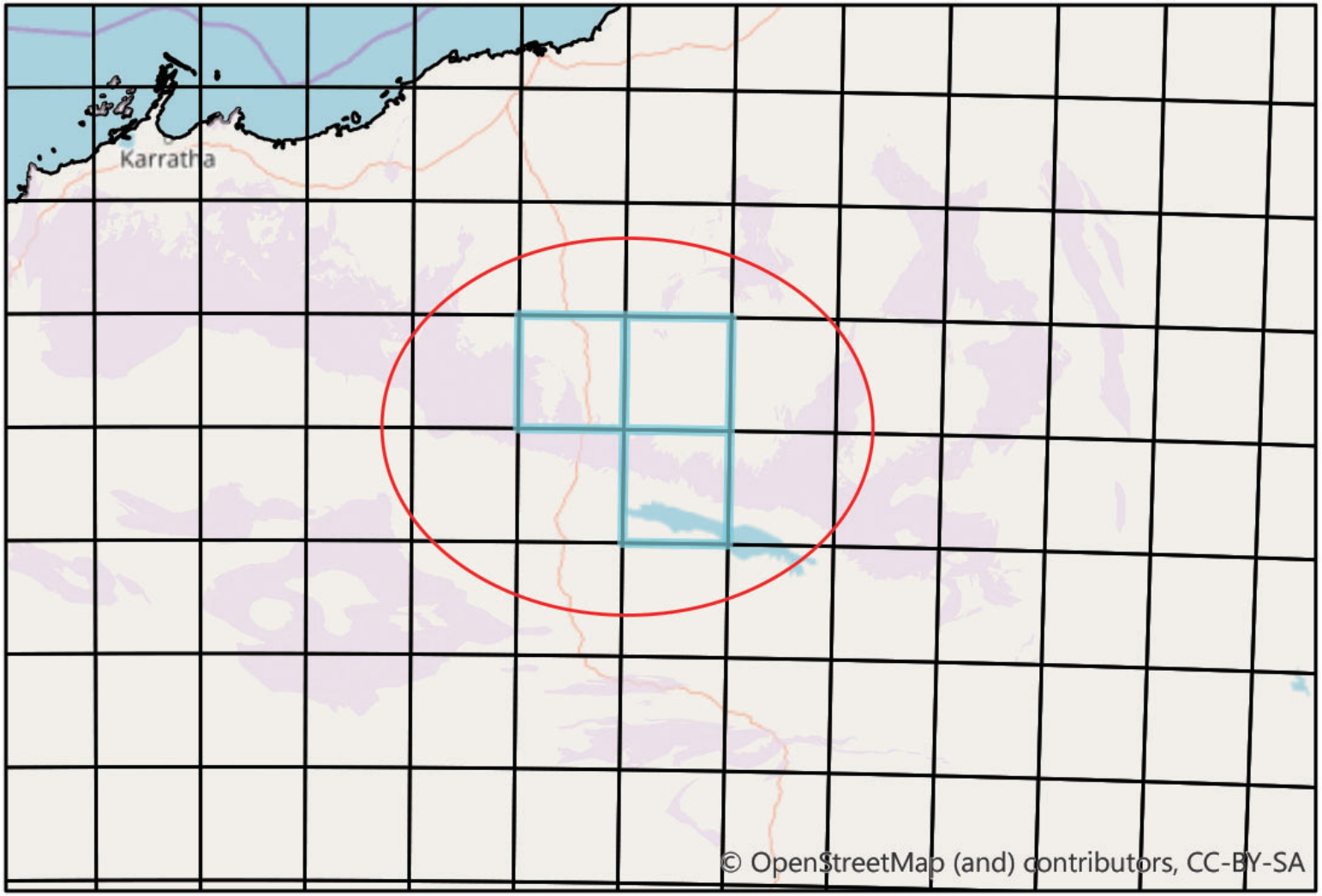
- How do we sample and quantify the mineralisation?

Finding them - Back to basics!

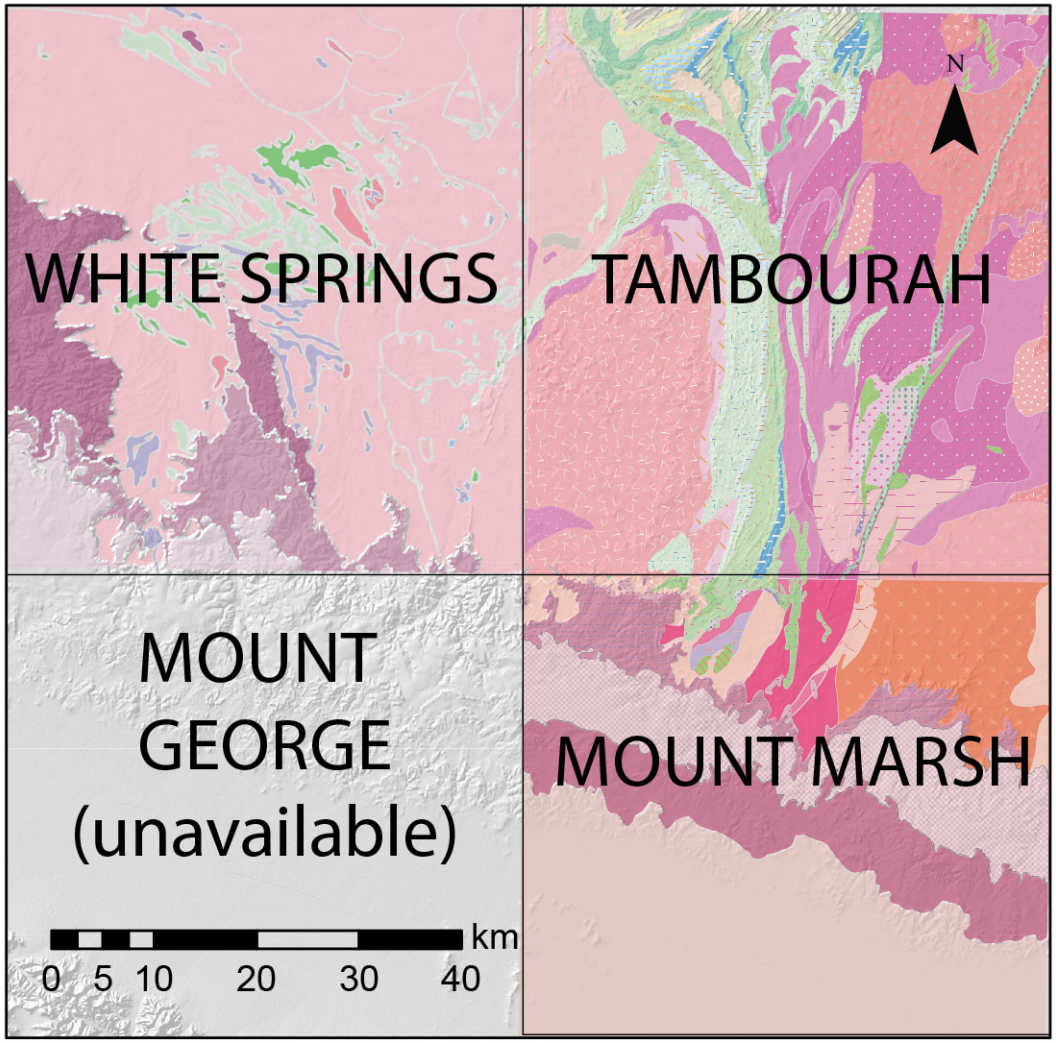
- Locate and characterise conglomerates, basement and structure
- Sedimentology: type, character, shape, and style of clasts, grading, maturity, imbrication and cross-bedding
- Mineralisation: alteration, sulphides,…nuggets!
- Basement, character, structure

