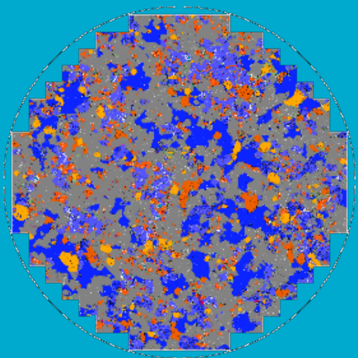
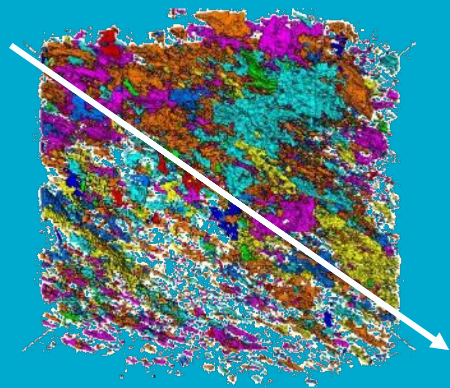
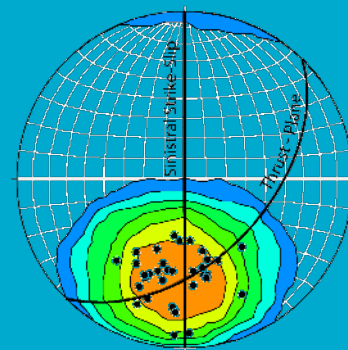
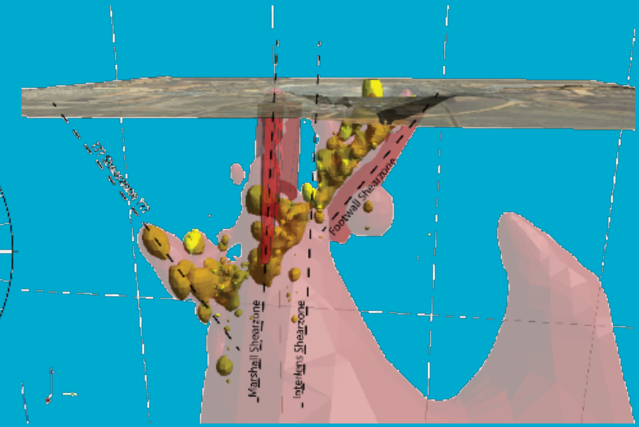








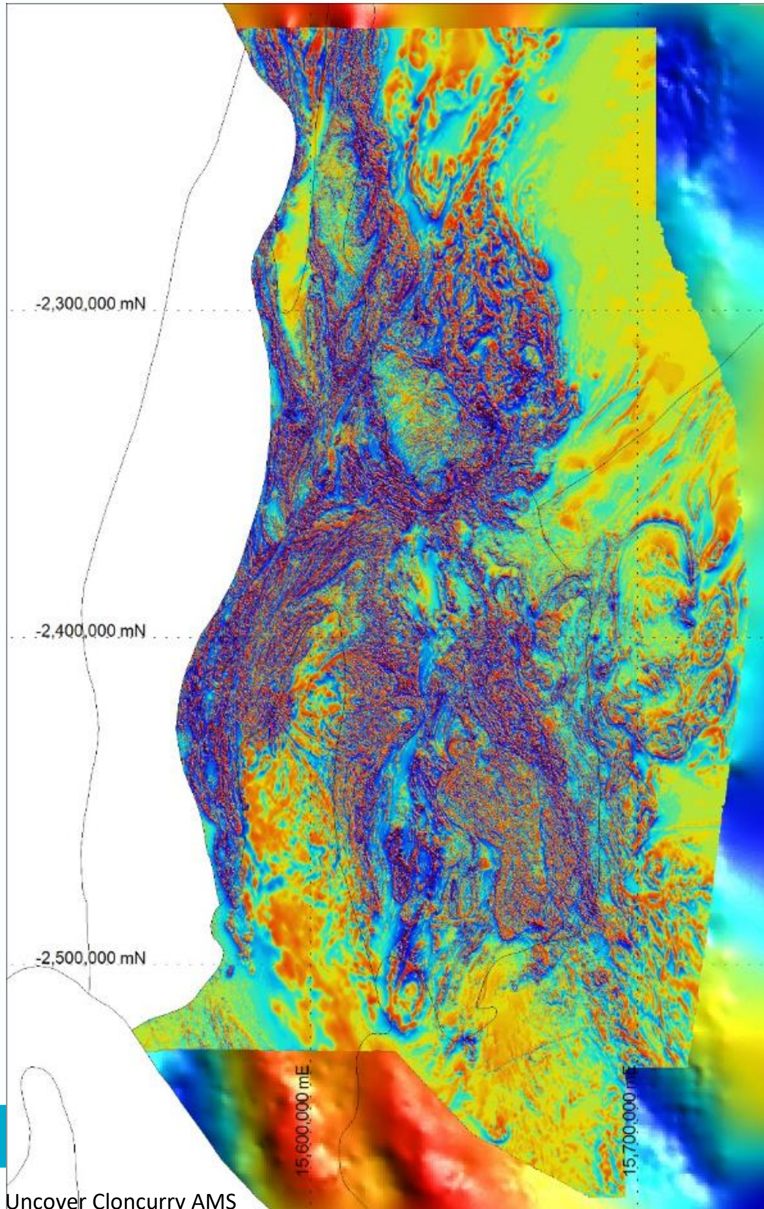
Integrating insights from geophysics, geochemistry and structural geology in 3D to understand mineral systems

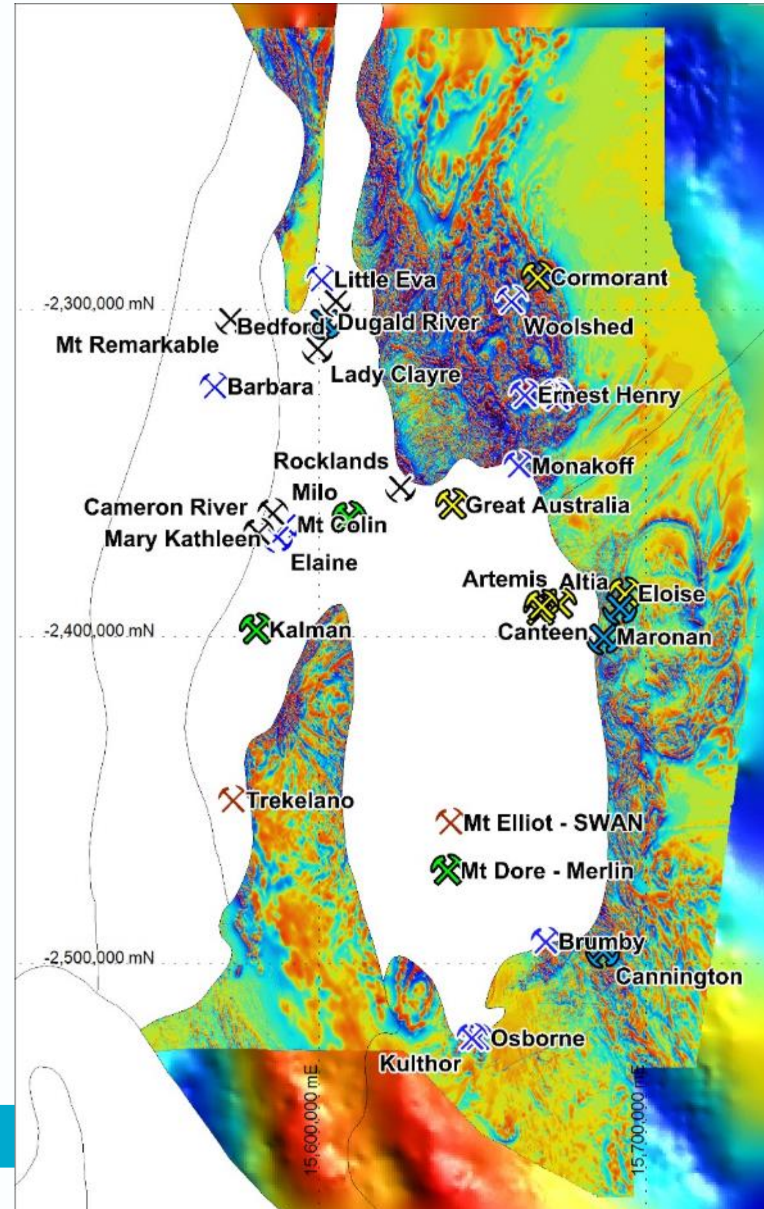
Examples from Eastern Succession , Mt Isa Inlier

Jim Austin + Ben Patterson, Michael Gazley, John Walshe Belinda Godel, Steph Hawkins, Matt Sisson

Queensland Government
Geological Survey of Queensland
Industry Priorities Initiative
MOUNT ISA MINES
A GLENCORE COMPANY
MINOTAUR EXPLORATION
CST MINING GROUP LIMITED
SANDFIRE RESOURCES NL
CSIRO

Exploration Undercover



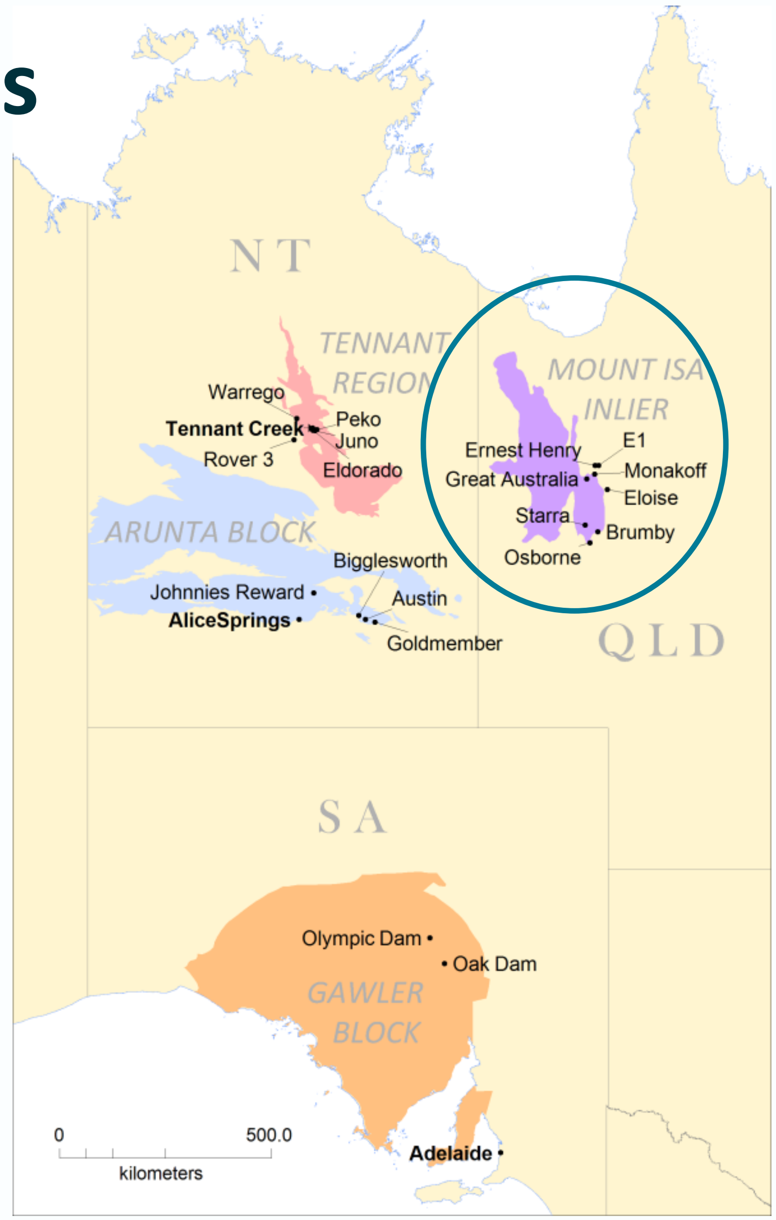


Batting Order

- Why are we (still) confounded about Cloncurry
- What new techniques are we using
- An example of the outputs from Ernest Henry
- What are the relationships between:
  - Structural Controls and Mineralisation?
  - Different generation Structures and different alteration styles?
  - Alteration, Redox and Magnetic signatures?
- How can we use these insights to explore under cover??

