Identifying sulphide mineralisation from physical property measurements and its application to mineral exploration inversions

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***pmd*CRC* Building 3D Maps Workshop**

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Australian Government
Geoscience Australia

pmd*CRC

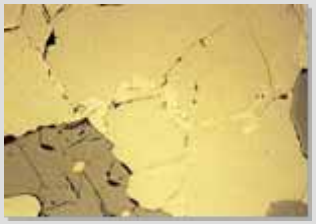
bhpbilliton

MDRU
Mineral Deposit Research Unit
UBC

GIF

Rank exploration targets

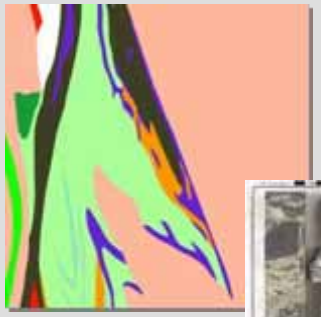
Mineralogy (± texture)



e.g. Ni drill core

e.g. IOCG regional inversions

Mapping

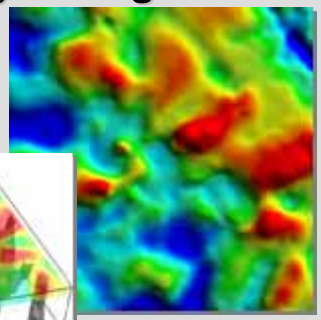


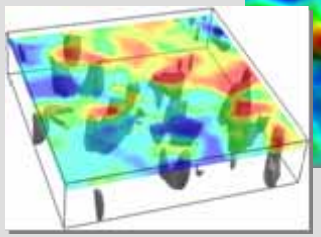
Collect

Density and susceptibility

Calculate

Gravity & Magnetic Data



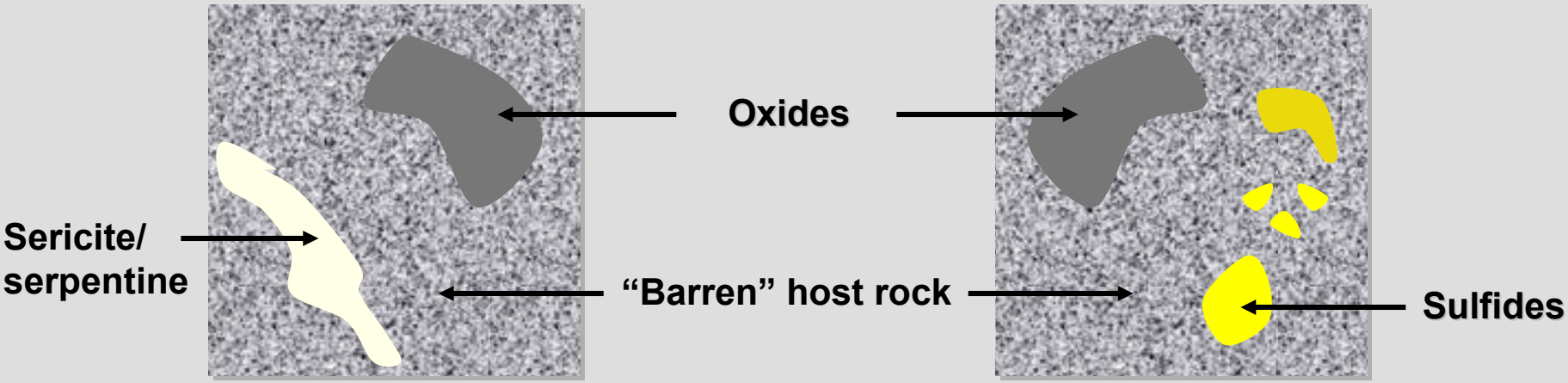


Sampling/drilling/mining

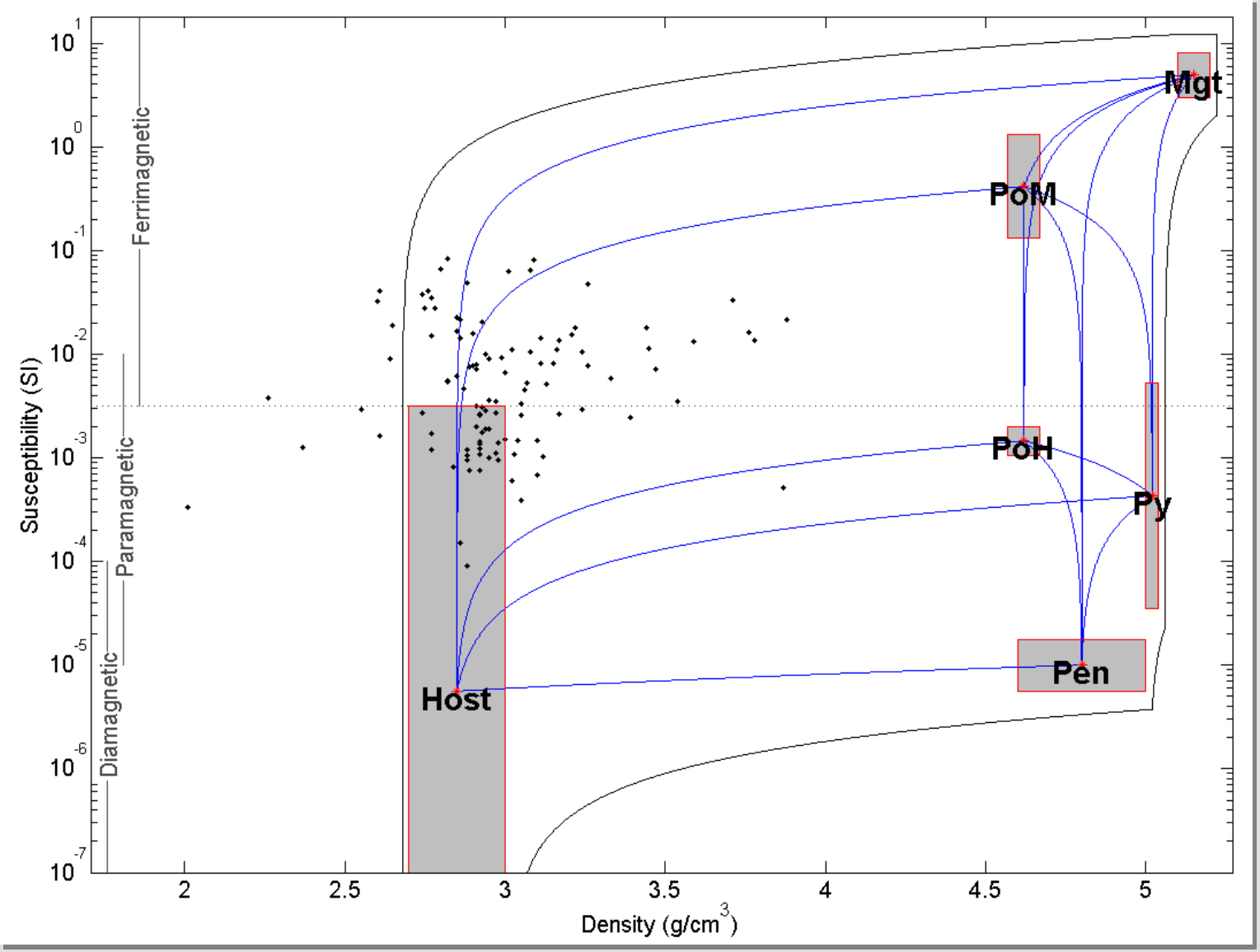
Inversion/forward modelling

Strategy

- **Samples consists of:**
  - Those minerals in the expected geology or deposit style that contribute most to physical properties:
    - ***Sulphides & oxides*** (high ρ; low to high κ)
    - ***Low density alteration phases*** (sericite, serpentine,…)
  - Average silicate/carbonate ***"barren" host rock*** (granite, sandstone, gneiss, …) that contains all other minerals



