# Identifying sulfide mineralization from physical property measurements and its application to mineral exploration inversions


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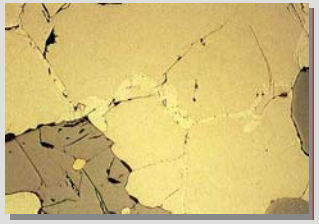
UBC

GIF

# Rank exploration targets

Mineralogy (± texture)

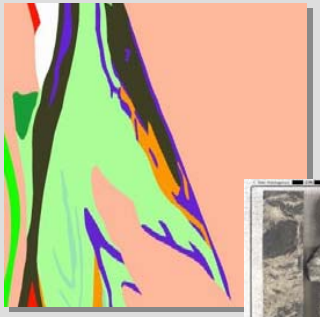


e.g. Ni drill core

e.g. IOCG regional inversions

**Density and susceptibility**

Mapping

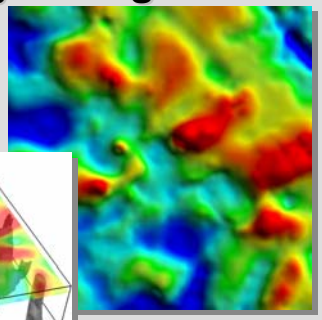


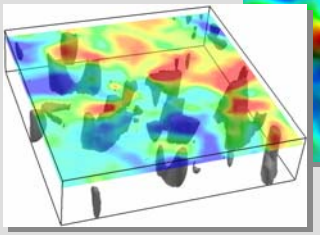
Collect

Sampling/drilling/mining