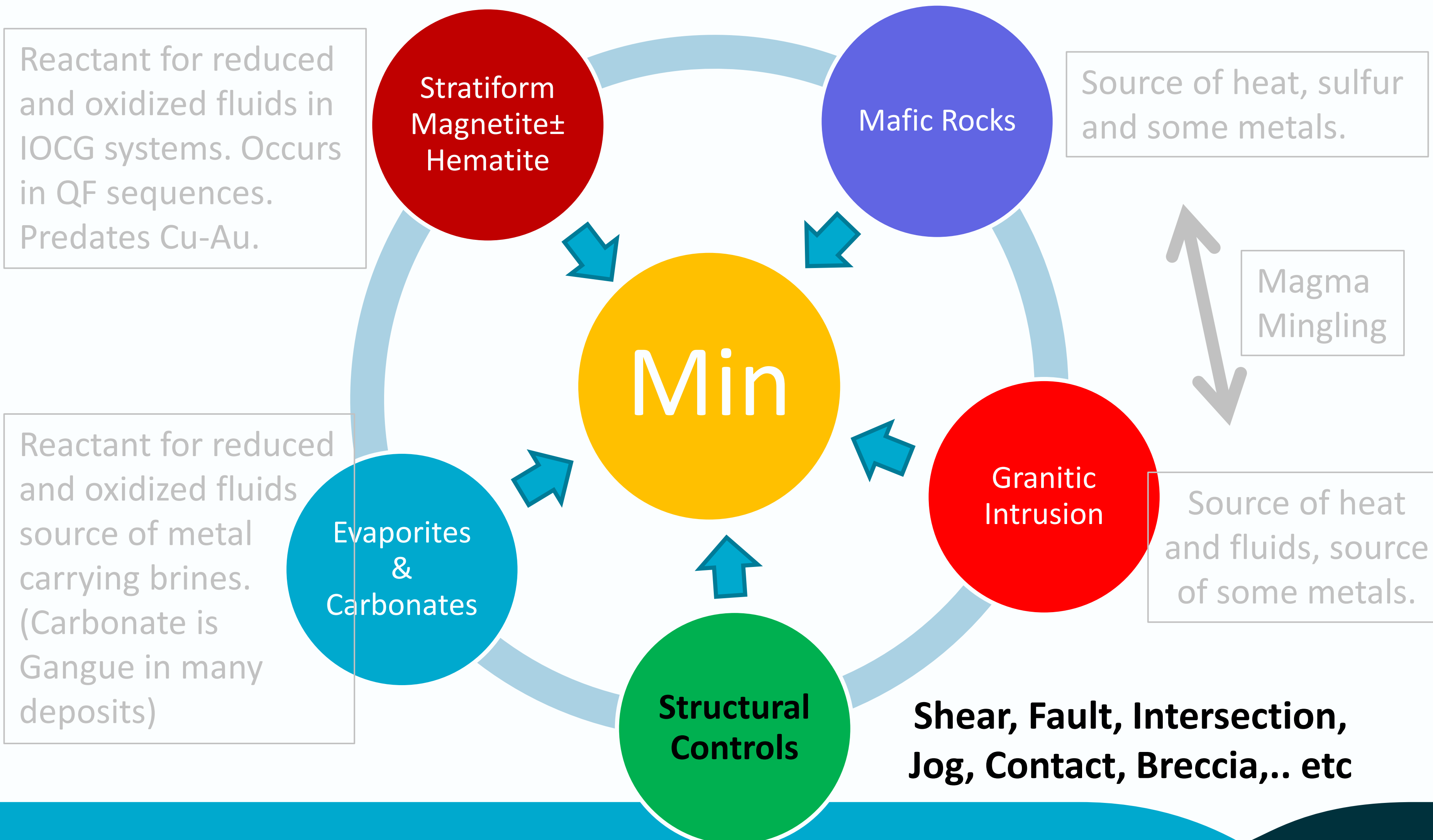
Cloncurry Mineral Systems

- Pb-Zn-Ag BHT deposit (Cannington)
- Mt-rich IOCG Breccia Pipes (e.g., Ernest Henry)
- Au-rich, Mt-poor, Po-rich Breccias (Eloise)
- Mt-rich Stratiform Iron with Cu-Au (Osborne, Starra)
- Mt+Po Stratiform Iron with Cu-Au (Monakoff)
- Po-rich linear horizons with Au and Cu (Cormorant)
- Mt-rich Stratiform Iron with Pb-Zn-Ag (Pegmont)
- Non-Magnetic Po-rich systems with Cu, Zn (Artemis)
- Carbonate-rich (non-magnetic) Cu (Great Australia)
- Skarn-like deposits (Near Mary K)
- REE-rich deposits (Merlin and Milo)



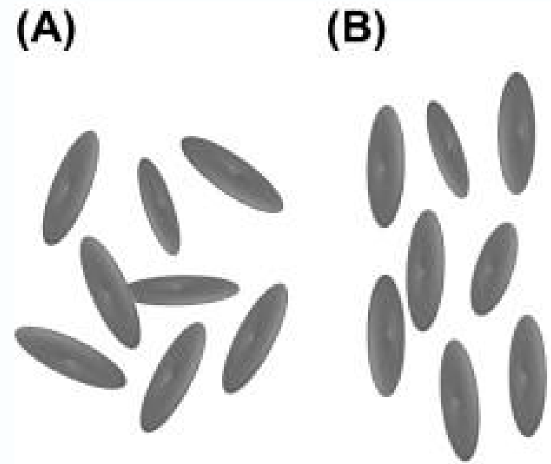
- Large variation in deposit style, but……
- Many different alteration styles
- All deposits have <u>**strong structural controls**</u>

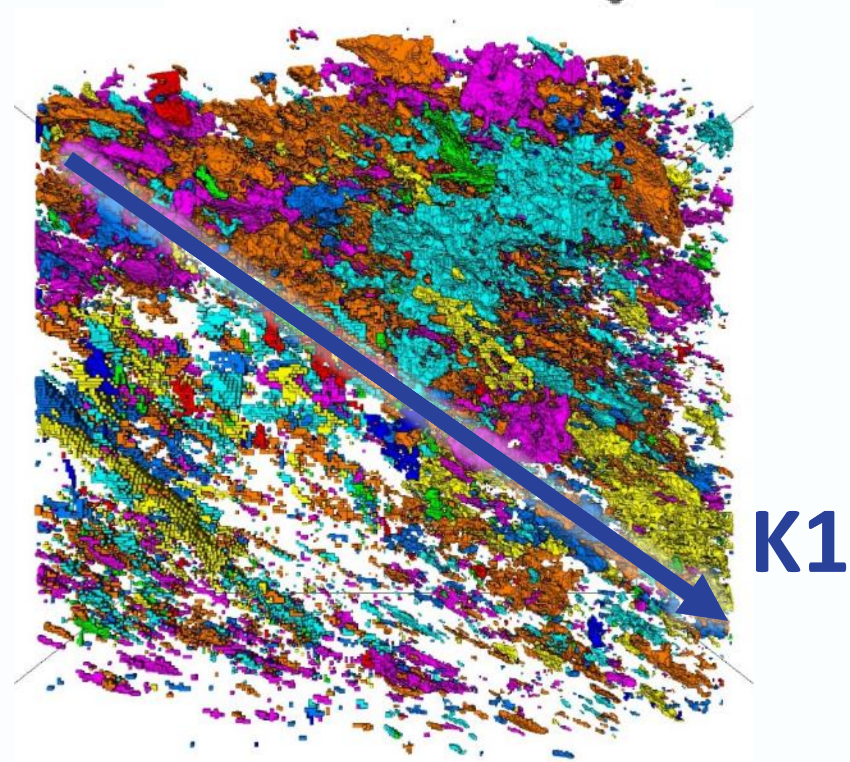
Mineral System Ingredients (Isan Orogeny)



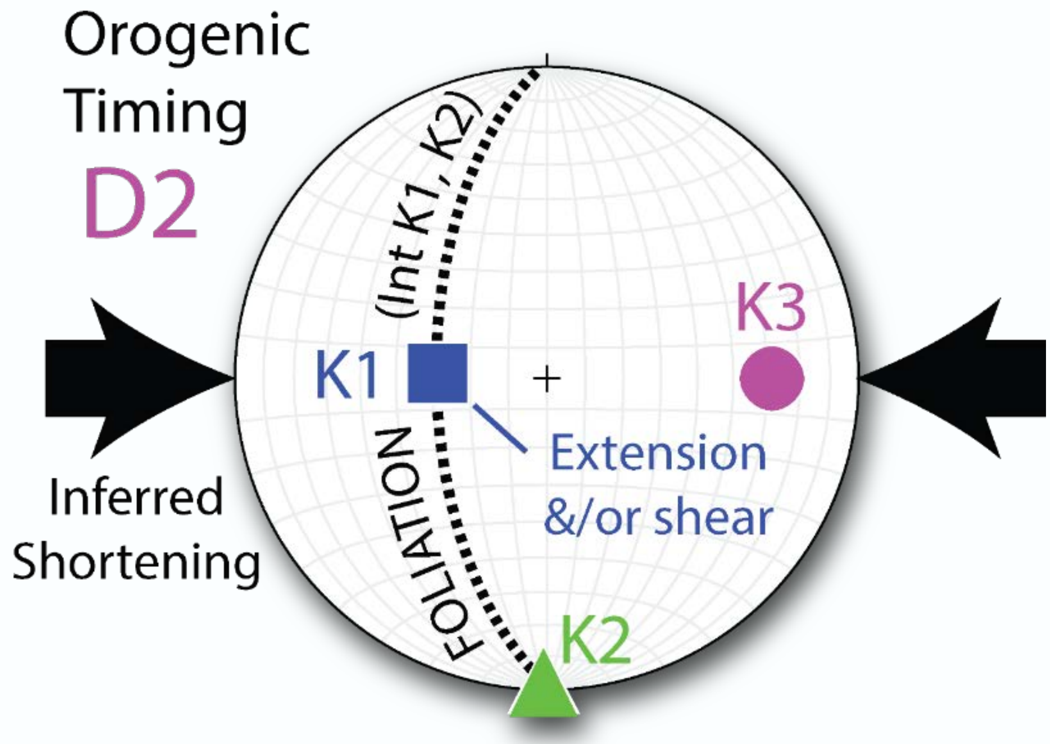
AMS (Anisotropy of Magnetic Susceptibility)

- Anisotropy of magnetic susceptibility (AMS)
  - physical property of rock ,
  - Caused by preferred orientation of anisotropic magnetic minerals.
  - It is essentially a magnetic fabric
  - Can be used to define strain distribution prior to mineralisation





Key to AMS data



K1= Lineation (Long Axis) K2=Intermediate

K3= Short Axis (typically azimuth of shortening)

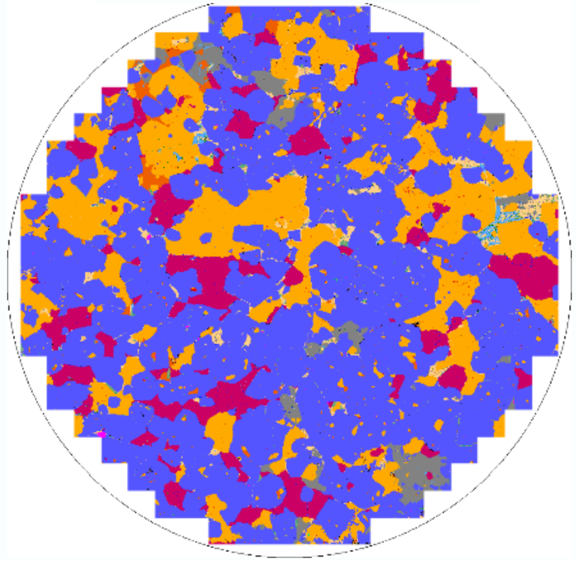
Great circle joining K1 and K2 defines the foliation

TIMA

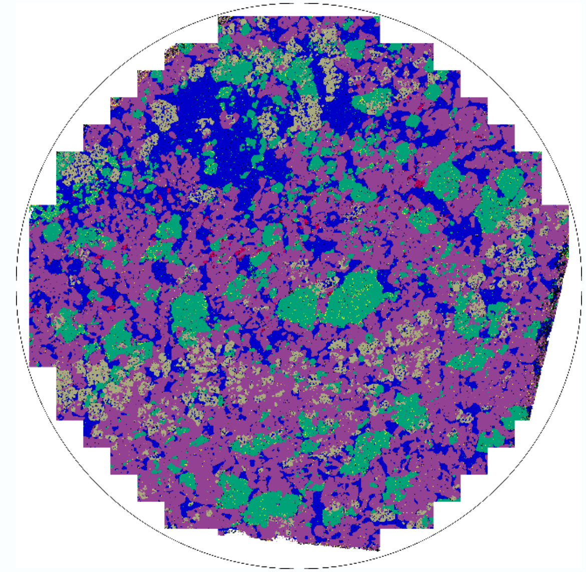
(Tescan Integrated Mineral Analyser)