Strategy (eg. Nickel-Sulphide Deposits)



Solving The Problem

- **Estimate mineral abundance in a sample**
- **For any sample there will be:**
  - ***2 data***: sample density **(ρ_{obs})** and susceptibility **(κ_{obs})**
  - ***Many unknowns***: the proportions of each component present **(x_i)**
  - ***Some geological/petrological constraints on mineral abundances***:
    - Alteration minerals are more common than ore minerals
    - Pentlandite < Pyrrhotite
    - Maximum and minimum abundance (0 to 10 % pyrite)

Linear Programming

- **Assuming magnetite ≤ ~10 vol. %**

$$\sum_{i=1}^{n} x_i = 1 \qquad \sum_{i=1}^{n} \kappa_i x_i = \kappa_{obs} \qquad \sum_{i=1}^{n} \rho_i x_i = \rho_{obs}$$

Mineral abundance

Mineral Susceptibility

Sample Susceptibility & Density

An objective function of *x*

Constraint coefficients

Constraint limits

$$\min_{x} \mathrm{F}(x) \text{ such that } \begin{cases} A \cdot x \le b \\ lb \le x \le ub \end{cases}$$

Lower bound on *x*

Upper bound on *x*

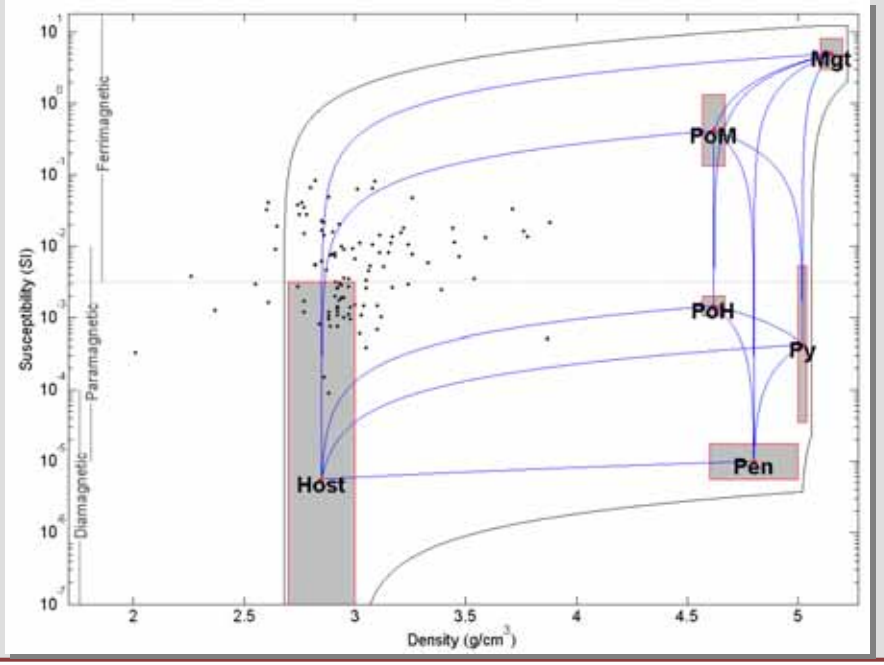
- **Can readily allow for uncertainty in parameters**
- **No exact solution possible, only a range of solutions as defined by objective functions**