Calculate

Gravity & Magnetic Data

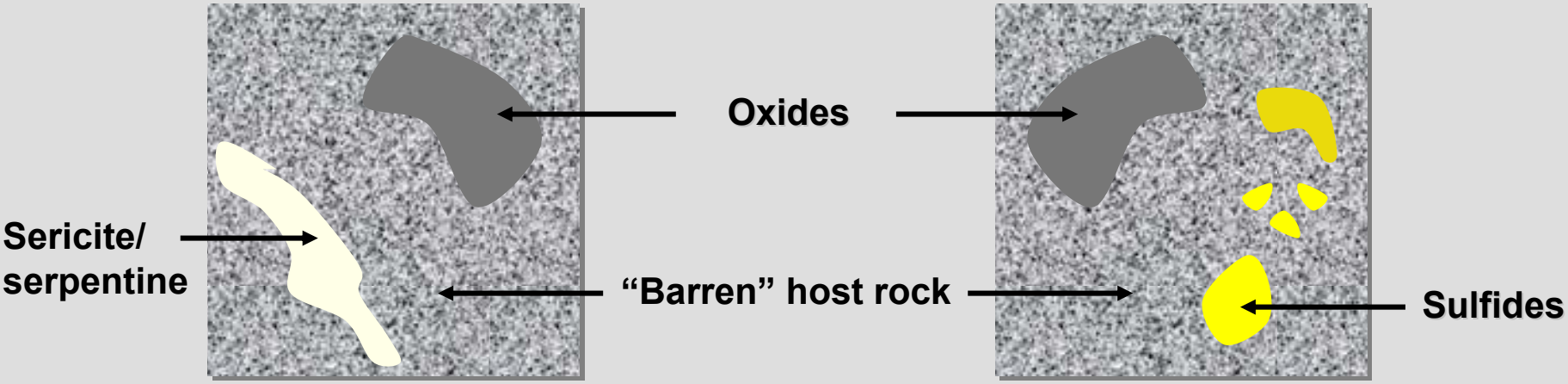




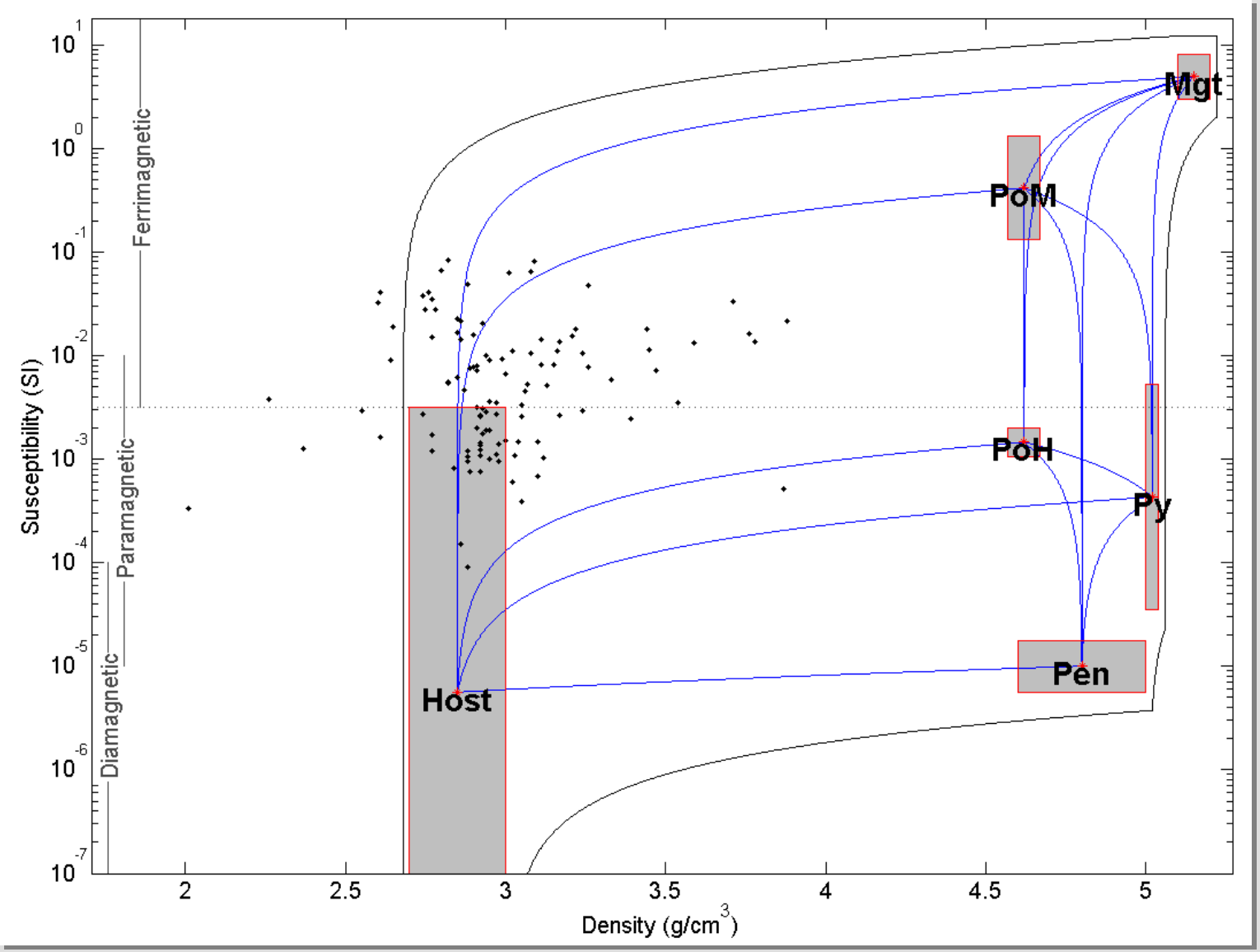
Inversion/forward modelling

# Strategy

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



# Strategy (eg. Nickel-Sulfide Deposits)



# Solving The Problem

- **Estimate mineral abundance in a sample**
- **For any sample there will be:**
  - ***2 data***: sample density **($\rho_{obs}$)** and susceptibility **($\kappa_{obs}$)**
  - ***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