- 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!

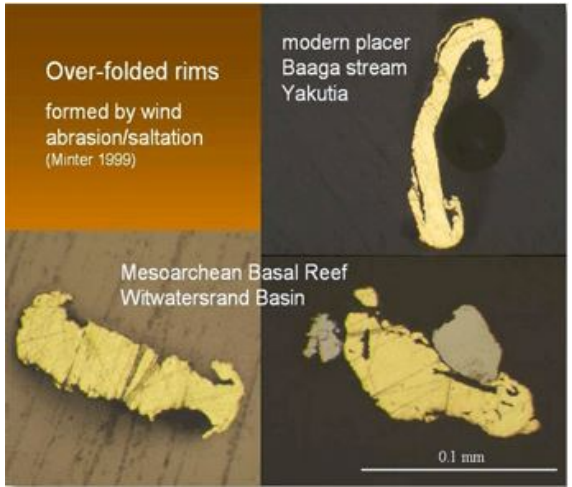


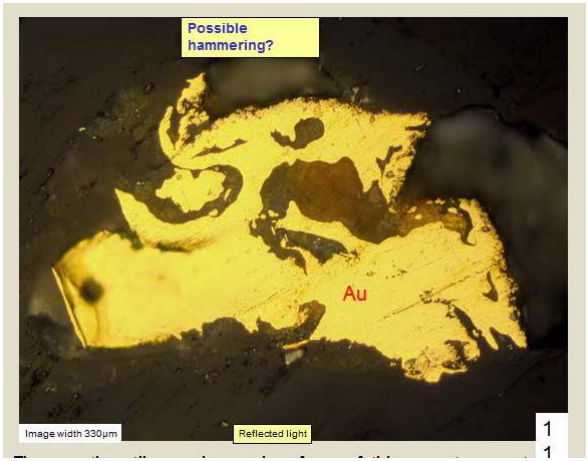
Mapping is key!

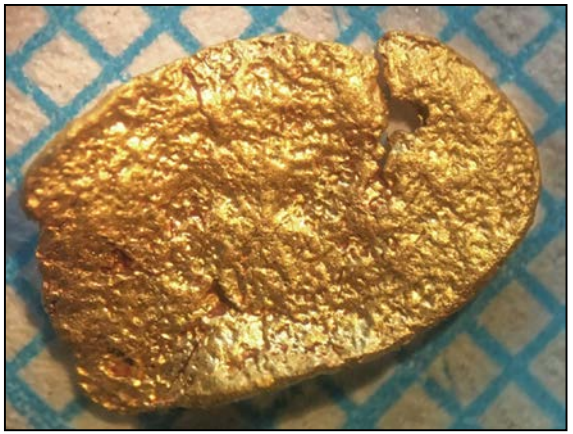


Conglomerate gold – grade continuity

- 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?

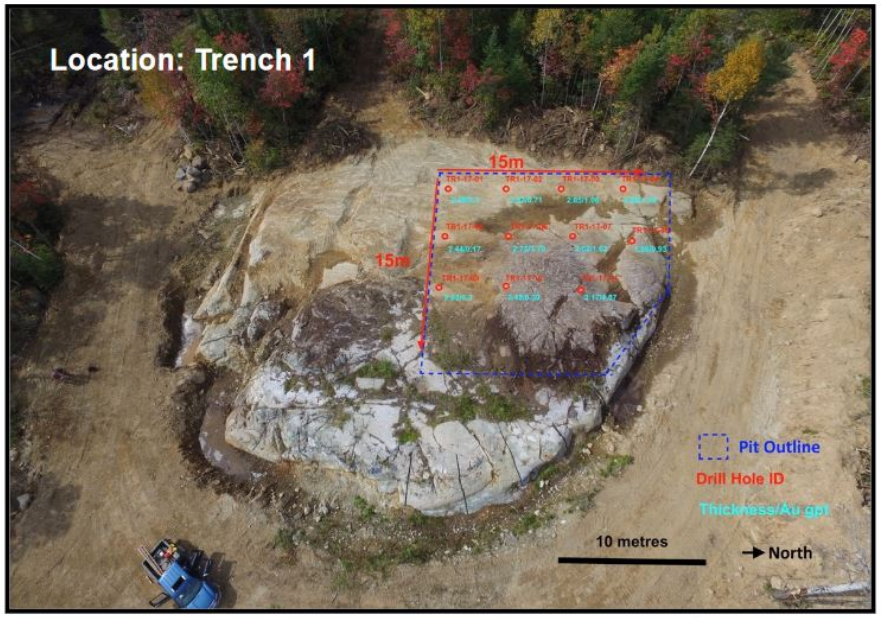
Sampling Methodology

- 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**



INVENTUS

https://static1.squarespace.com/static/56d987d21bbee076a4c0be7f/t/5a4cc4a79140b791bb344688/1514980519550/Inventus_Jan3.pdf