Defining a Solution

- **Define objective functions to guide the solution**
  - Possible range of ore abundance
    - **Minimise ore** → Maximise “barren” host rock
      - e.g. Minimise pentlandite abundance; maximise all others
    - **Maximise ore**
      - e.g. Maximise pentlandite abundance; minimise all others
  - Possible range of alteration abundance

Nickel Exploration: Measurements on Drill Core

- **Perseverance Ni-sulphide deposit, Western Australia**
  - Mean properties for 109 different rock and ore types
- **Determine maximum range of pentlandite, given:**
  - Total pyrrhotite is more than double the amount of pentlandite
  - Magnetite < 5 %; pentlandite < 15 %; pyrite < 15 %



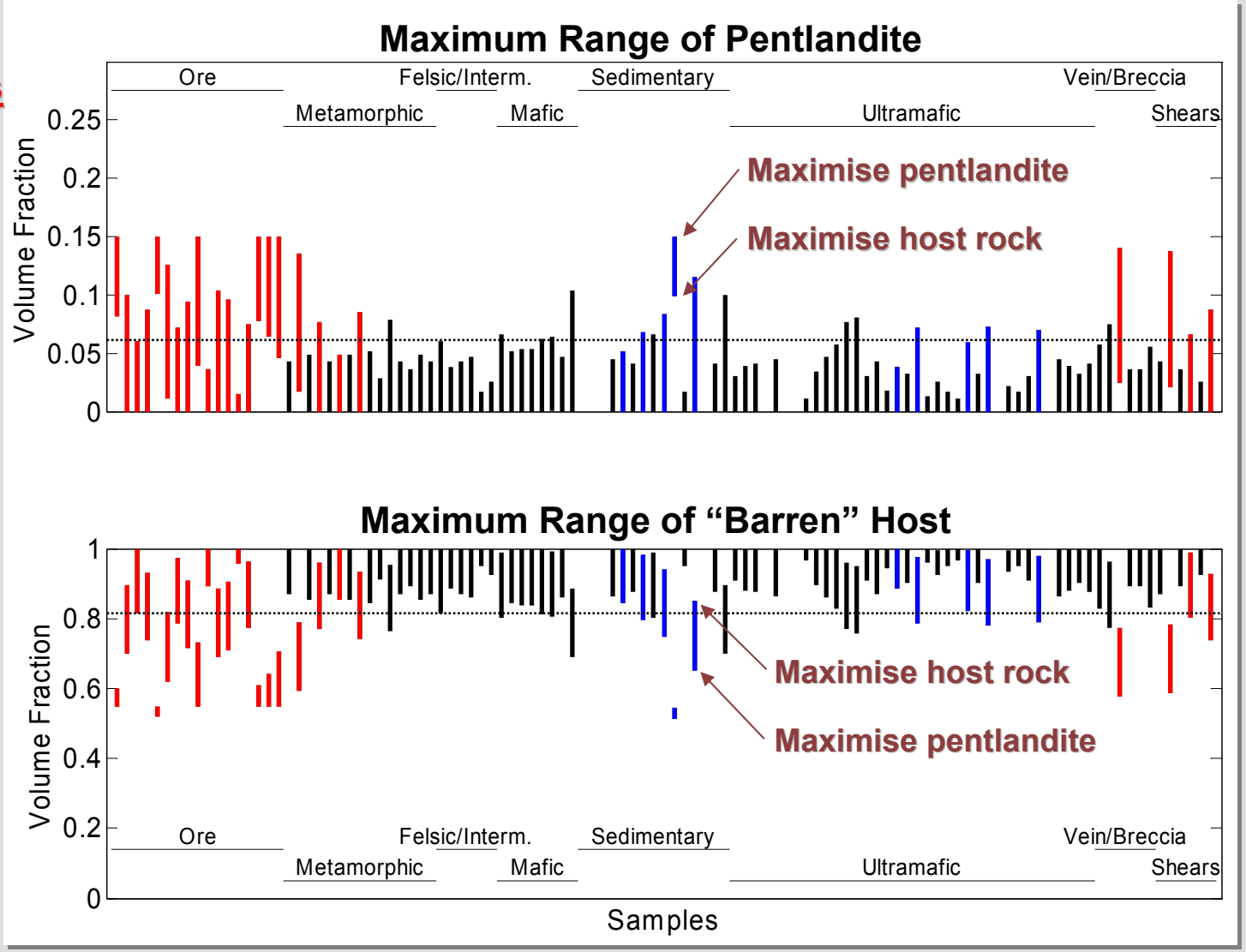
Nickel Exploration: Identifying Ore