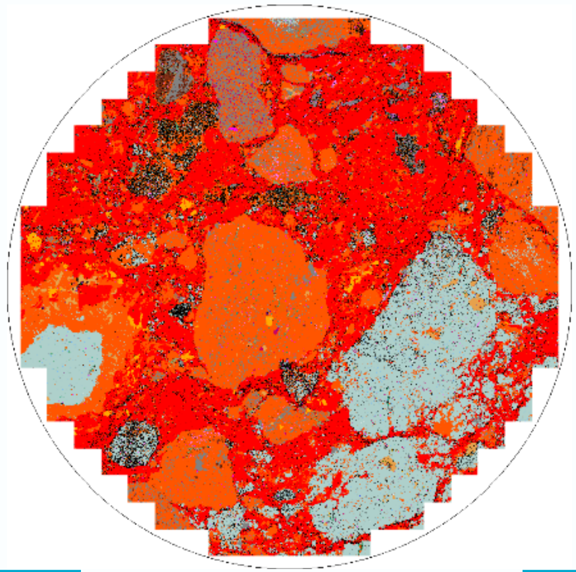
- 10 µm resolution
- spectra-matched to international & in-house standards,
- Allows us to:
  - Observe textures
  - Quantify (consistently) mineralogy
  - Infer different styles of alteration.
  - & Different styles of mineralisation

Magnetite-Pyrite-Apatite –Osborne

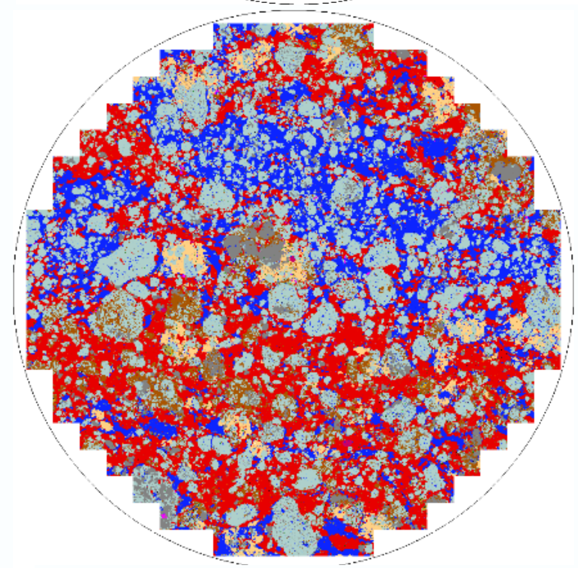


Leucophoenicite, Mn-calcite-Bixbyite -Garnet-Rhodochrosite – *Maronan*



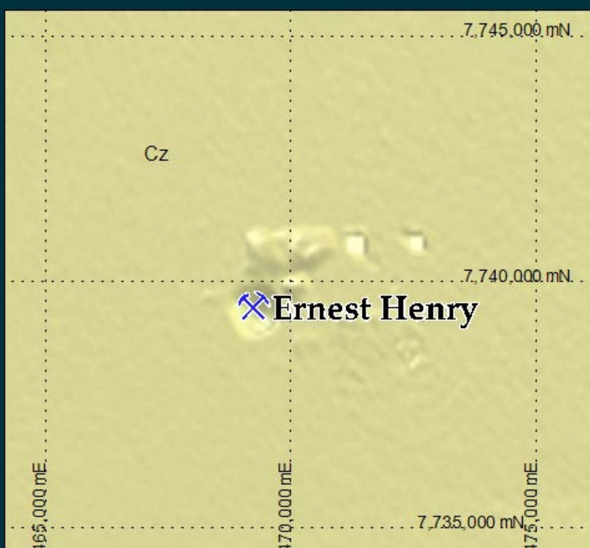


Molybdenite Matrix Breccia – Merlin

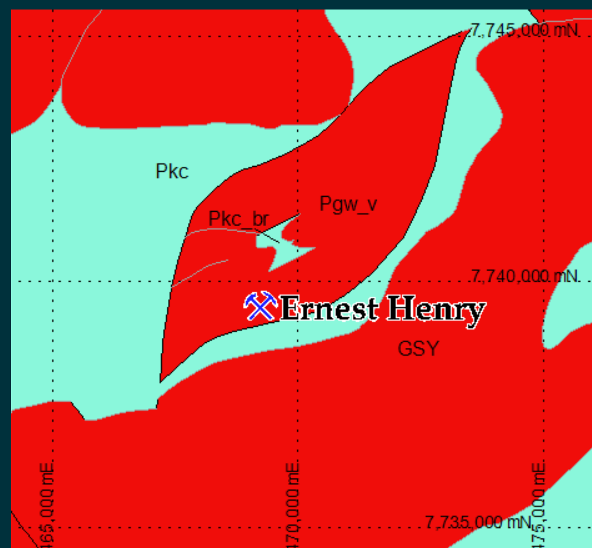


Calcite-Pyrrhotite Matrix Breccia –Canteen

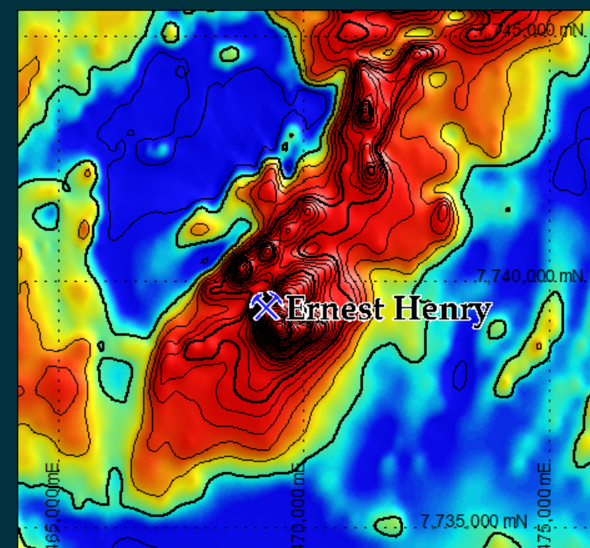
Ernest Henry Cu-Au
(Hematite-Magnetite)



Actual Geology



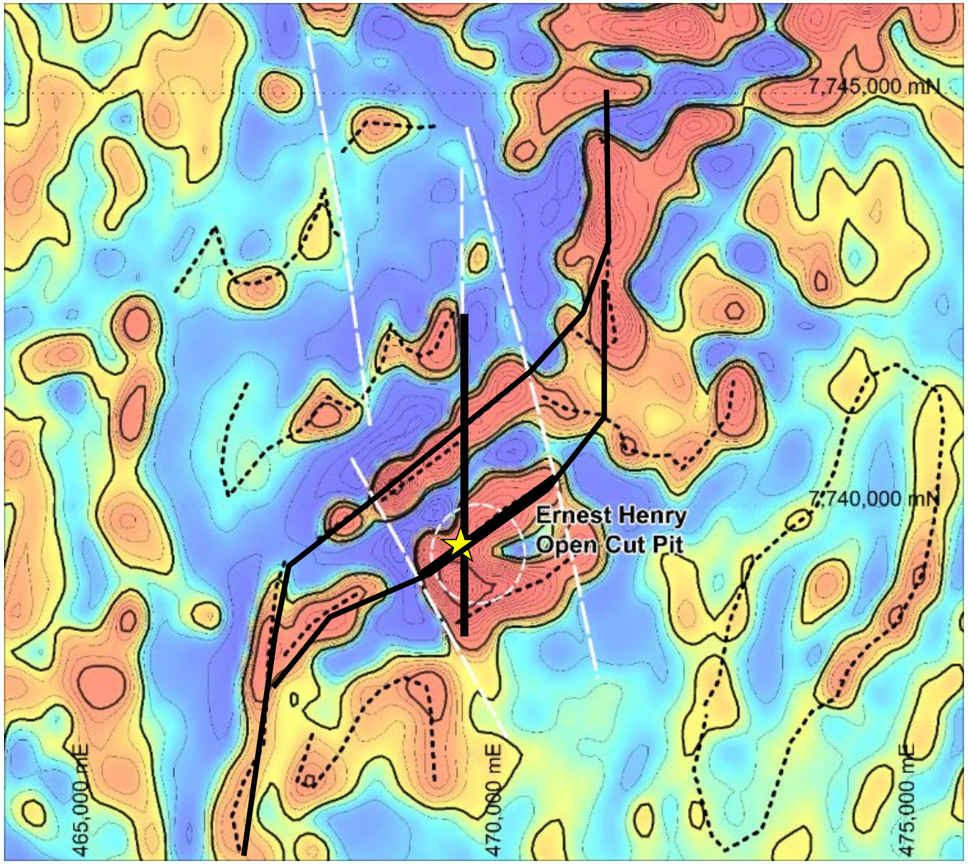
Interpreted Geology



Magnetics

Reassessment of Geophysical evidence

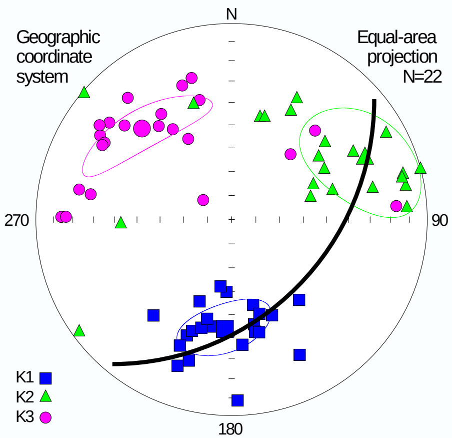
- Yes there are NE- fabrics
- But N-S and NNW fabrics control magnetite.
- The N-S structure passes straight through ore-body
- Mineralisation sits on intersection lineation



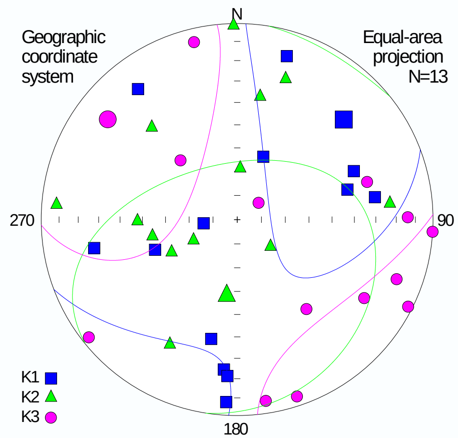
Magnetics 1st Vertical derivative of RTP