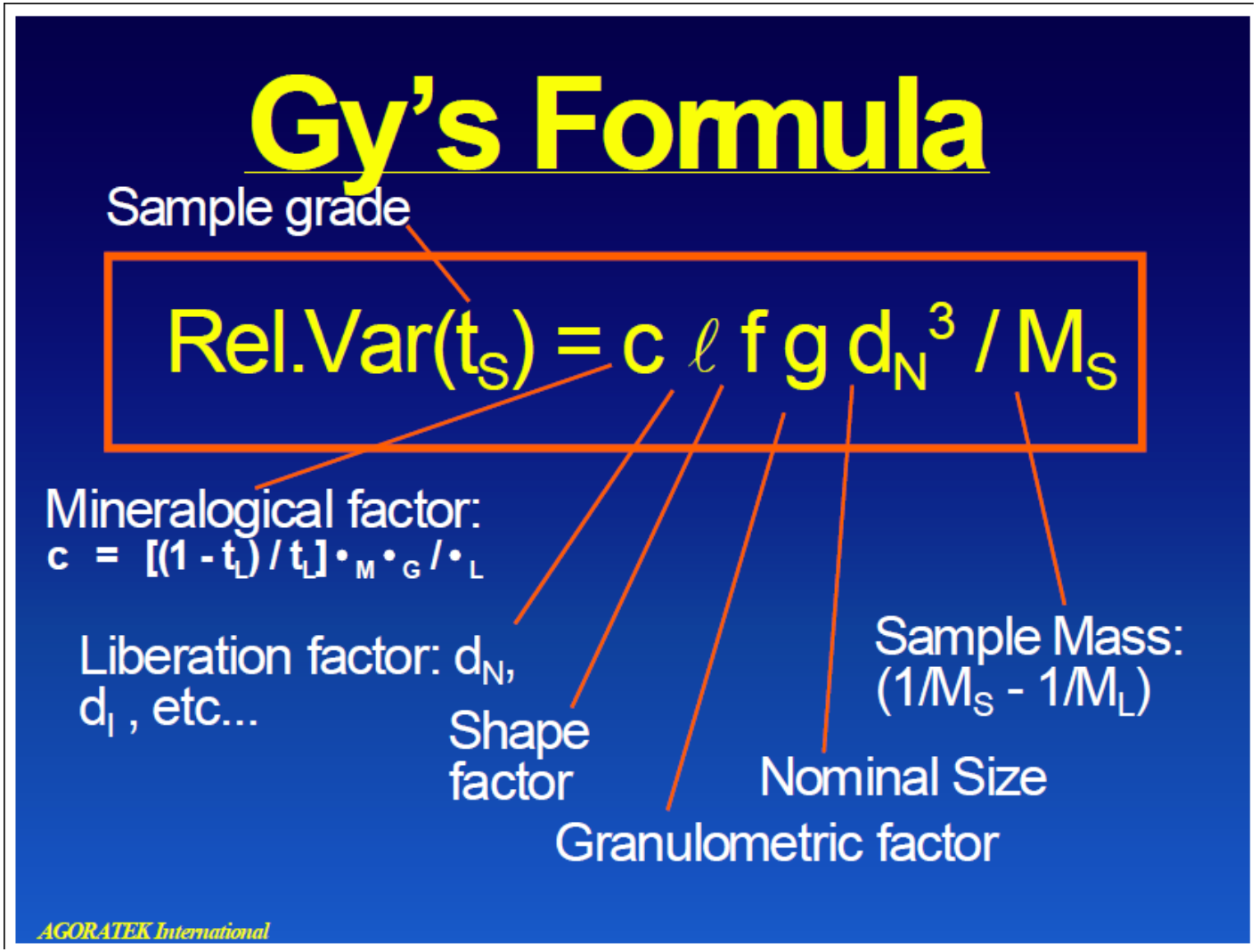
Sampling Errors

- ***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]

Richard Minnitt et al., Part 1: Understanding the components of the fundamental sampling error: a key to good sapling practice

Gy's Formula – Reminder!



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, Explor Minging Geol, 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 *α* parameters to substitute into Gy's formula
- Determining sampling variance of the Fundamental Error