Massive Ni-sulphides & Ni-stringers
21 / 25
84 % Success

Abundant disseminated and other sulphides
7 / 10
70 % Success

Barren samples
64 / 74
86 % Success

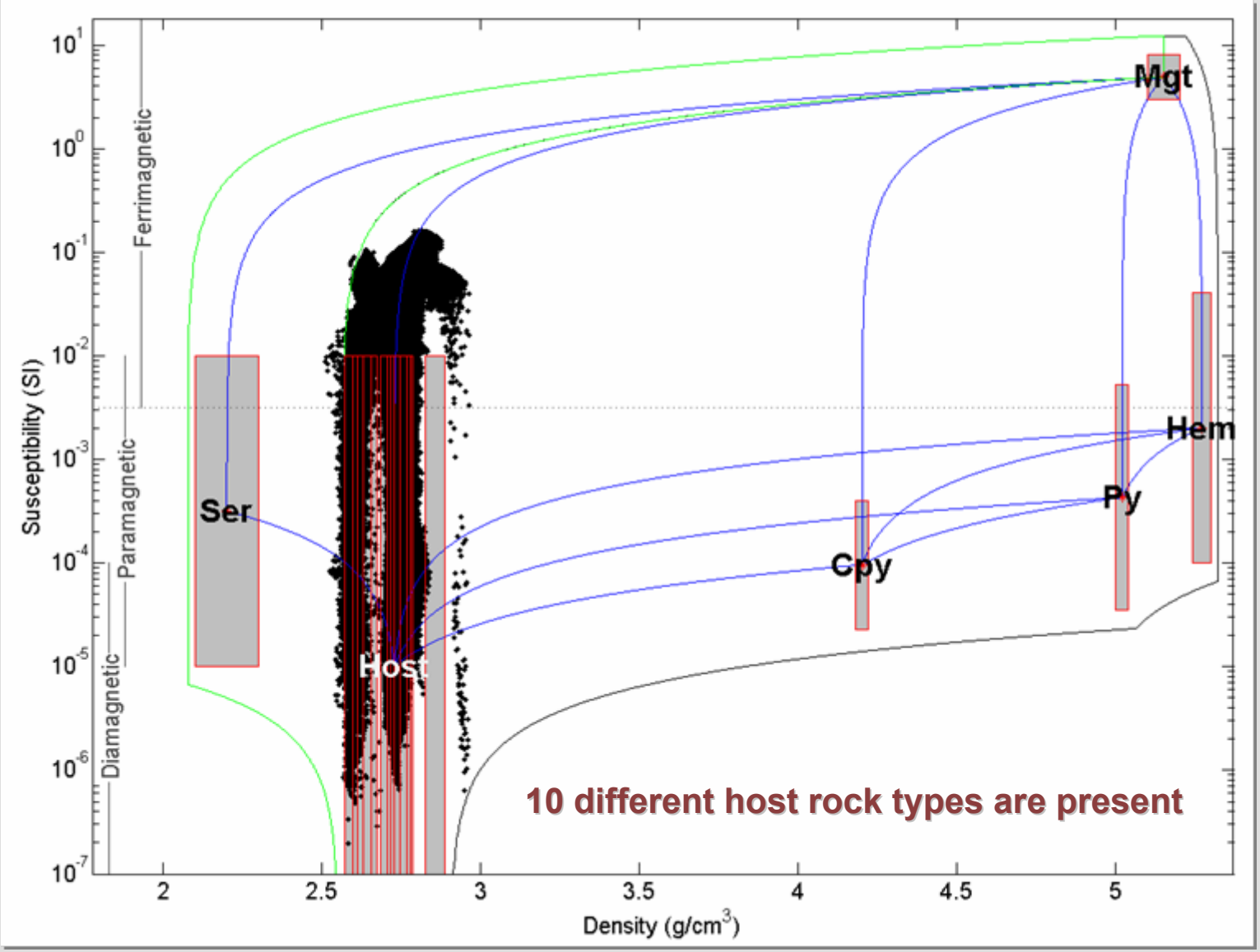
False positives
10 / 74
14 % Failure



IOCG Exploration: 3D Inversion Models

- **Area surrounding Olympic Dam Fe-oxide Cu-Au (IOCG) deposit, South Australia**
  - Under > 300 m transported cover
- **Regional geologically-constrained UBC-GIF inversions of gravity and magnetic data**
  - Use reference model of expected lithologies and properties
  - Obtain 3D models of estimated density and susceptibility consistent with observed gravity and magnetic data
  - Differences between reference models and inversion models due to:
    - Gaps in geological understanding of the area
    - Alteration or mineralisation