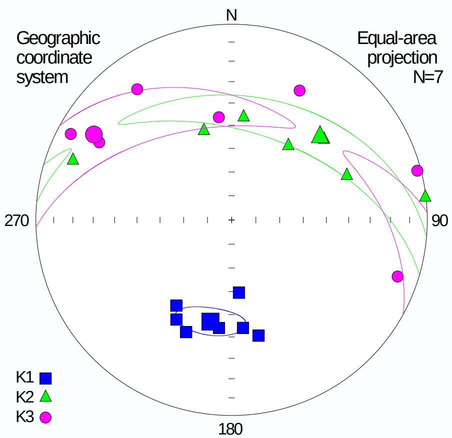
Matching AMS and Structural Controls

Hanging Wall AMS

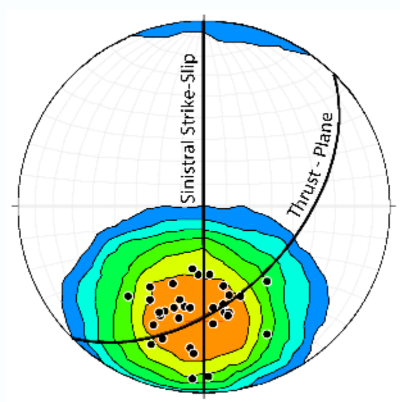


Breccia AMS

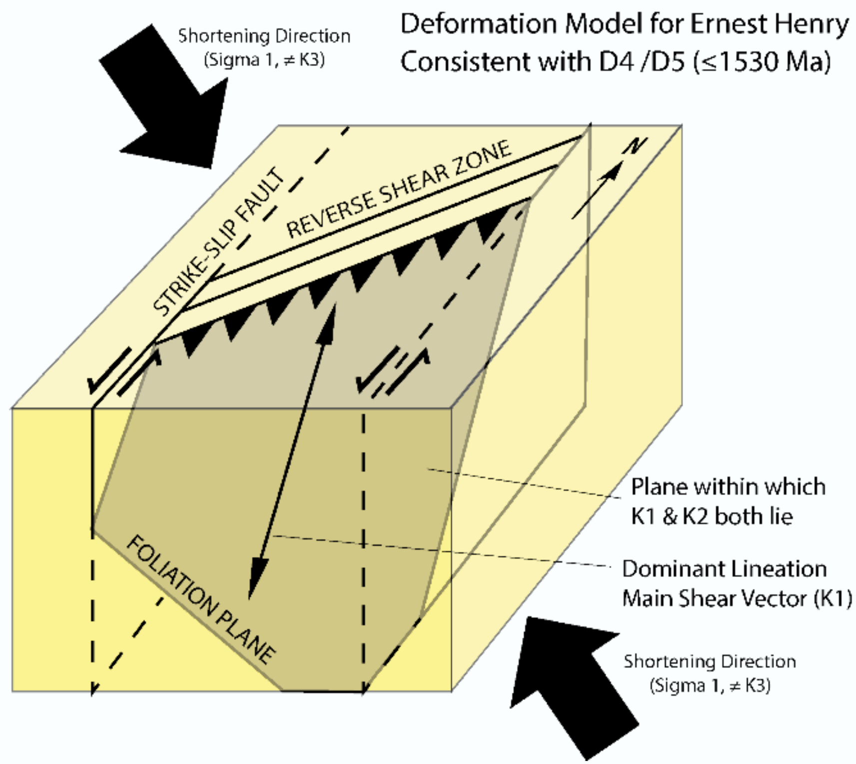




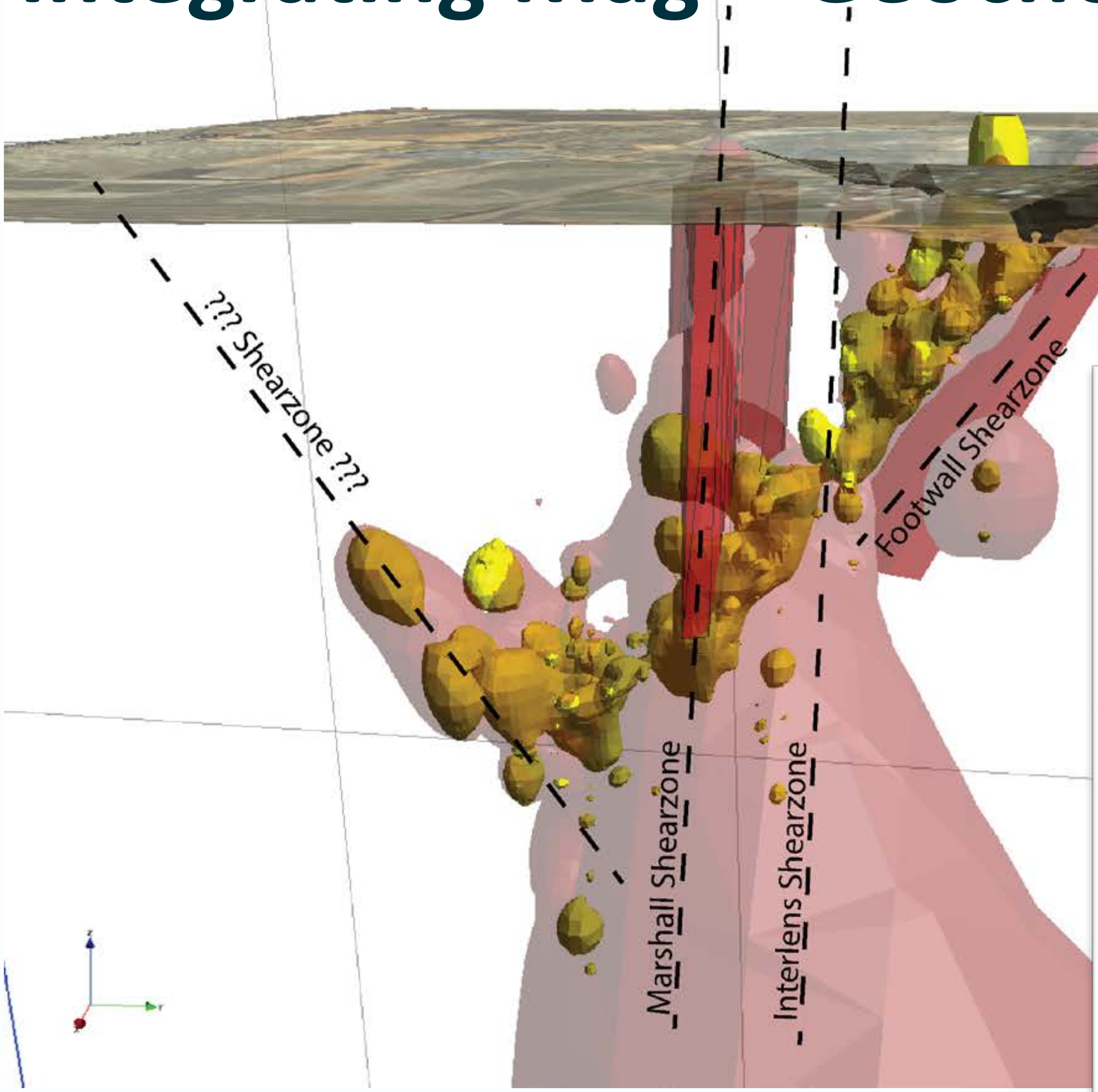
Foot Wall AMS

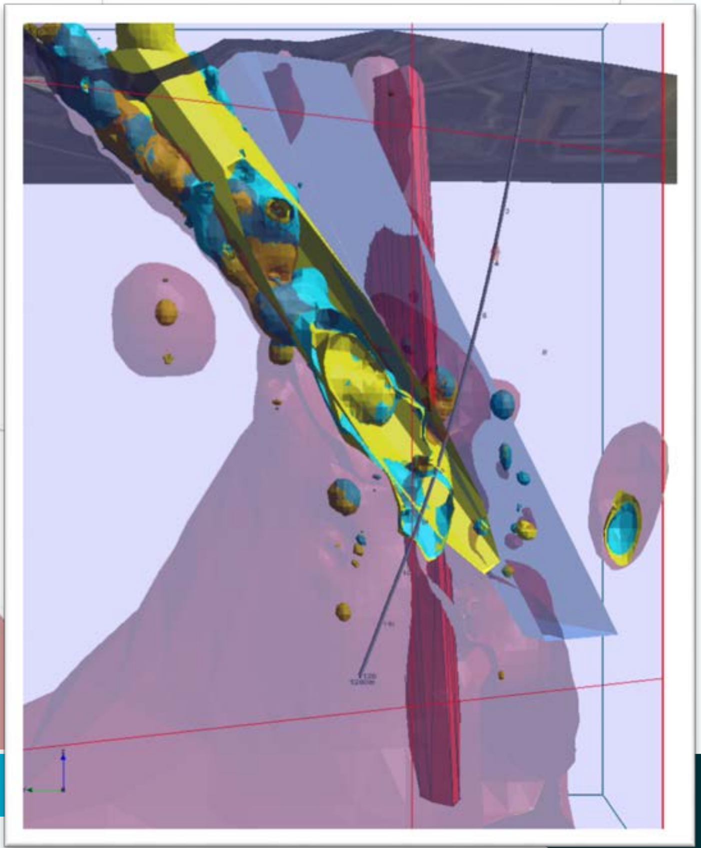


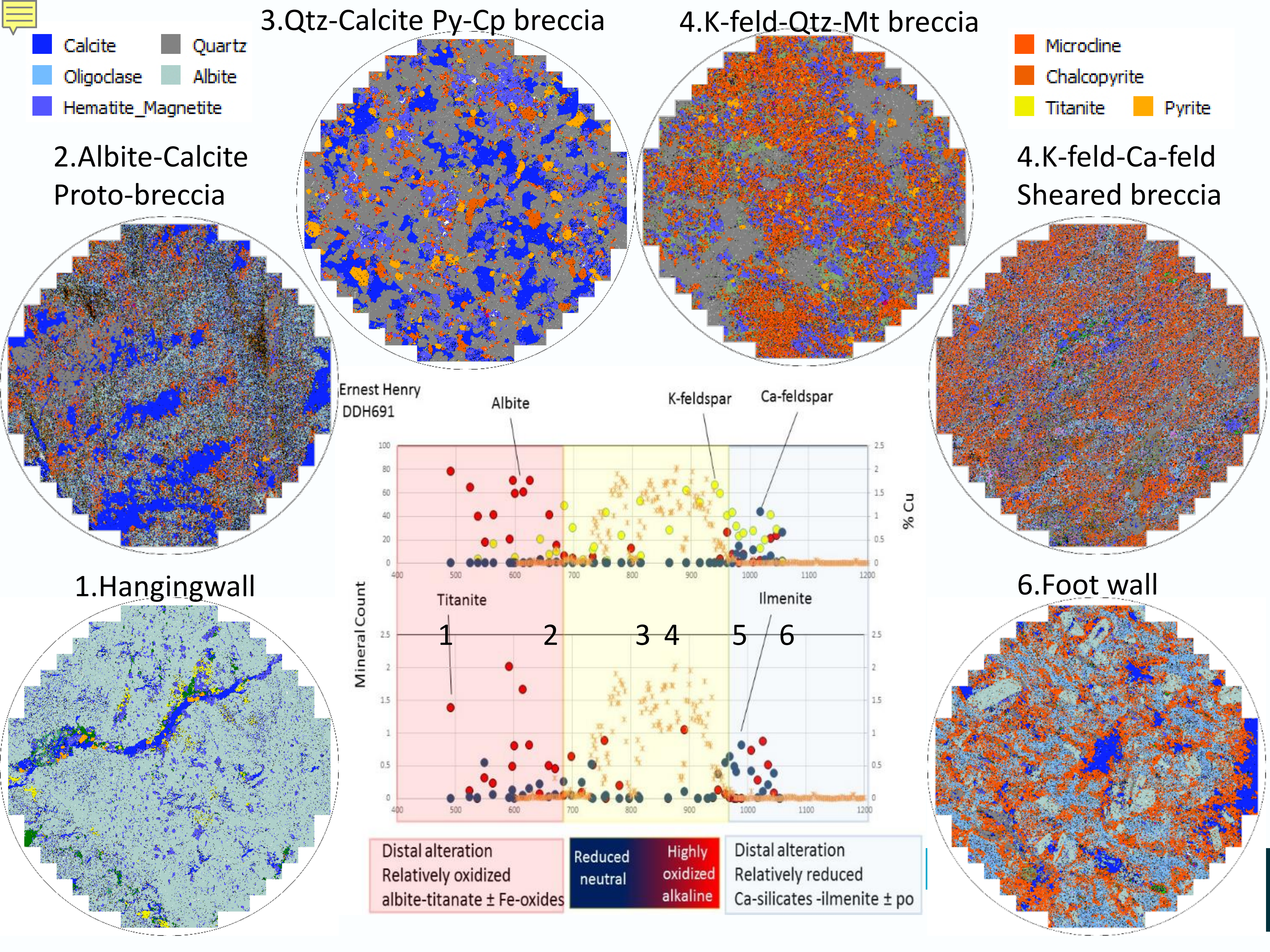
K1 With Structure



Integrating Mag + Geochem modelling







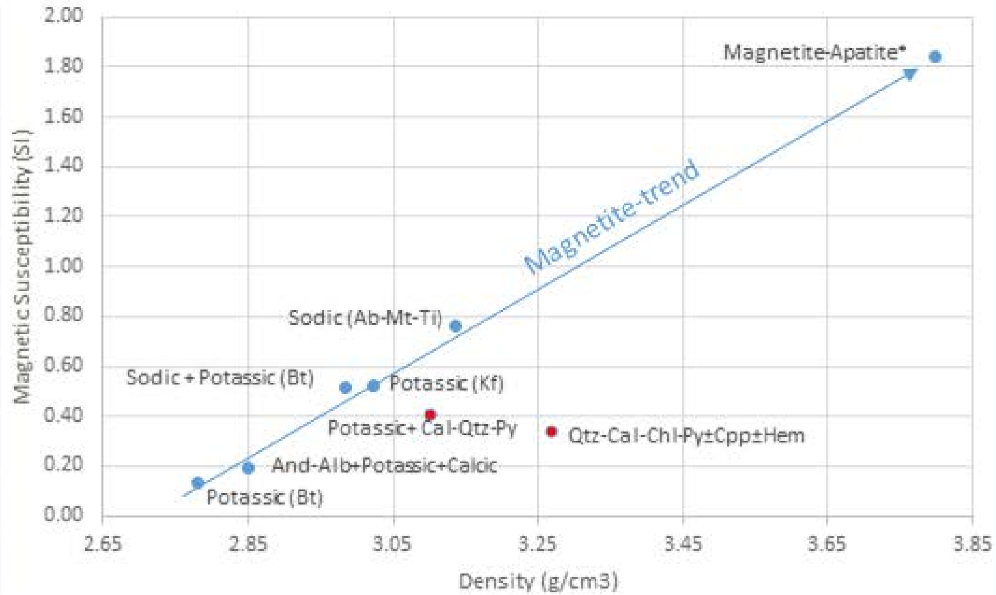
Calcite
Quartz
Oligoclase
Albite
Hematite_Magnetite
3.Qtz-Calcite Py-Cp breccia
4.K-feld-Qtz-Mt breccia
Microcline
Chalcopyrite
Titanite
Pyrite
2.Albite-Calcite Proto-breccia
4.K-feld-Ca-feld Sheared breccia
Ernest Henry DDH691
Albite
K-feldspar
Ca-feldspar
% Cu
Mineral Count
1.Hangingwall
6.Foot wall
Titanite
Ilmenite
1
2
3
4
5
6
Distal alteration
Relatively oxidized
albite-titanate ± Fe-oxides
Reduced
neutral
Highly
oxidized
alkaline
Distal alteration
Relatively reduced
Ca-silicates -ilmenite ± po