$$\sum_{i=1}^{n} x_i = 1$$

Mineral abundance

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

Mineral Susceptibility

Sample Susceptibility

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

Mineral Density

Sample Density

An objective function of *x*

Constraint coefficients

Constraint limits

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

Lower bound on *x*

Upper bound on *x*

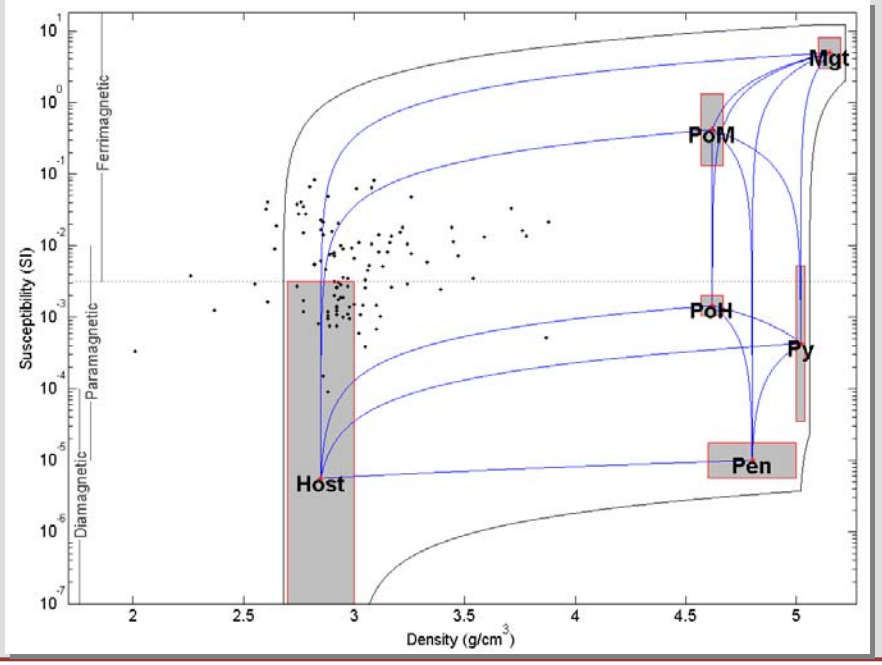
- **Can allow for uncertainty**
- **No exact solution possible, only a range of solutions as defined by objective functions**

# Defining a Solution

- **Define objective functions to guide the solution**
  - Possible range of ore abundance
    - **Minimize ore** → Maximize “barren” host rock
      - e.g. Minimize pentlandite abundance; maximize all others
    - **Maximize ore**
      - e.g. Maximize pentlandite abundance; minimize all others
  - Possible range of alteration abundance

# Nickel Exploration: Measurements on Drill Core

- **Perseverance Ni-sulfide 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 %