IOCG Exploration: 3D Inversion Models



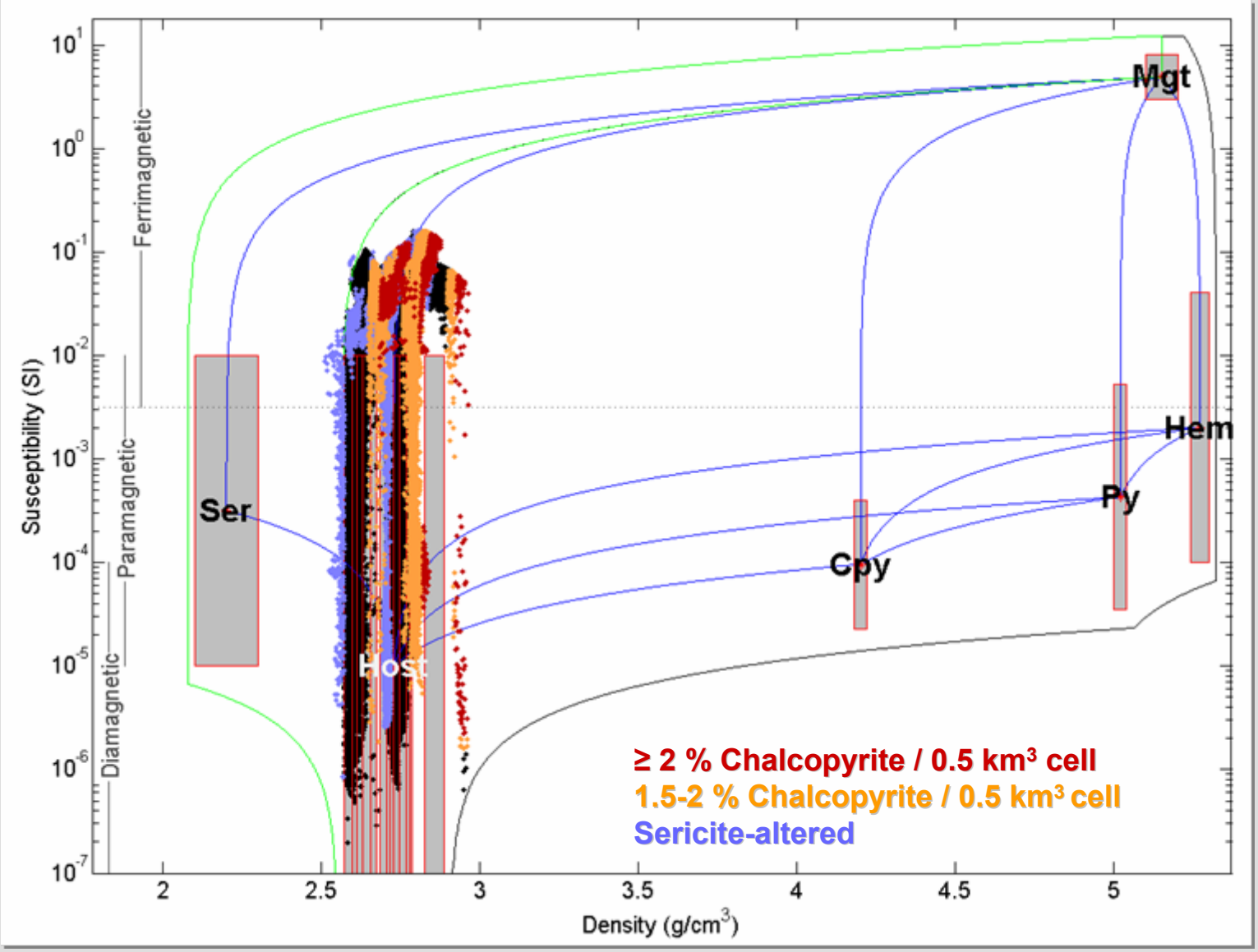
IOCG Exploration: Likely Minerals

- **Cells have sericite or sulphides, *but NOT both*, due to fundamental ambiguity:**
  - Properties of sericite and sulphides can combine to look like "barren" host:
    - **83 % sericite** *(ρ = 2.2 g/cm^3)* **+ 17 % pyrite** *(ρ = 5.0 g/cm^3)* → **bulk density of 2.67 g/cm^3** *(average crust)*
  - Separation would require other physical property data (eg. electrical conductivity)
- **Samples with densities lower than minimum possible host density *MUST* have sericite:**
  - Host + sericite ± magnetite
- **All other samples:**
  - Host ± sulphides ± oxides