Alteration Type as a function of petrophysics and mineralisation

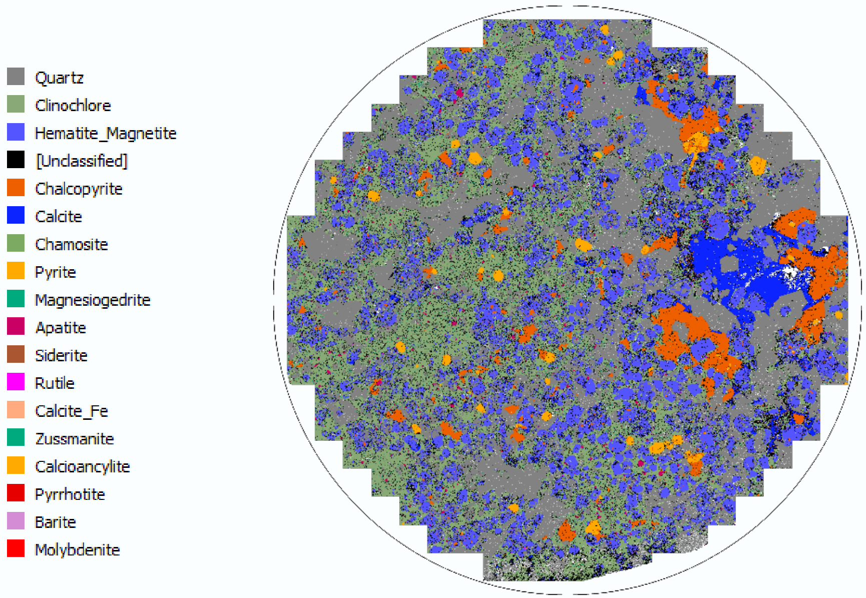
For Ernest Henry

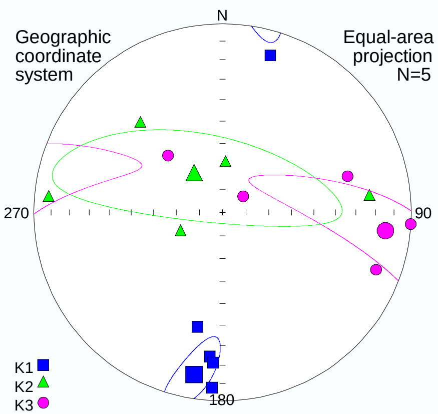
Alteration type	Chalcopyrite	Chamosite	Pyrite	Albite	Microcline	Quartz
And-Alb+Potassic+Calcic	0.00	0.82	0.27	7.41	23.54	10.56
Magnetite-Apatite*	3.80	1.84	1.09	1.09	1.09	1.09
Potassic (Bt)	0.00	0.29	0.07	58.79	2.80	8.48
Potassic (Kf)	0.25	2.27	3.38	2.52	45.91	8.22
Potassic+ Cal-Qtz-Py	2.00	1.19	4.03	0.96	31.62	15.88
Qtz-Cal-Chl-Py±Cpp±Hem	2.88	10.26	13.96	0.16	2.70	33.56
Sodic (Ab-Mt-Ti)	0.00	0.31	0.31	54.96	3.73	2.38
Sodic + Potassic (Bt)	0.05	1.12	0.27	20.11	20.00	10.03

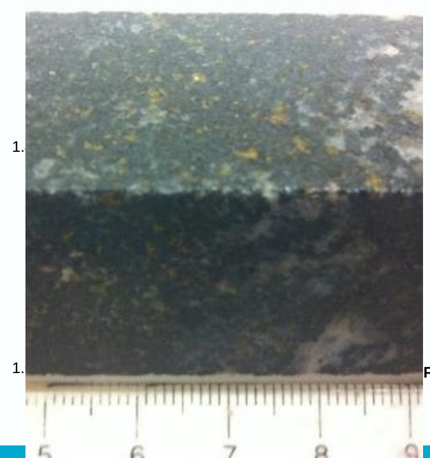
Alteration	Density (g/cm^3)	Mag Sus K (SI)	Koenigsberger Ratio (Q)
And-Alb+Potassic+Calcic	2.85	0.19	0.52
Magnetite-Apatite*	3.80	1.84	1.09
Potassic (Bt)	2.78	0.13	0.36
Potassic (Kf)	3.02	0.52	0.83
Potassic+Cal-Qtz-Py	3.10	0.41	0.70
Qtz-Cal-Chl-Py±Cpp±Hem	3.27	0.34	0.47
Sodic (Ab-Mt-Ti)	3.14	0.76	0.62
Sodic+Potassic (Bt)	2.98	0.52	3.31

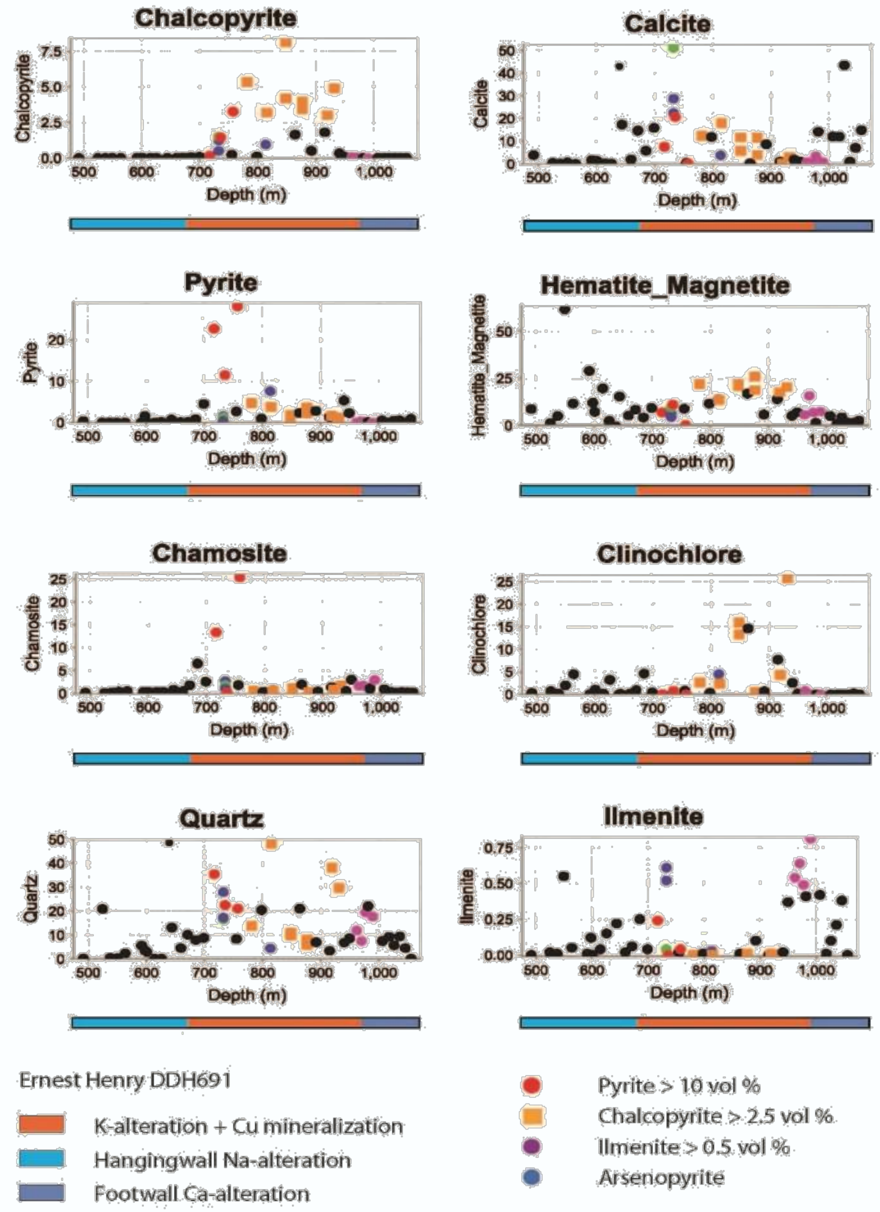


Mineralisation



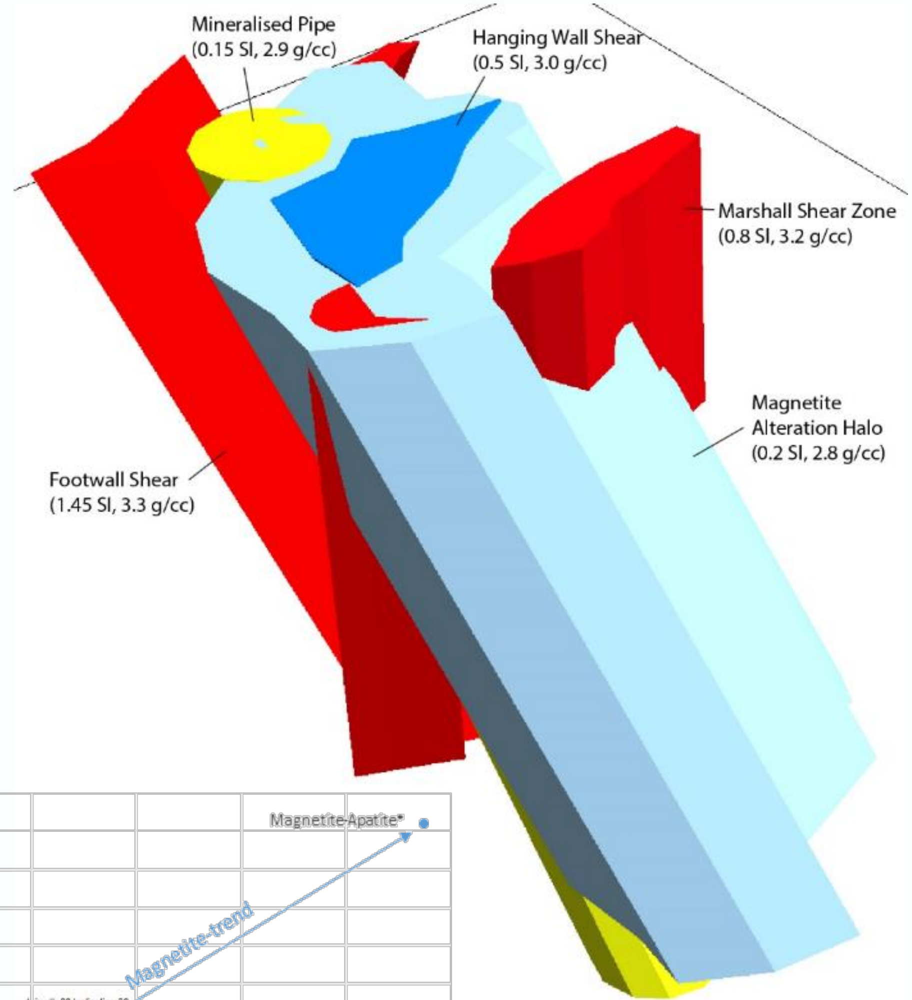






Magnetic Modelling

- Shearzones are highly magnetic
    - Sodic alt+Magnetite (reduced)
- Breccia is moderately magnetic
    - Mt-Destructive
- Orezone is weakly magnetic
    - Hematite-Pyrite (Oxidised)
- Inverse Bullseye mag target