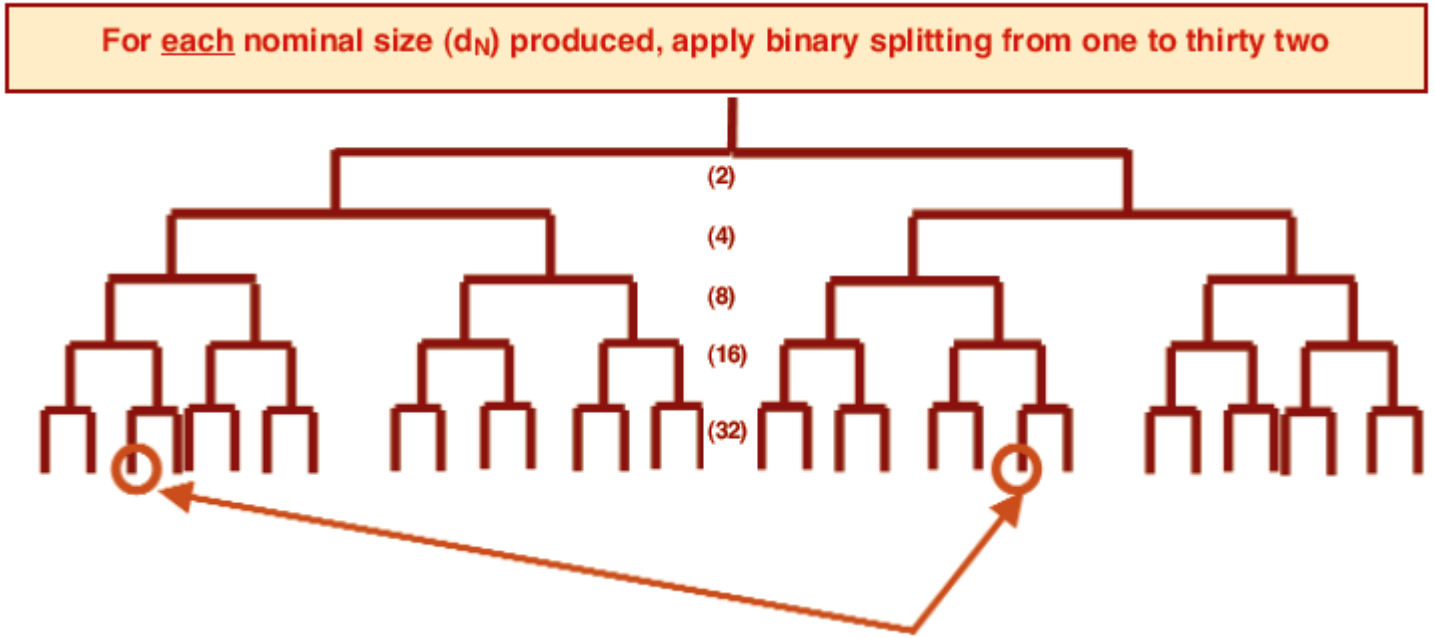
How do we determine these parameters?

- Heterogeneity test (Pitard, 1993, 2004, 2005)
- **Sampling Tree Method (Francois-Bongarcon, 1995 & 1998)**

Richard Minnitt et al., Part 2: Experimental calibration of sampling parameters K and alpha for Gy's formula by the sampling tree method

Sampling Tree - Nomogram

- Record all sample weight
- Assay 30 samples for gold



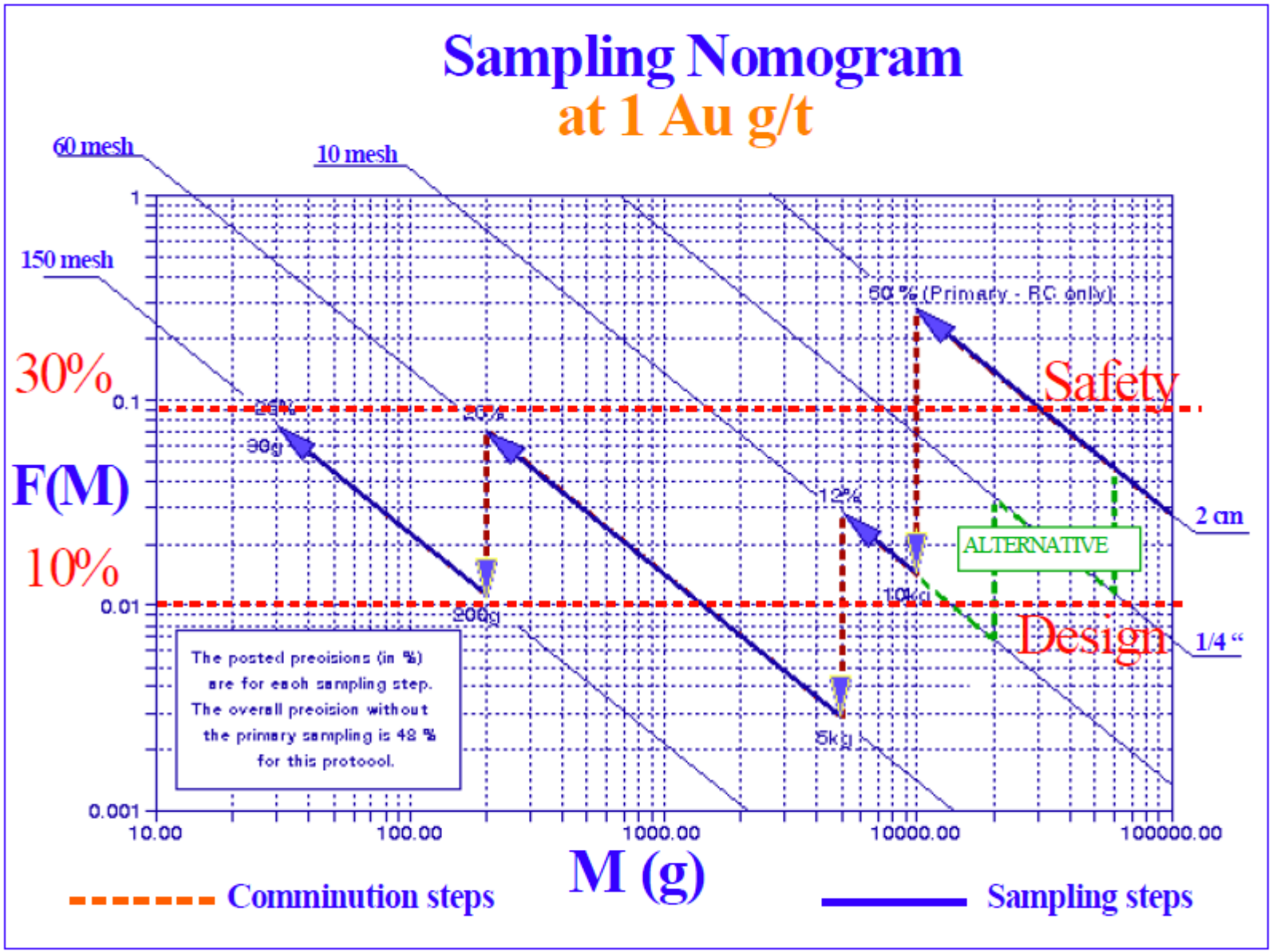
- Randomly select two samples for granulometric analysis