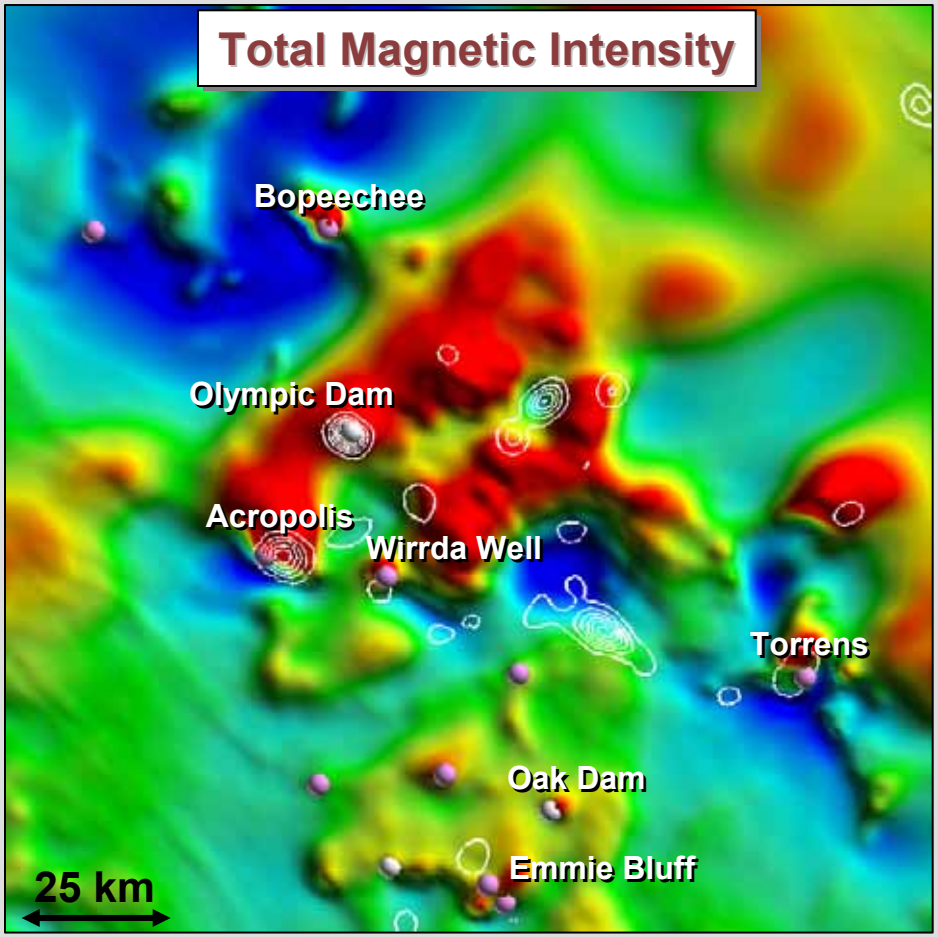
IOCG Exploration: Constraints

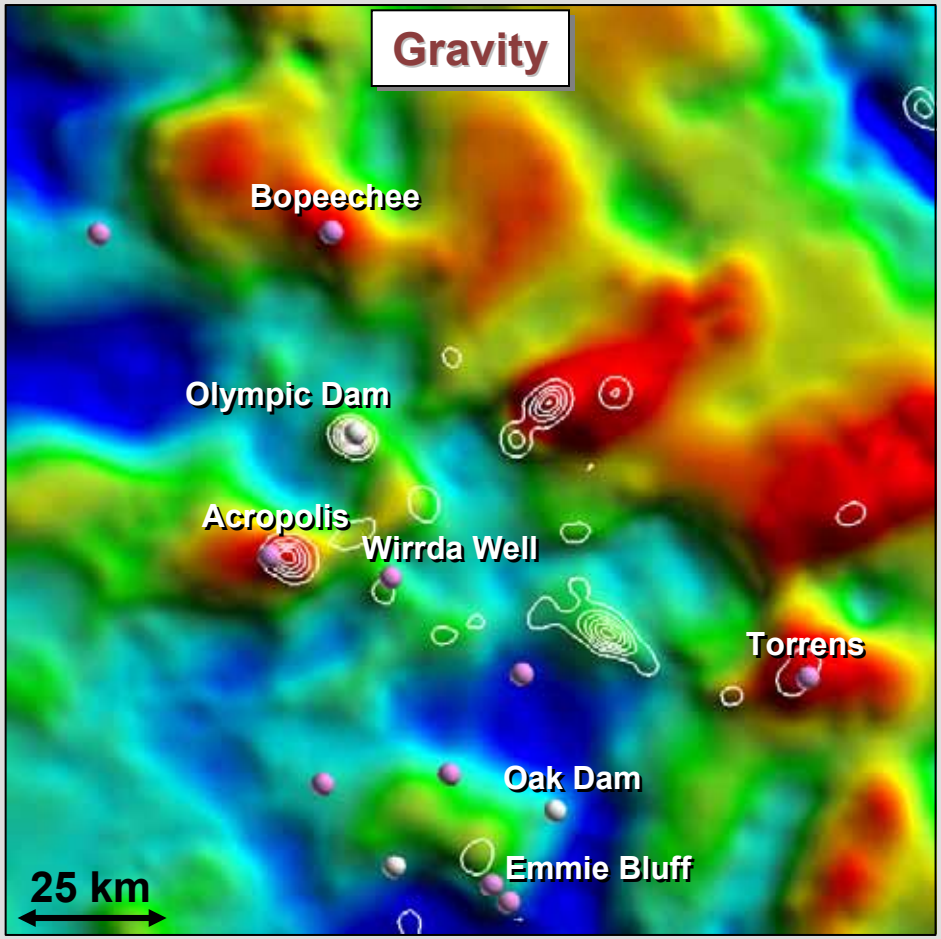
- **For those cells inferred to contain sericite**
  - Determine maximum range of sericite possible
- **For those cells inferred to contain sulphides or hematite:**
  - Determine maximum range of chalcopyrite possible
  - Alteration more common than mineralisation:
    - Hematite > Chalcopyrite
    - Pyrite > Chalcopyrite