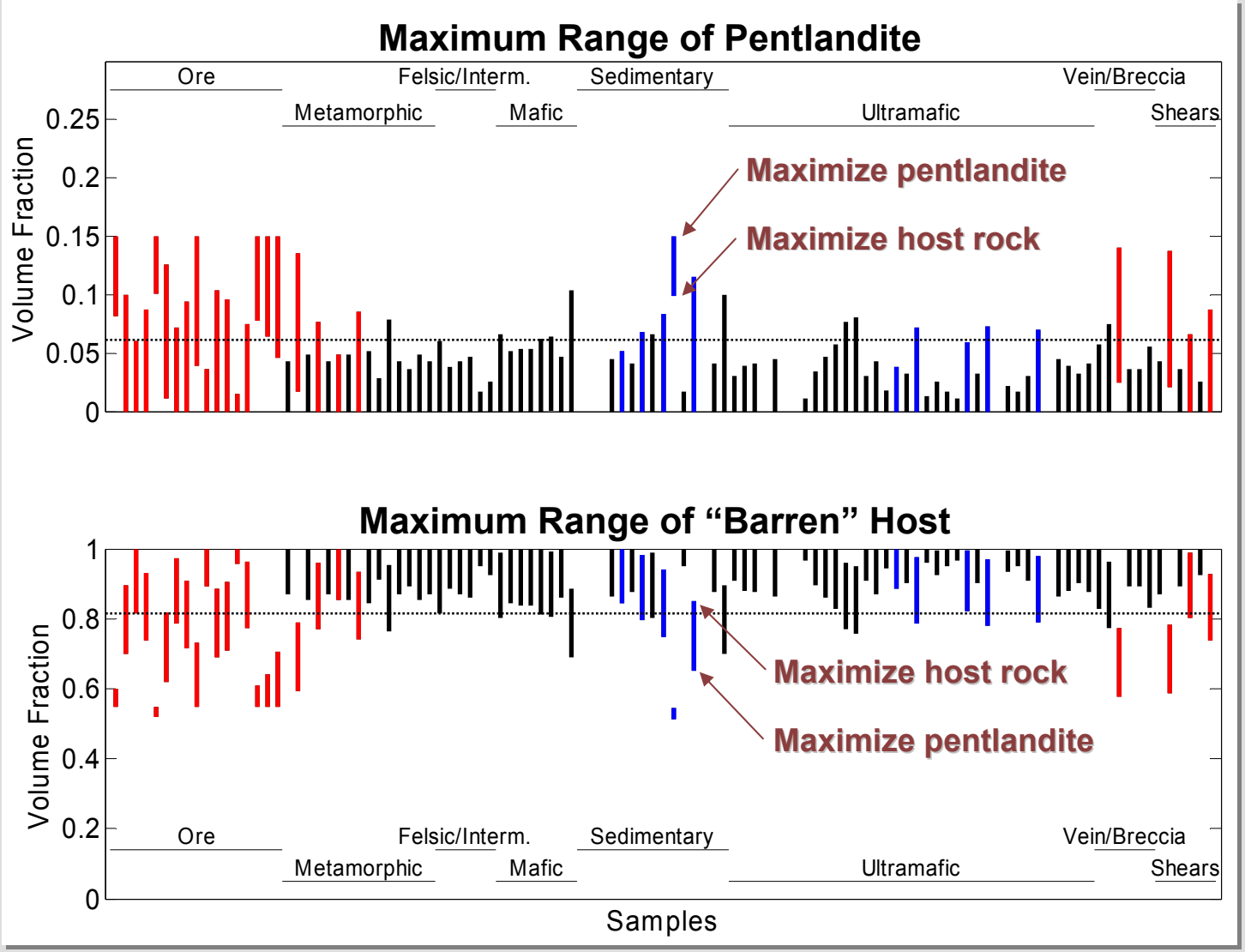
# Nickel Exploration: Identifying Ore

**Massive Ni-sulfides & Ni-stringers**
21 / 25
84 % Success

**Abundant disseminated