Sampling Tree - Nomogram

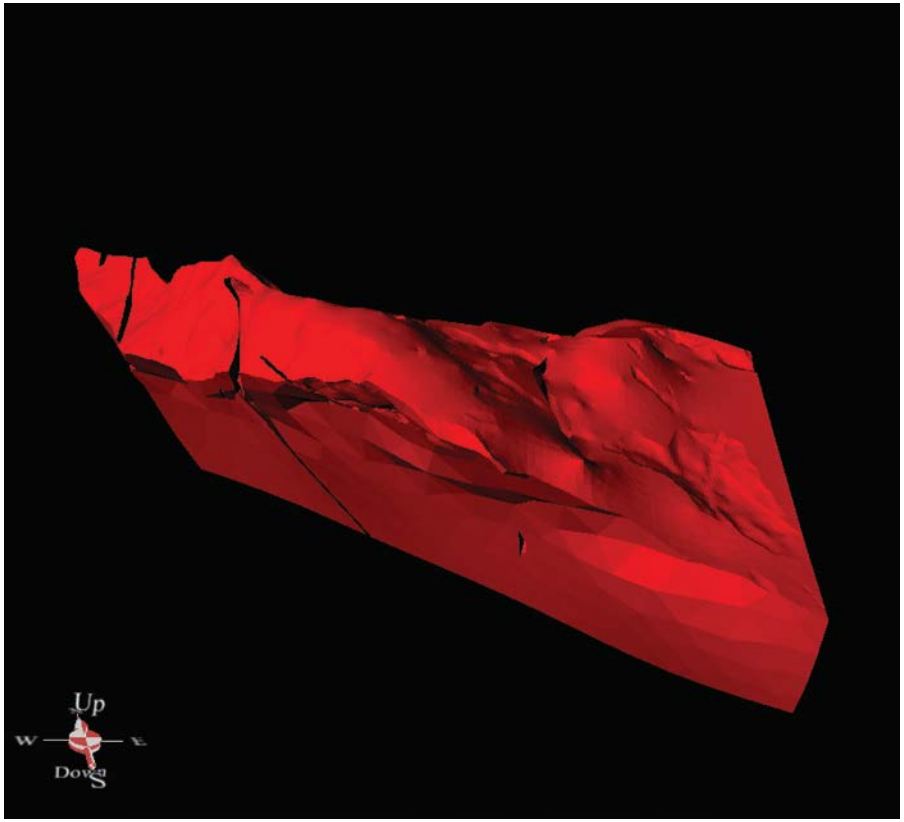
- Determine the variance of the 30 assays
- Ores at different calibrated comminution sizes
- Regression to derive best fit values for K and α
- Plot the curve on log scale
- Calculate the liberation size
- Compilation of sampling nomograms using calibrated constants for a particular ore