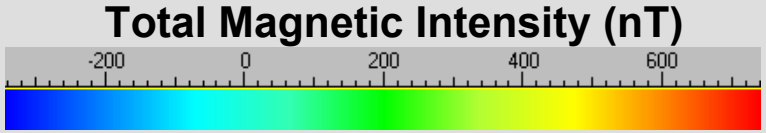
IOCG Exploration: Ranking Samples

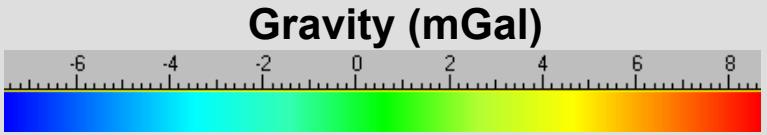


Target: Sulphides + Hematite + Magnetite ± Sericite







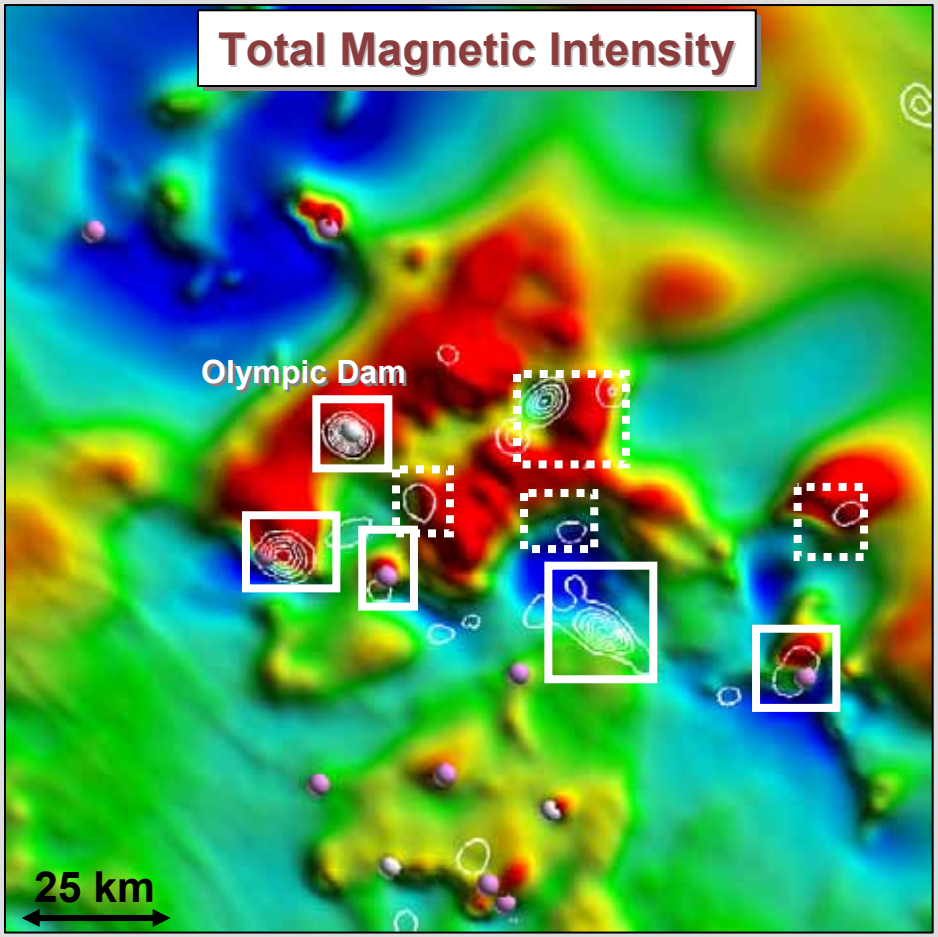


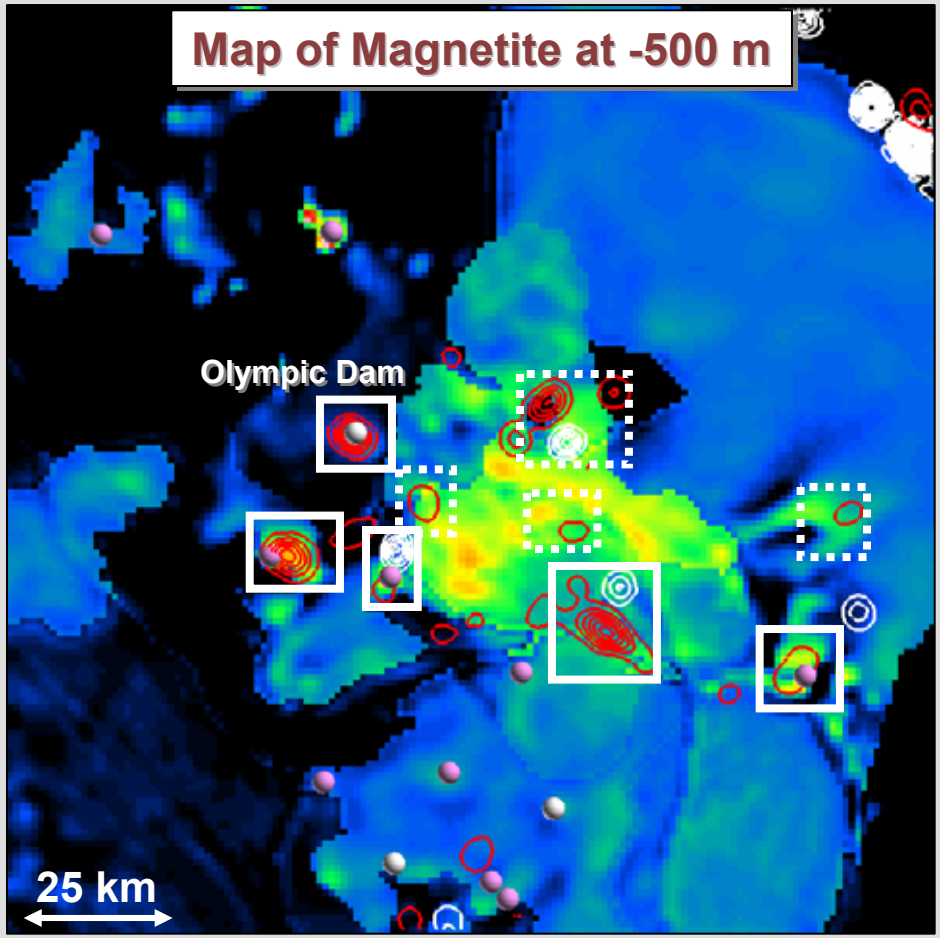
N

Cu Deposits

Cu Prospects

Target: Sulphides + Hematite + Magnetite ± Sericite





Total Magnetic Intensity (nT)