Alteration	Density (g/cm^3)	Mag Sus K (SI)	Koenigsberger Ratio (Q)
And-Alb+Potassic+Calcic	2.85	0.19	0.52
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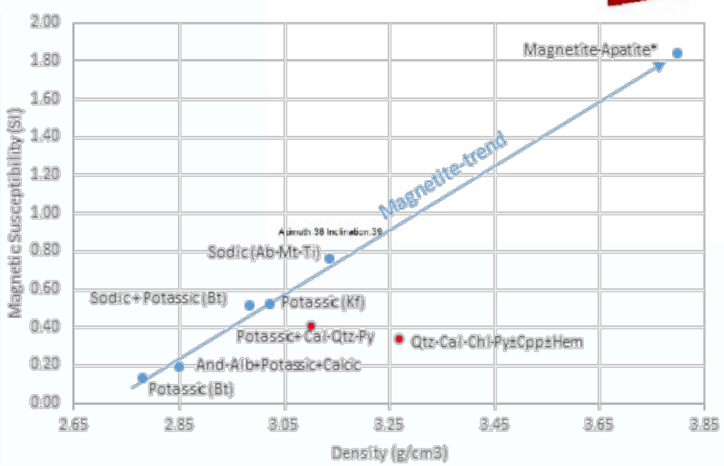
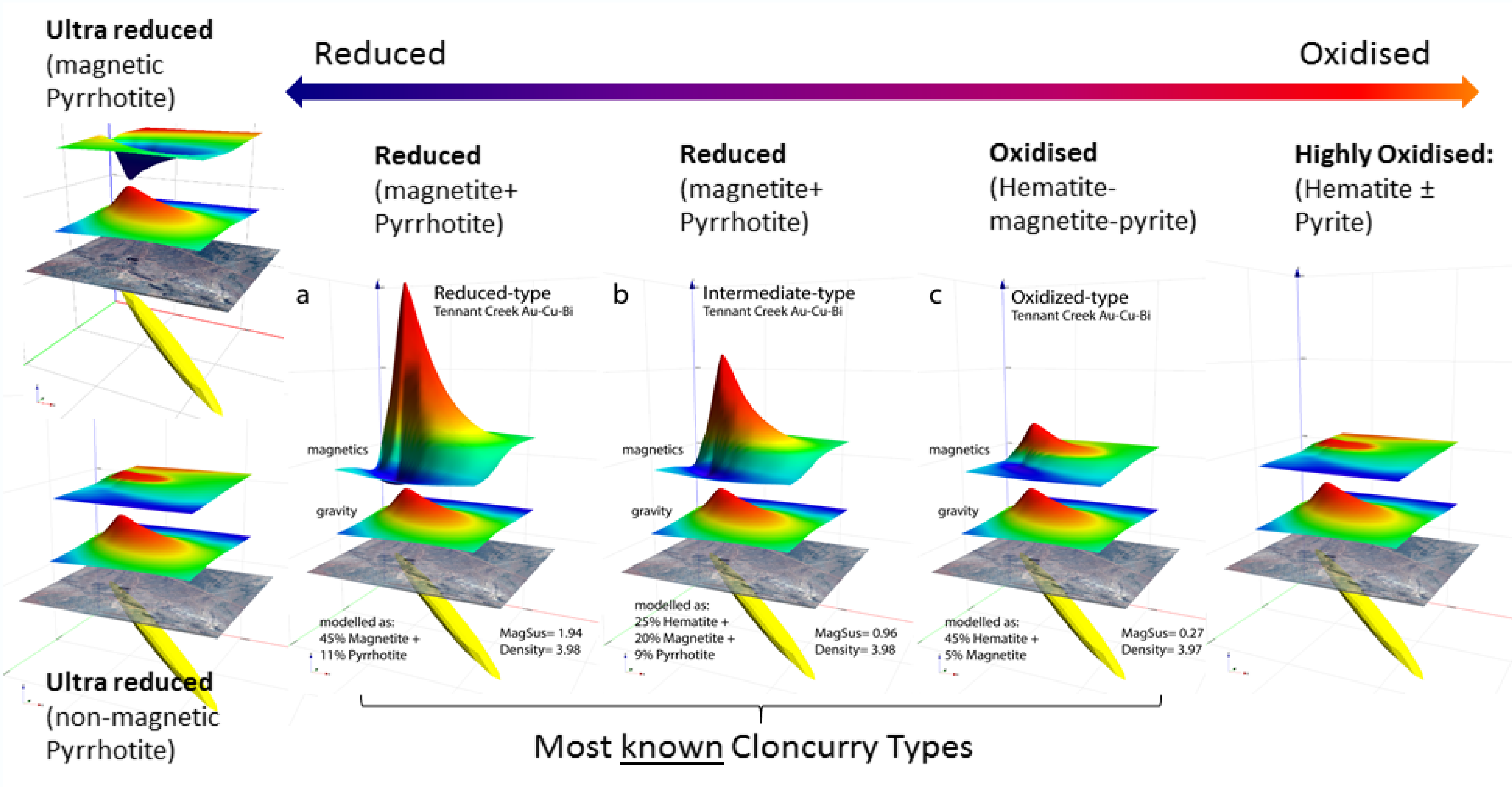
Potassic (Bt)	2.78	0.13	0.36
Potassic (Kf)	3.02	0.52	0.83
Potassic+Cal-Qtz-Py	3.10	0.41	0.70
Qtz-Cal-Chl-Py±Cpp±Hem	3.27	0.34	0.47
Sodic (Ab-Mt-Ti)	3.14	0.76	0.62
Sodic + Potassic (Bt)	2.98	0.52	3.31



Geophysical expression of mineralisation:

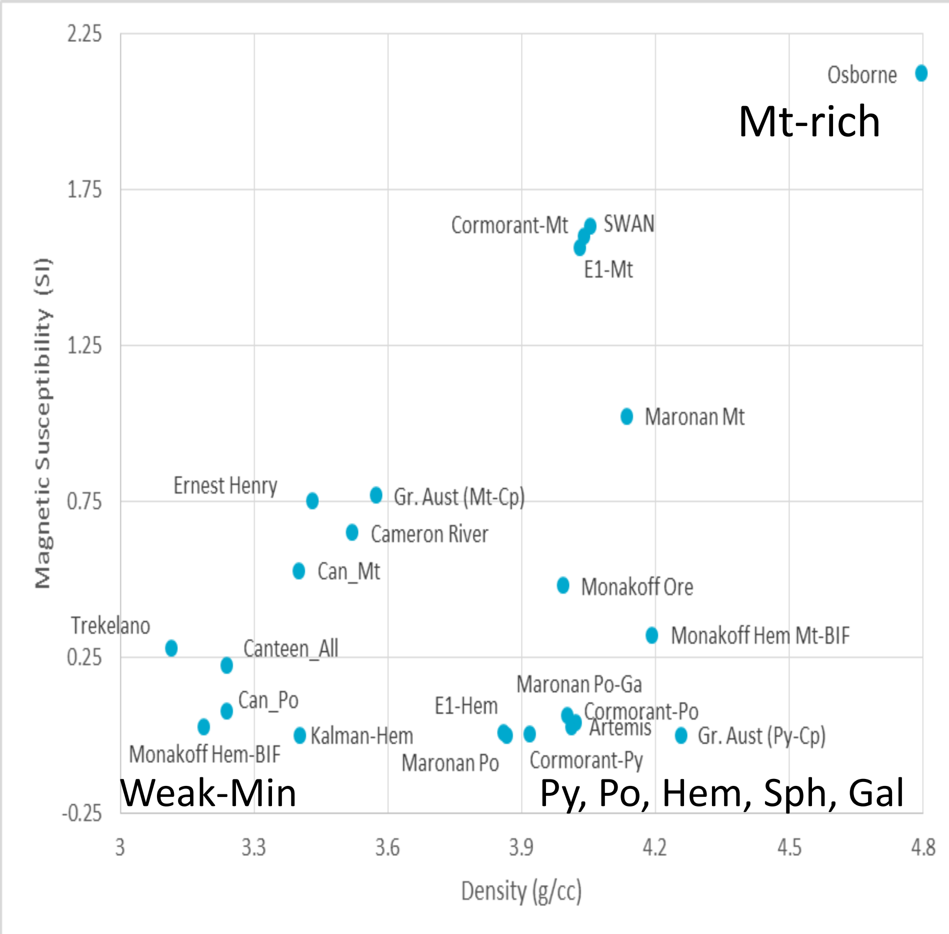
Redox or Overprinting Metasomatic events??

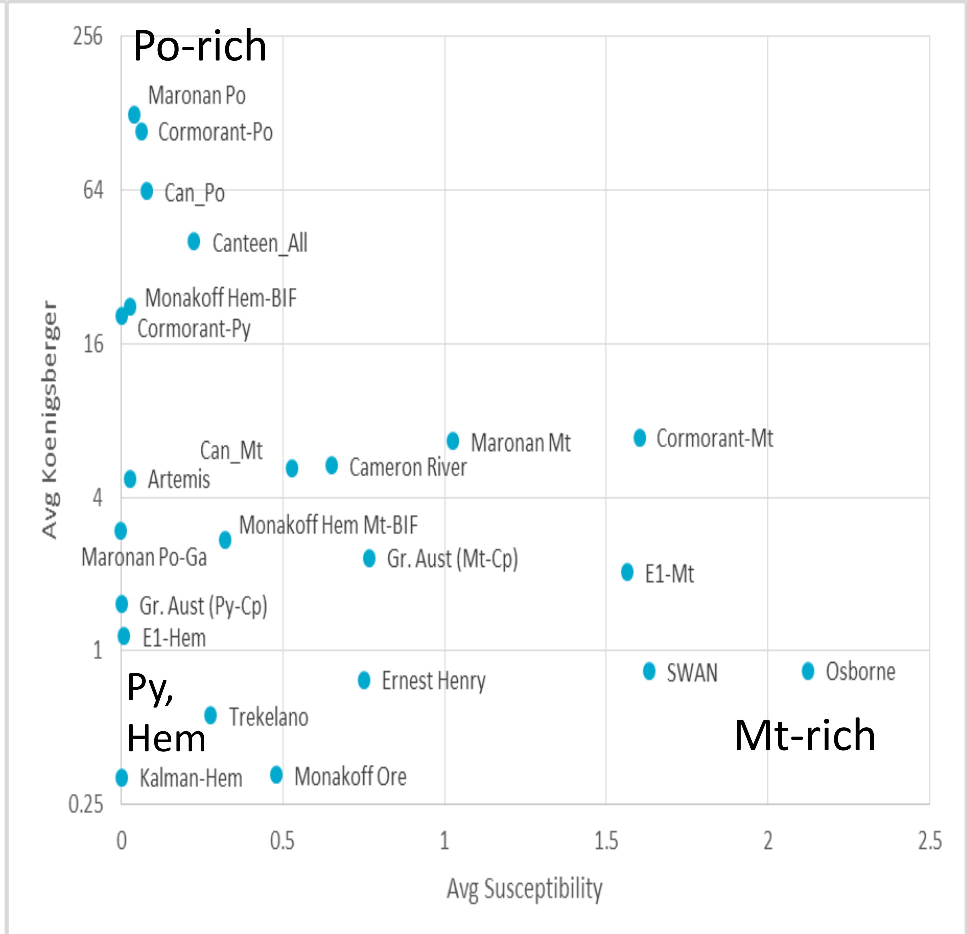
A simple view of Deposit geophysics (IOCG)



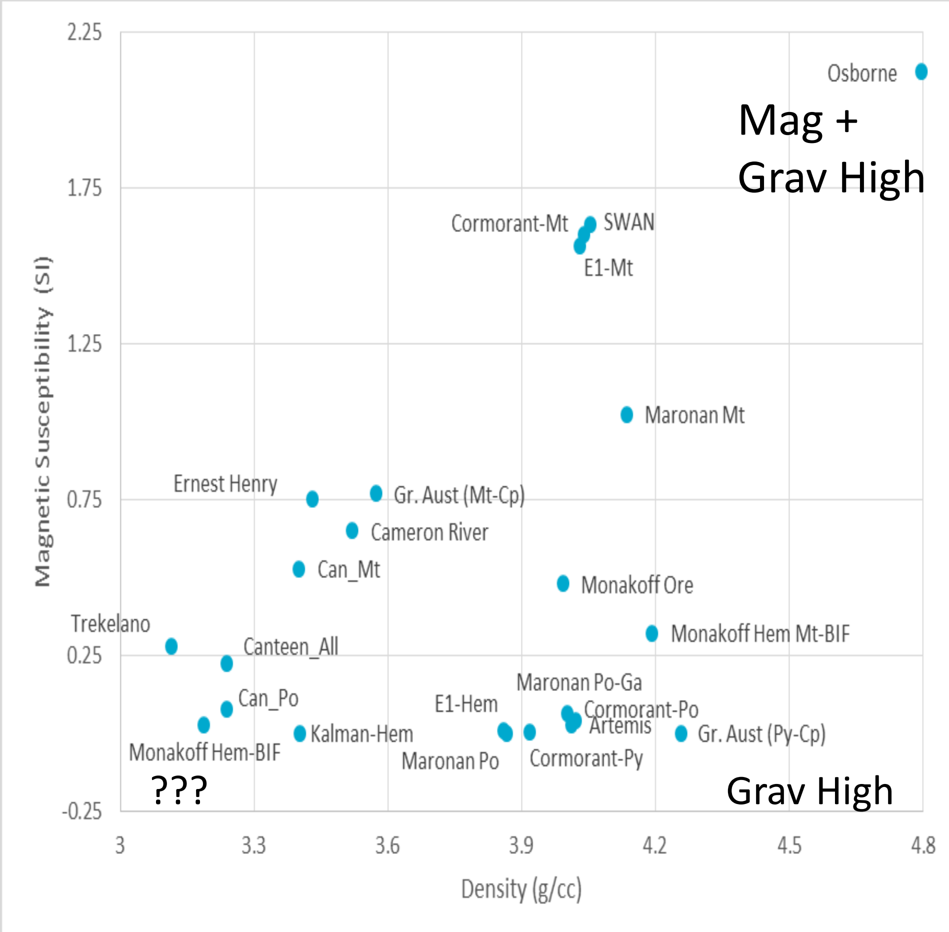
Big Question: Are mineral gradients controlled by redox or overprinting relationships or both????