and other sulfides**
7 / 10
70 % Success

**Barren samples**
64 / 74
86 % Success

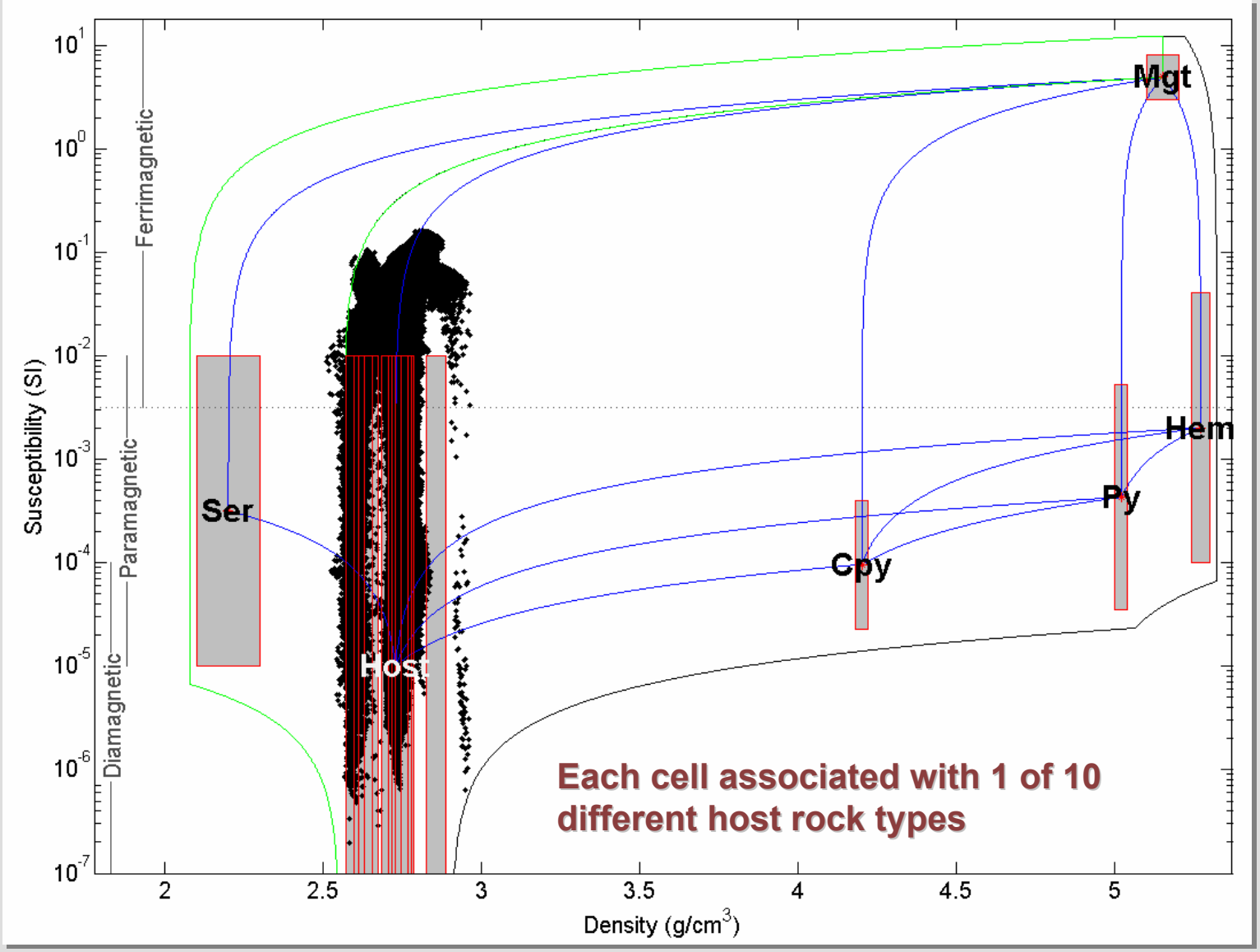
**False positives**
10 / 74
14 % Failure