- 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

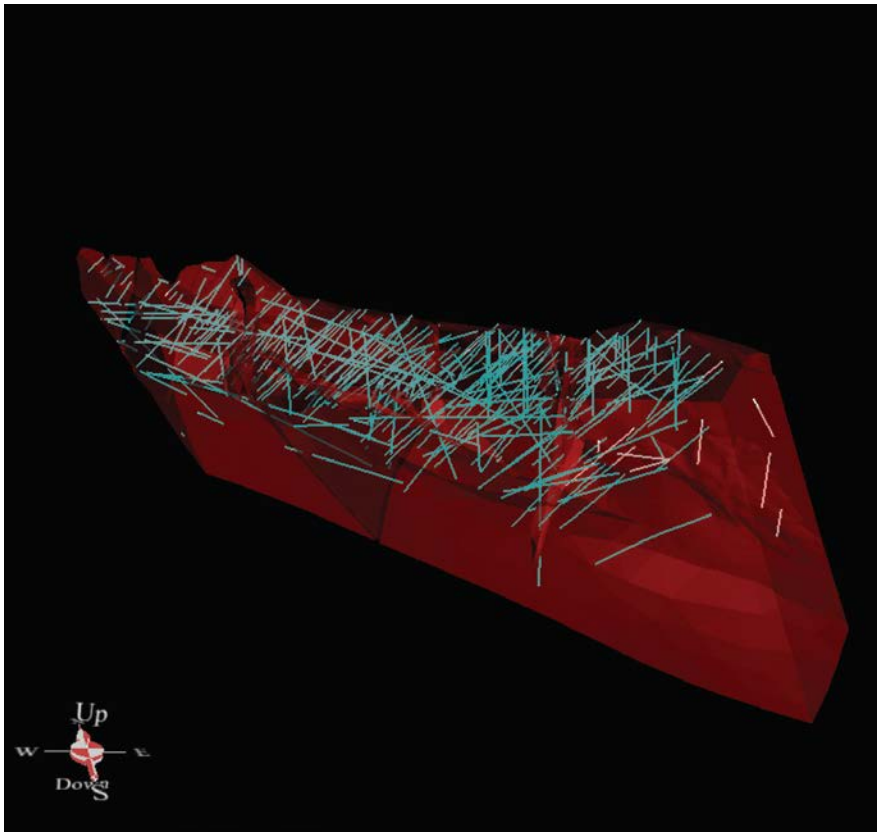


Geological Domains

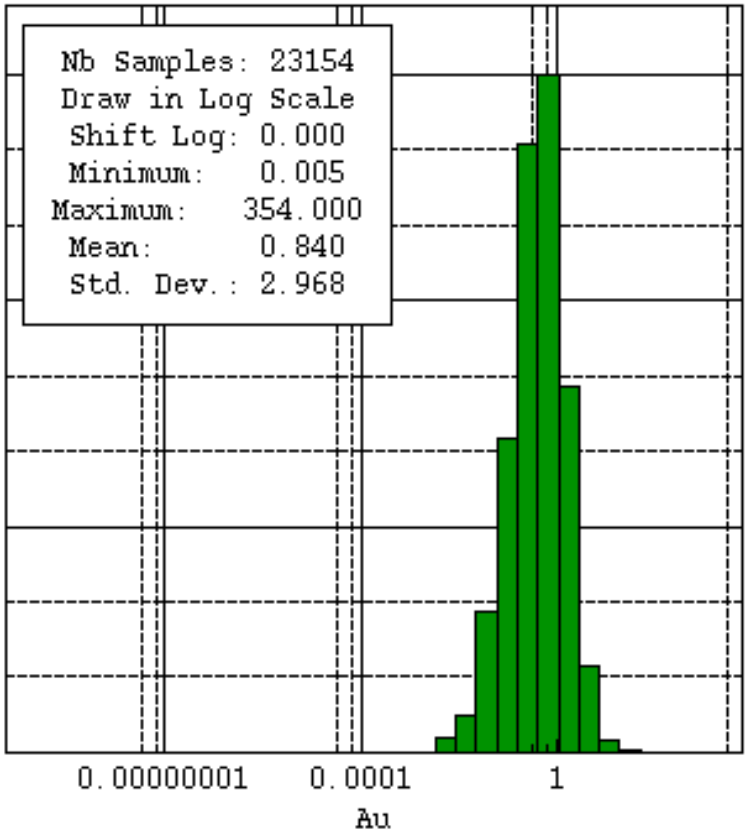


- Model domains correctly
- Use diamond drilling to define domain boundaries
- Surface and trenching to obtain global estimates