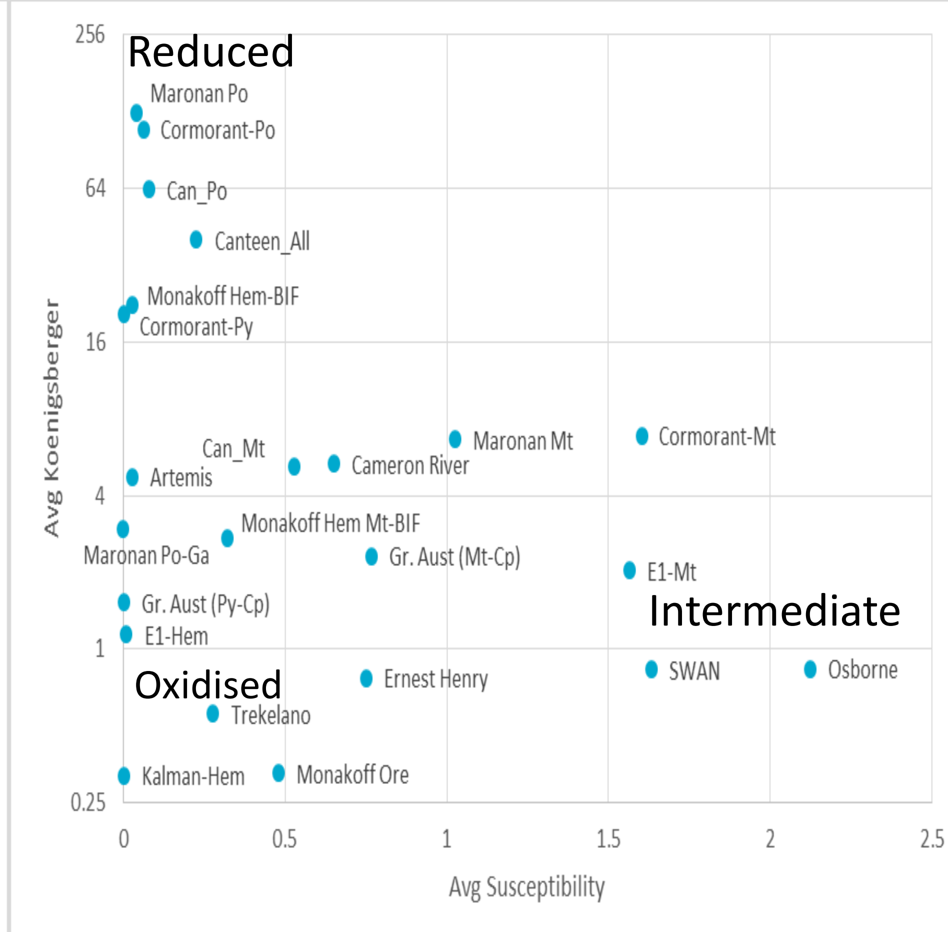
Petrophysics Overview

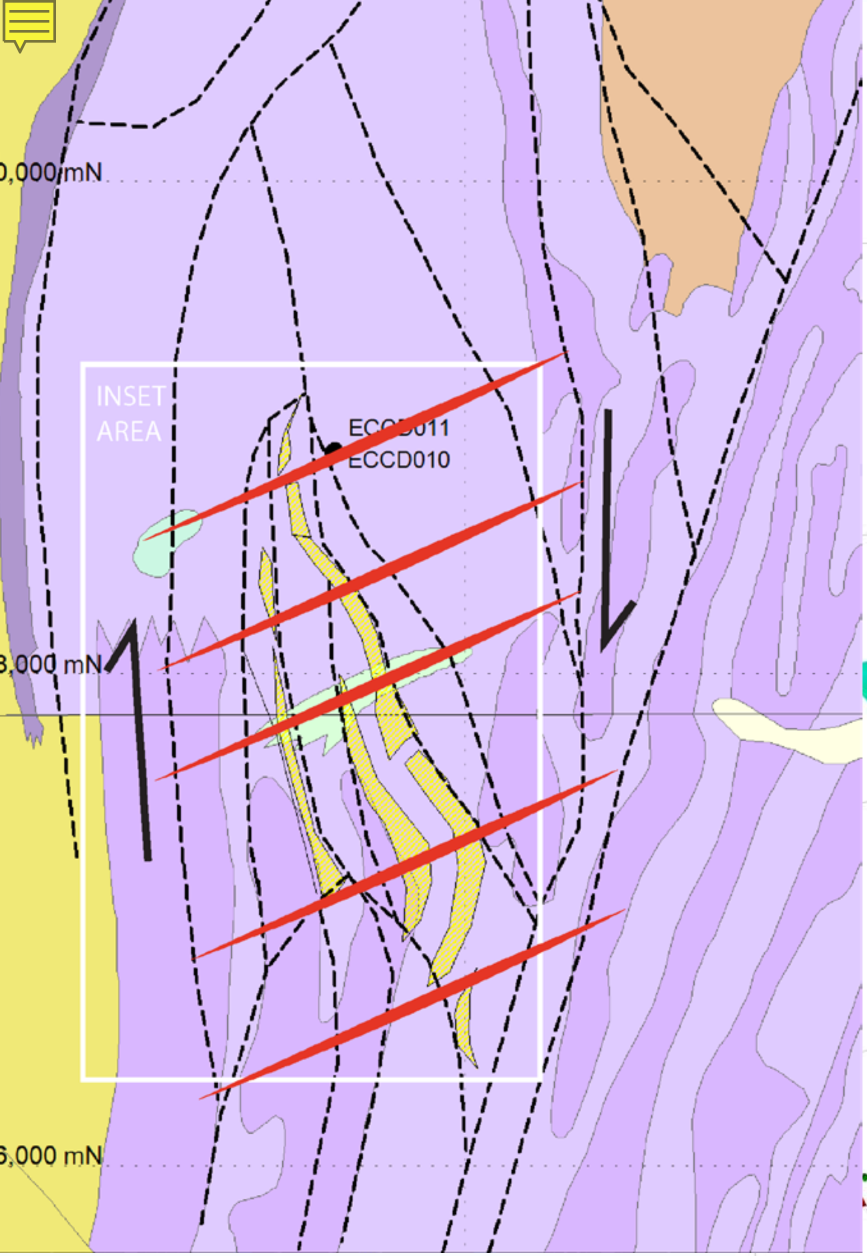


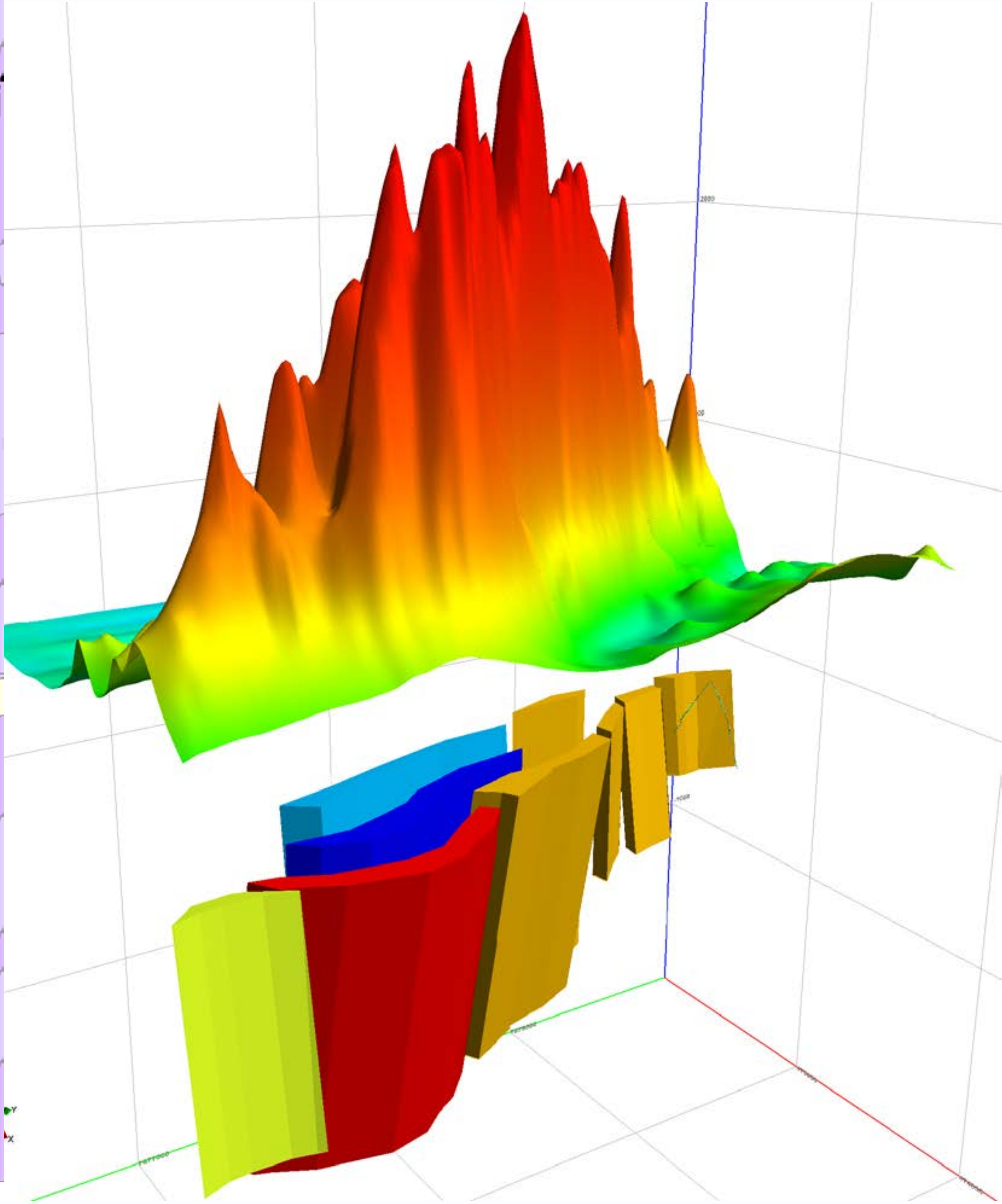


Petrophysics Overview

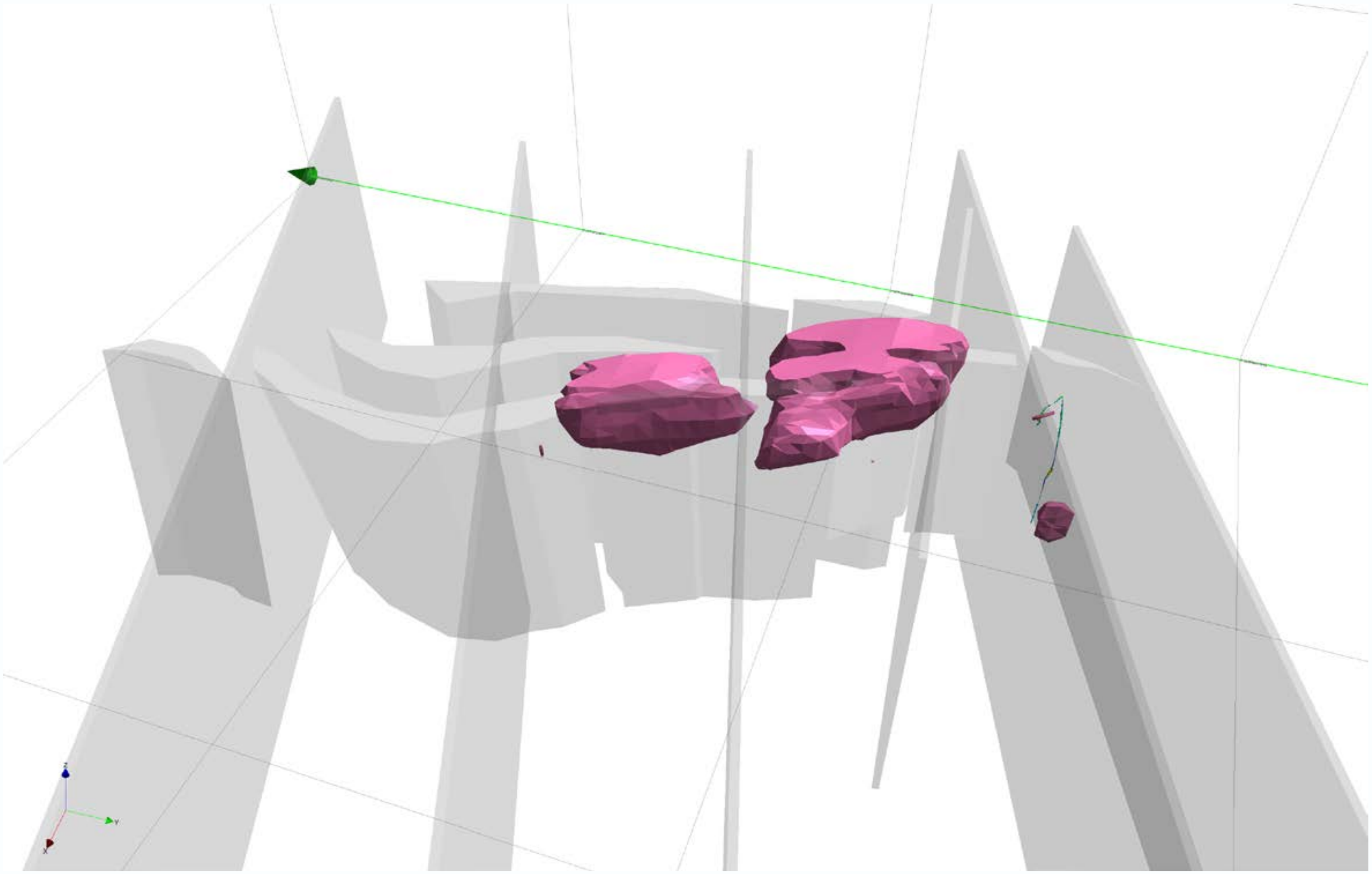




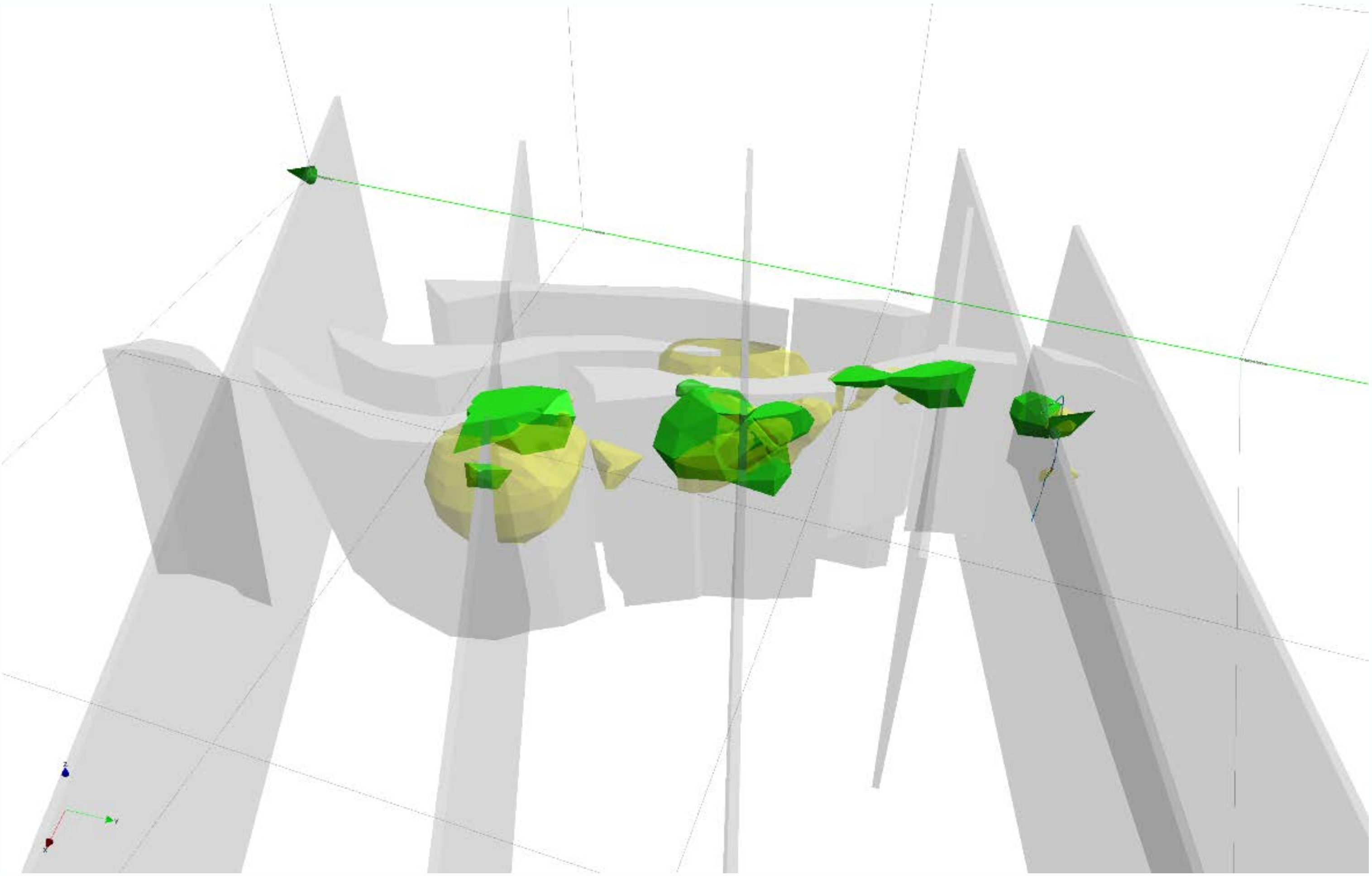

0,000 mN
INSET
AREA
ECCD011
ECCD010
3,000 mN
6,000 mN



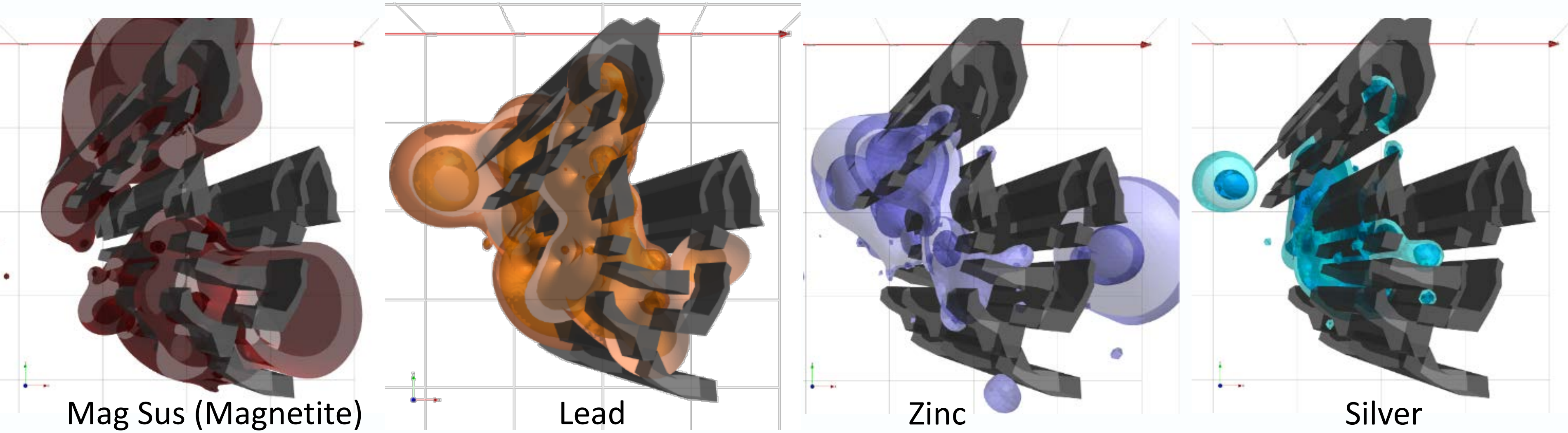
Magnetic Susceptibility

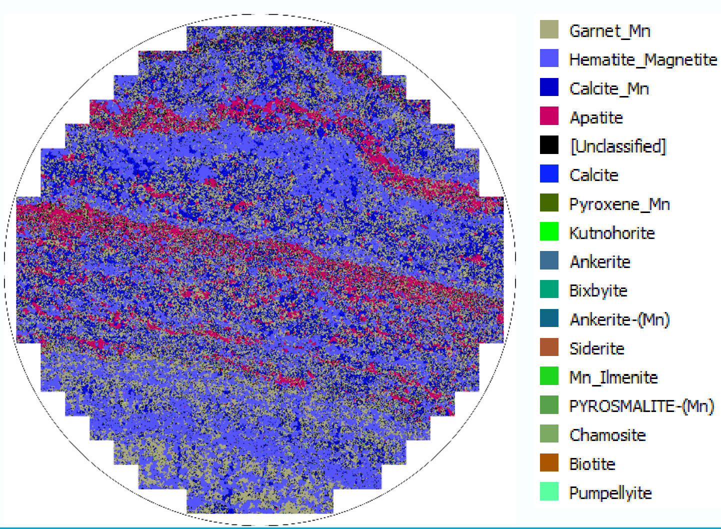


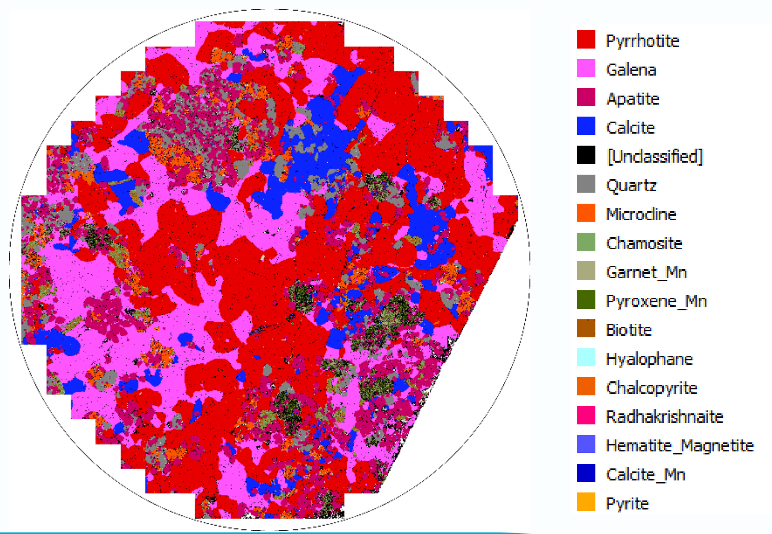