-200 0 200 400 600

Magnetite (% / 0.5 km^3)

0.0 0.5 1.0

0 0.002 0.004 0.006 0.008 0.01

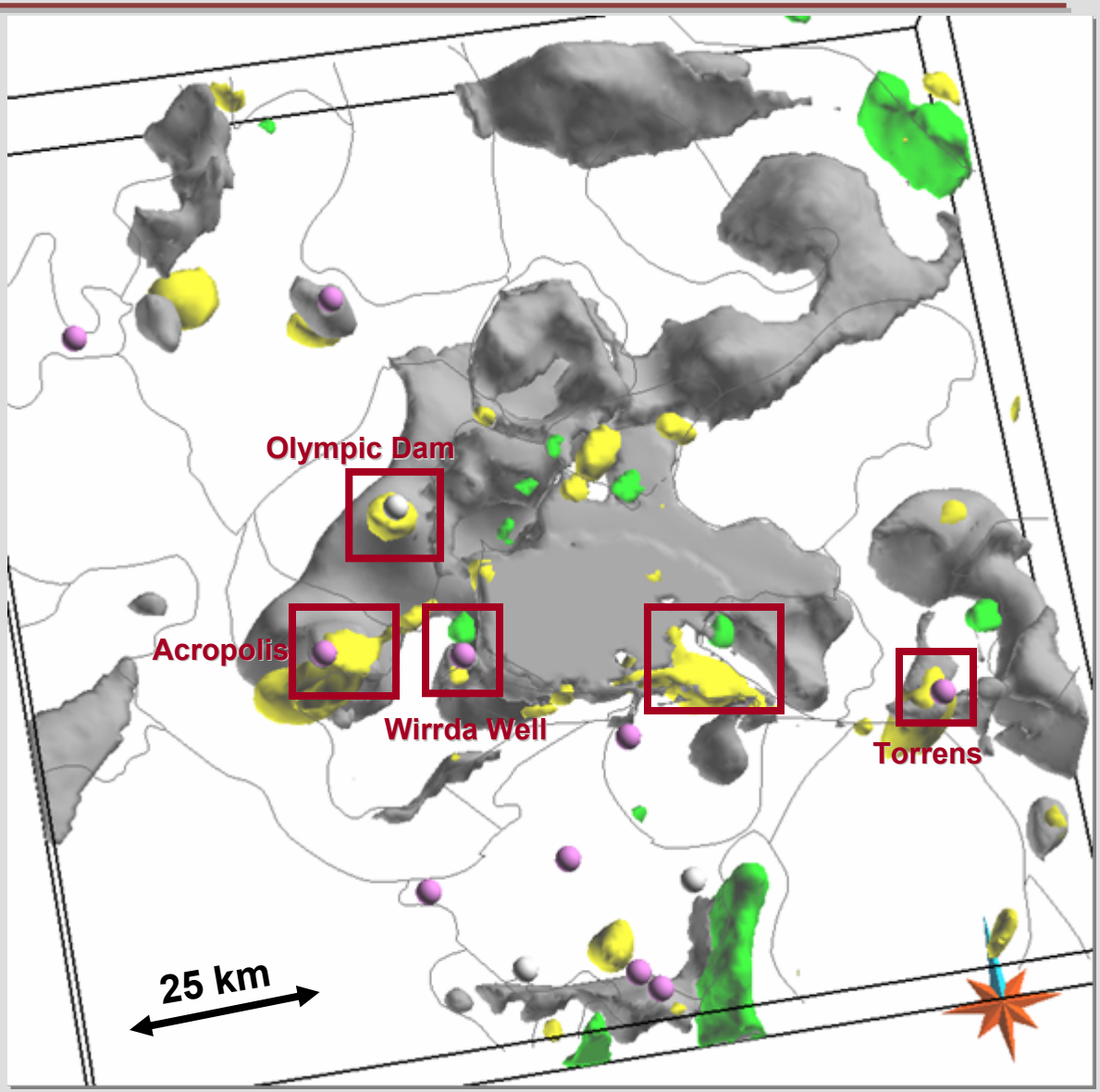
N

Cu Deposits

Cu Prospects

Nickel Exploration: 3D Mapping and Targeting

- **YELLOW:**
  > 0.1 % Sulphides
- **GREEN:**
  > 0.1 % Sericite
- **GREY:**
  > 0.25 % Magnetite
- **Lines show interpreted unit boundaries at top-of-basement**



Cu Deposits

Cu Prospects

Summary

- **Mineralogy (± texture) control ρ and κ**
- **ρ and κ easily measured**
- **ρ and κ can be estimated from gravity and magnetic data using inversions**
- **Mineralogy can be estimated from ρ and κ using linear programming**
  - Simple methods can include estimates of measurement uncertainty
  - Range of possibilities can be explored by using different objective functions and constraints

Conclusions

- **Identify Ni-ore from drill core ρ and κ measurements**
  - Successfully identified 84 % of samples with massive Ni-sulphides and stringers
  - Quick quantification of sulphide mineralisation prior to expensive geochemistry or petrography
- **Rank IOCG exploration targets directly using inferred proportions of ore minerals and alteration**
  - Previous targeting based on <u>magnetic anomalies</u> often identified <u>magnetite deposits</u> with very low grade Cu
  - Several new targets do not show magnetic anomalies