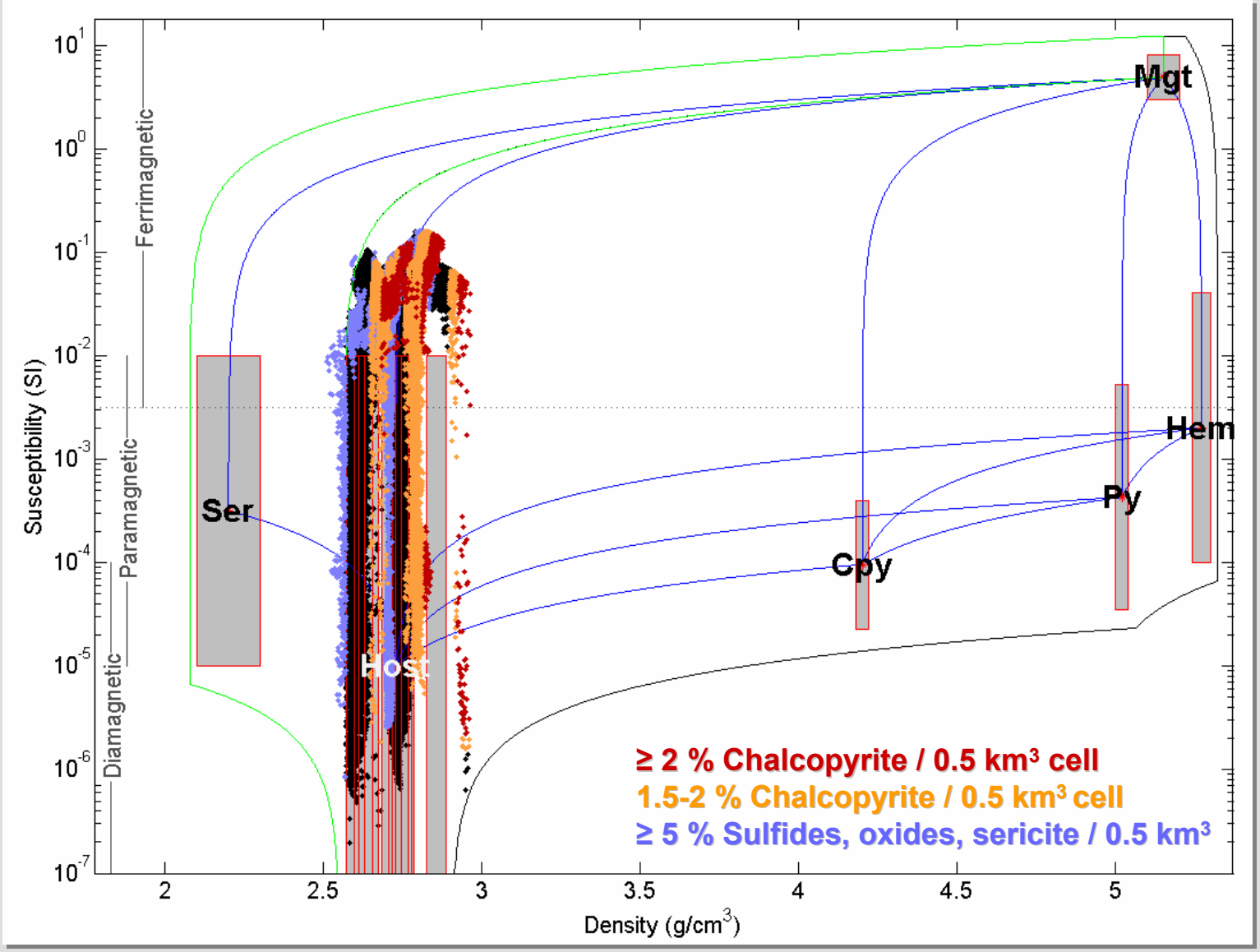
# IOCG Exploration: 3D Inversion Models

- **Area surrounding Olympic Dam Fe-oxide Cu-Au (IOCG) deposit, South Australia**
  - Under deep 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 mineralization