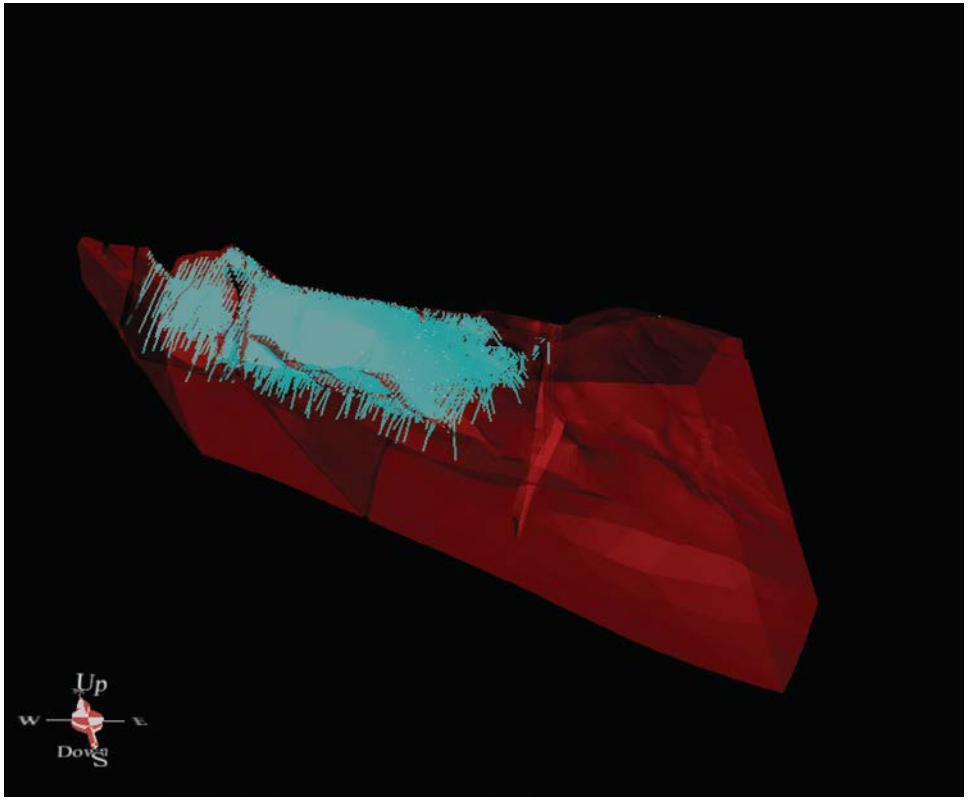
Conglomerate gold – Diamond drilling

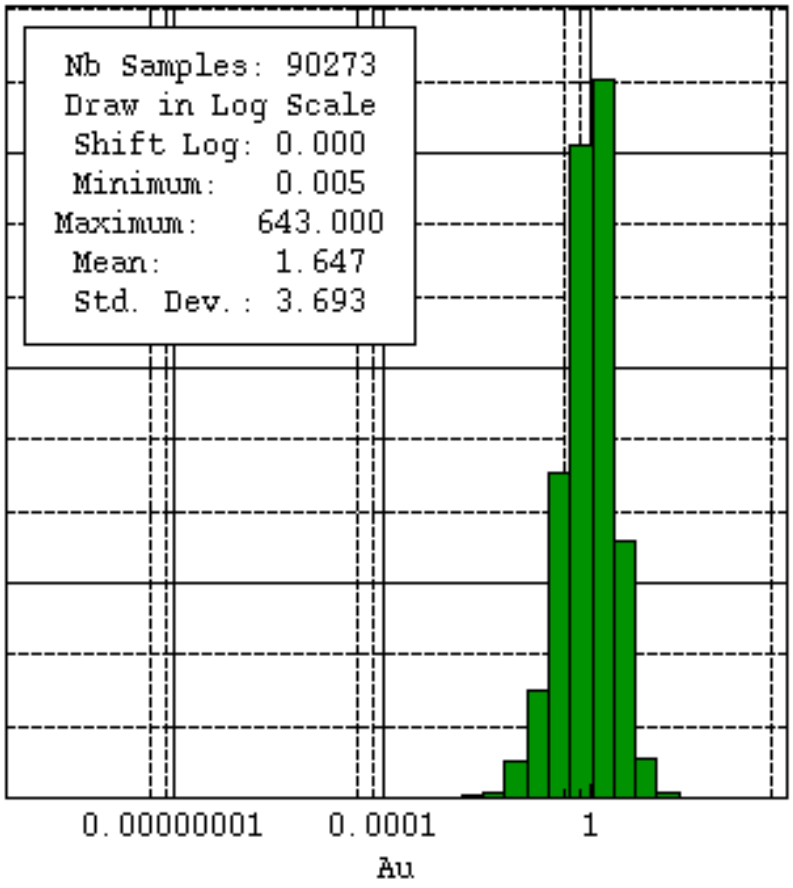


Grades measured on small support will be poorer than grades on larger support

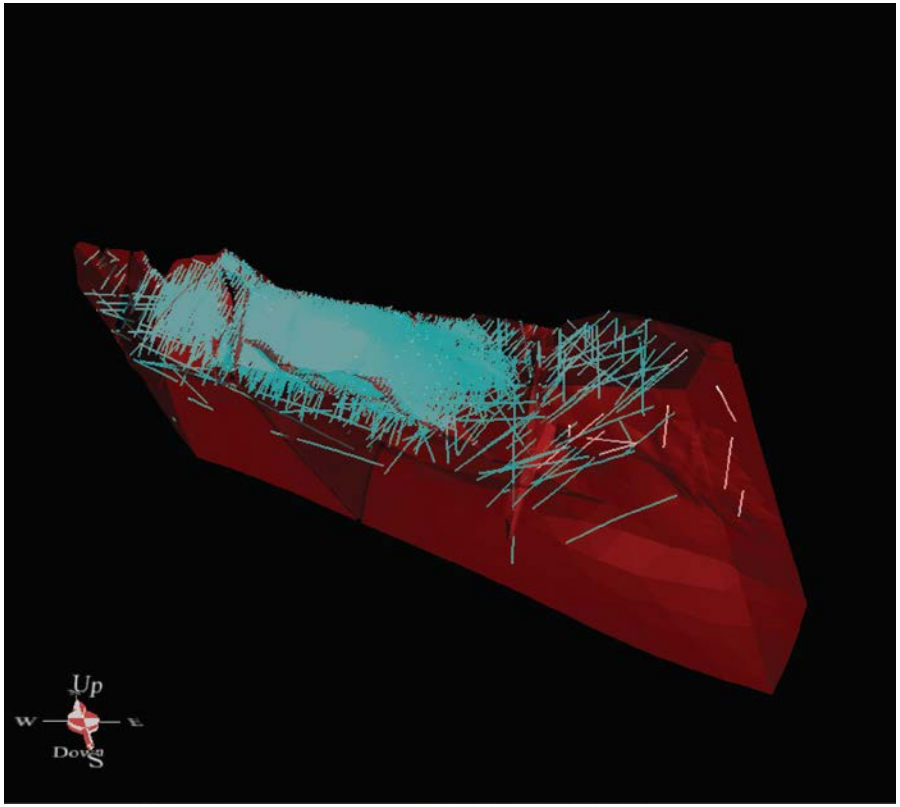


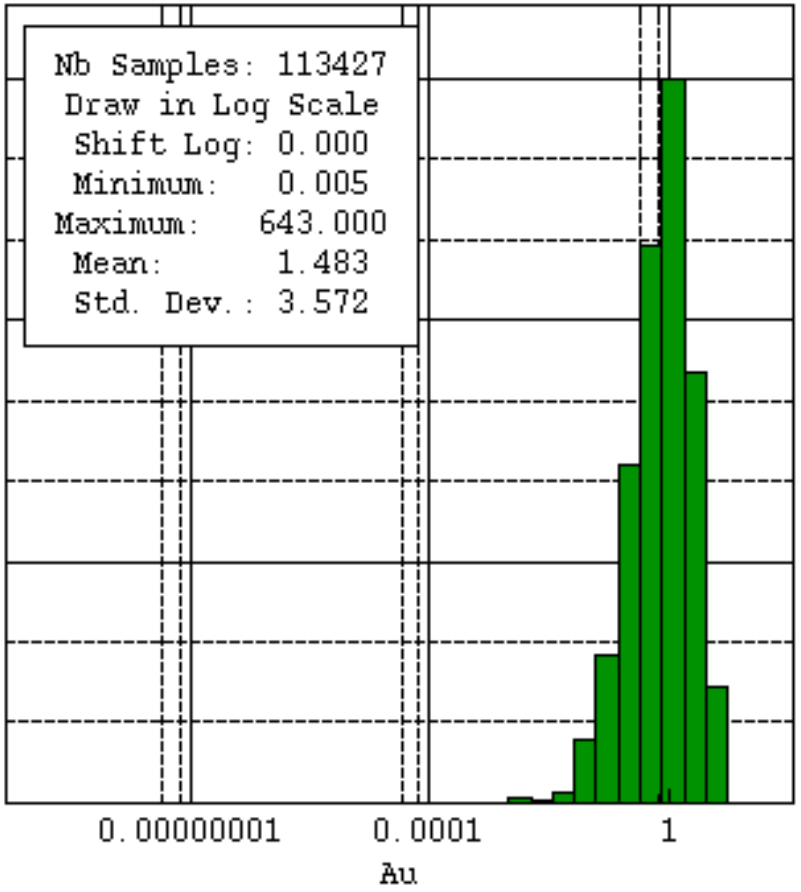
Conglomerate gold – RC drilling