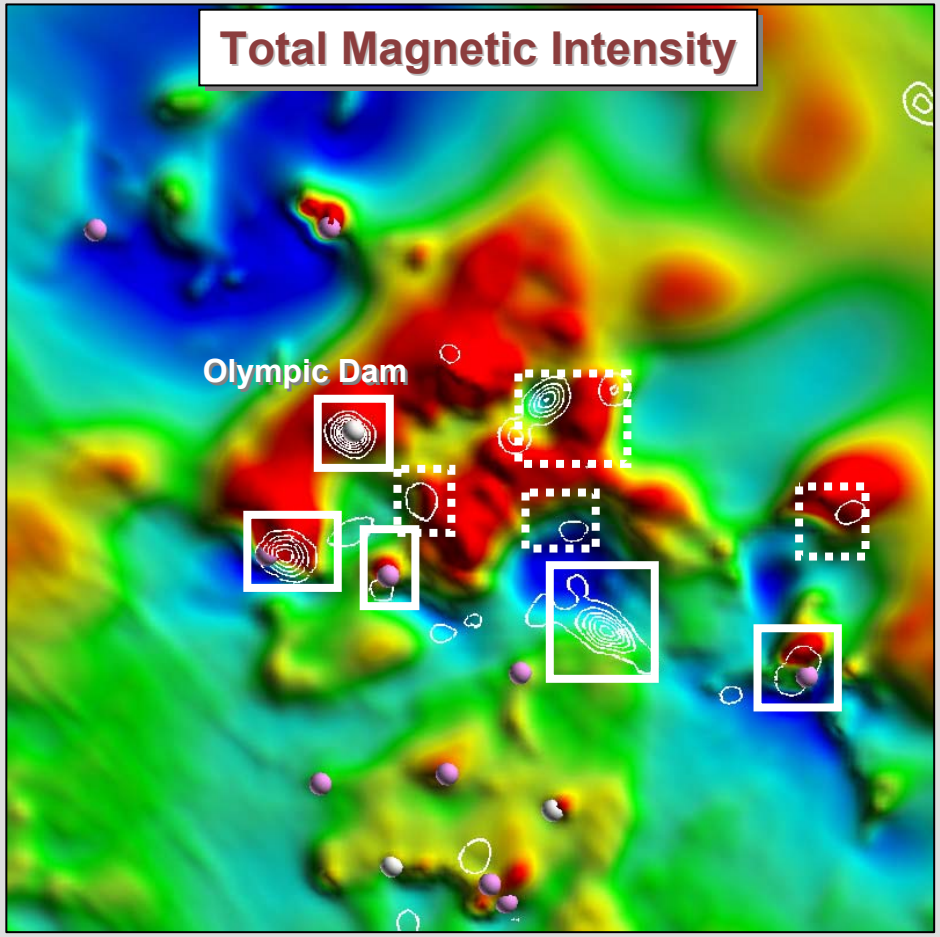
# IOCG Exploration: 3D Inversion Models

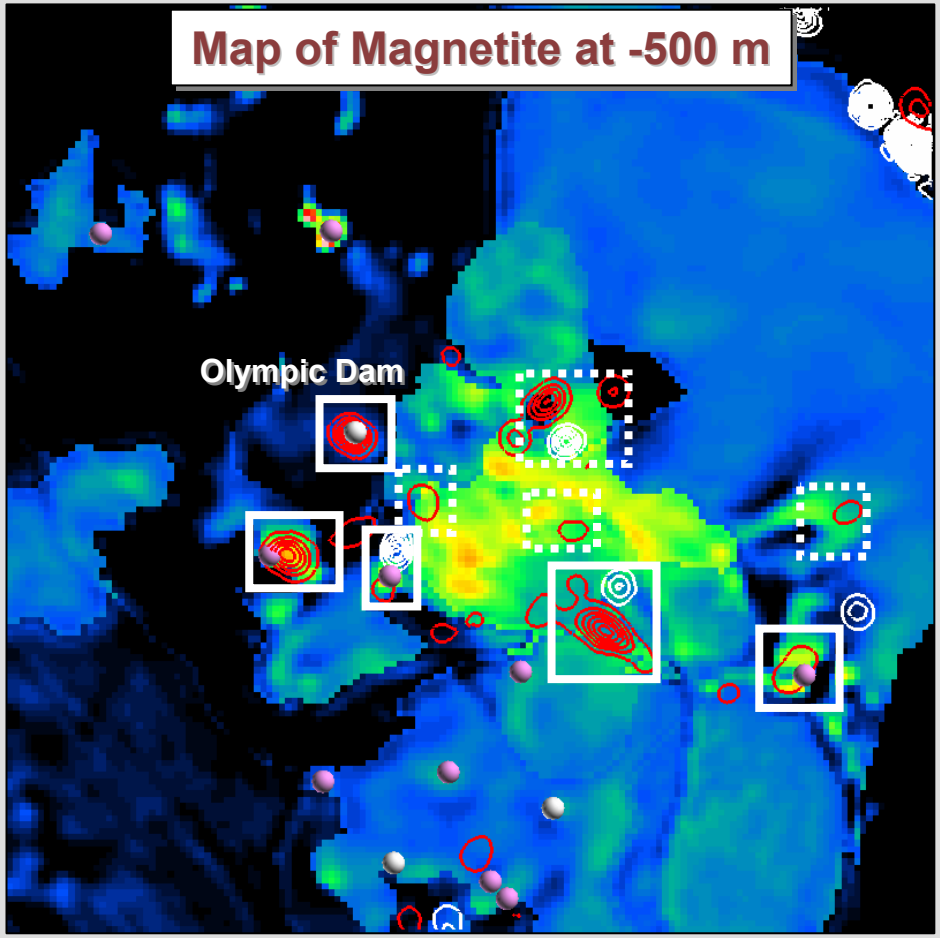


# IOCG Exploration: Ranking Samples



# Target: Sulfides + 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

# Summary

- **Mineralogy (± texture) control $\rho$ and $\kappa$**
- **$\rho$ and $\kappa$ easily measured**
- **$\rho$ and $\kappa$ can be estimated from gravity and magnetic data using inversions**
- **Mineralogy can be estimated from $\rho$ and $\kappa$ using linear programming**
  - Range of possibilities can be explored by using different objective functions and constraints

# Conclusions

- **Identify Ni-ore from drill core $\rho$ and $\kappa$ measurements**
  - 84 % of samples with massive Ni-sulfides and stringers identified
  - Quick quantification of sulfide mineralization without expensive geochemistry or petrography
- **Rank IOCG exploration targets directly using inferred proportions of ore minerals and alteration**
  - Previous targeting based on magnetic anomalies often identified magnetite deposits with very low grade Cu
  - This new method ranks regions based directly on the target of interest: sulfide abundance
  - Several new targets do not show magnetic anomalies