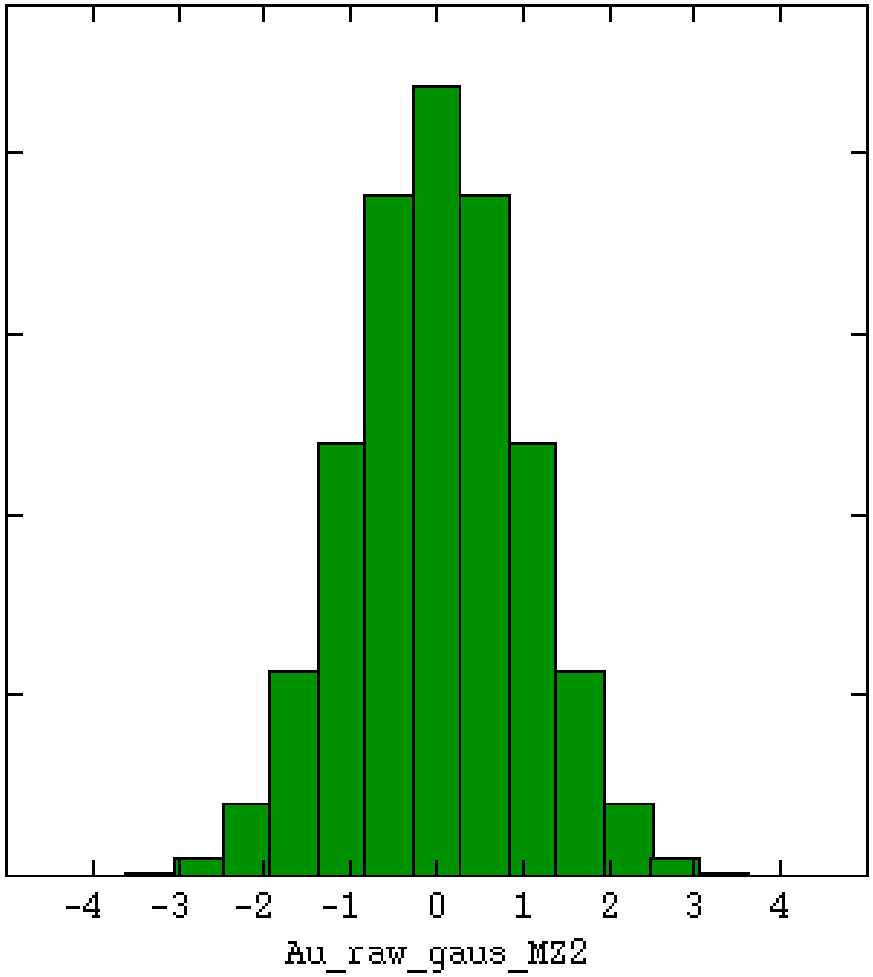


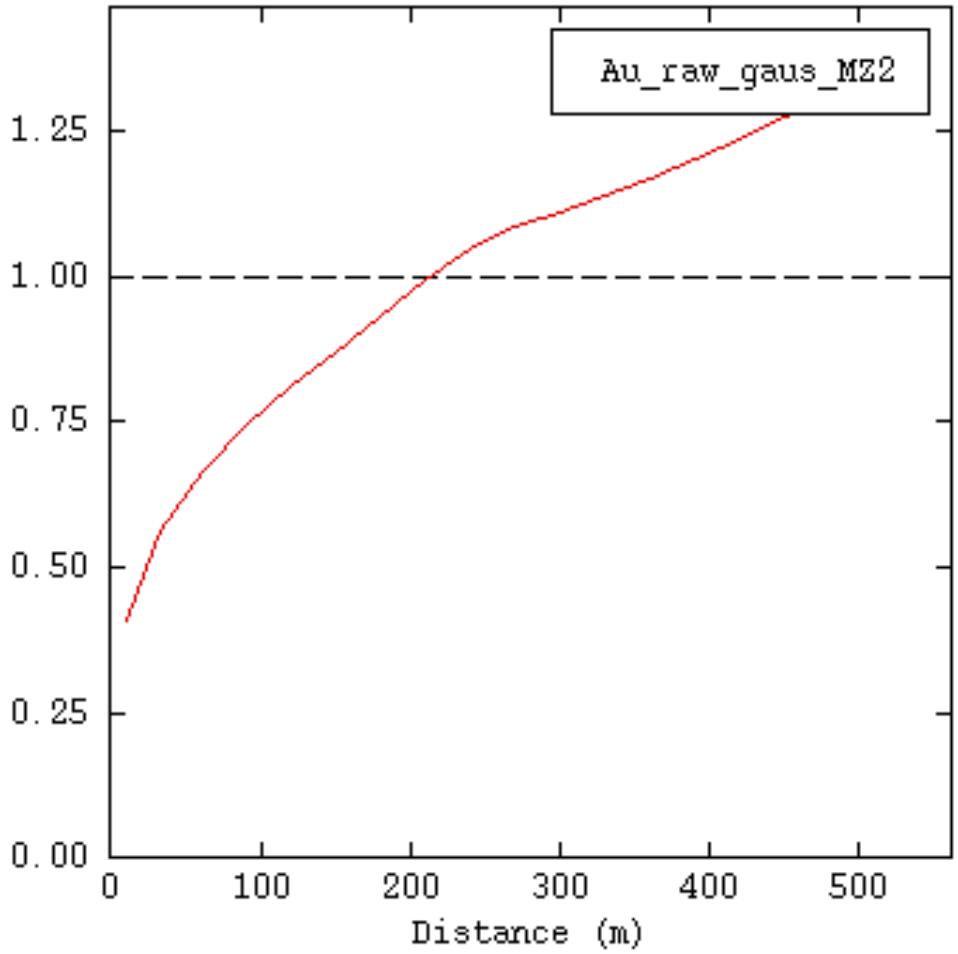
Conglomerate gold – Diamond Drilling & RC drilling





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:

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- Novo Resources, De Grey Mining, Agoratek International, Inventus Mining Corp