Sulfur and Copper



Mag vs Min - Maronan



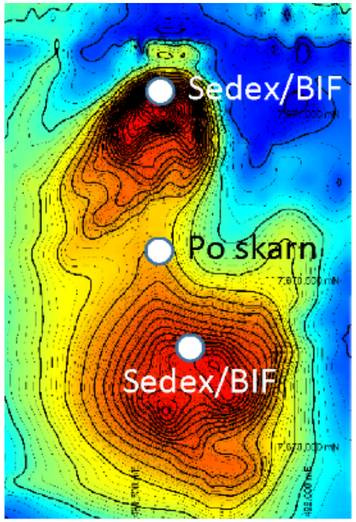




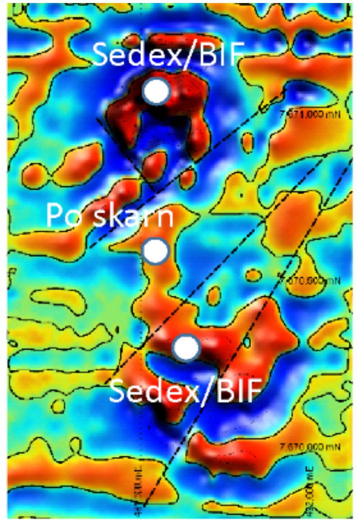
Distal Magnetite-Apatite
(Intermediate)

Core: Pyrrhotite-Galena
(Reduced)

ca 1650 Ma (CS_3) Sedex/ BHT mineralisation

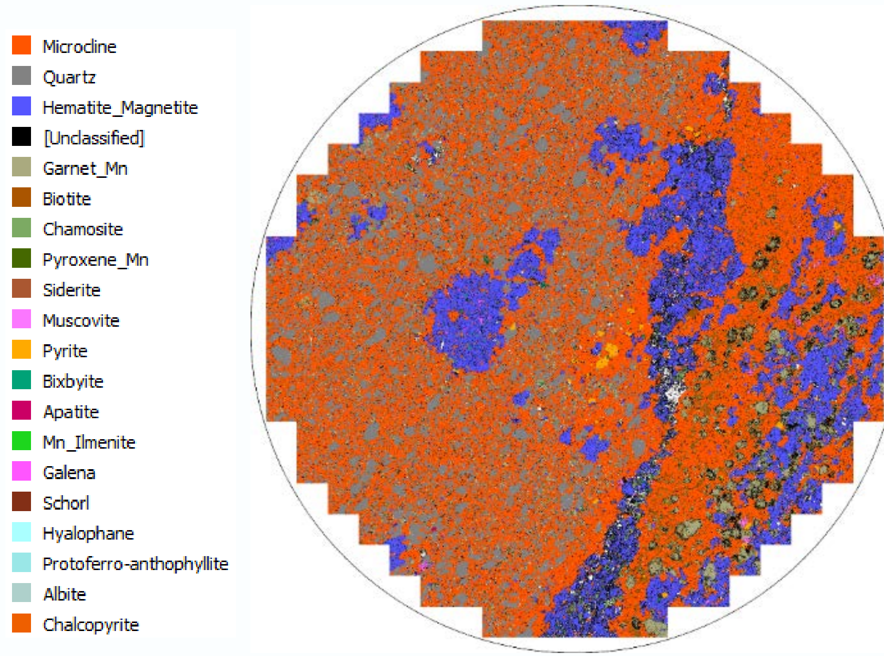


Maronan TMI



Maronan 1VD

Maronan	Density (g/cm^3)	Mag Sus K (SI)	Koenigsberger Ratio (Q)
host rock	2.91	0.01	11.37
Po skarn	3.27	0.01	62.17
Potassic Alt	2.91	0.37	0.99
sedex	3.71	0.62	5.32

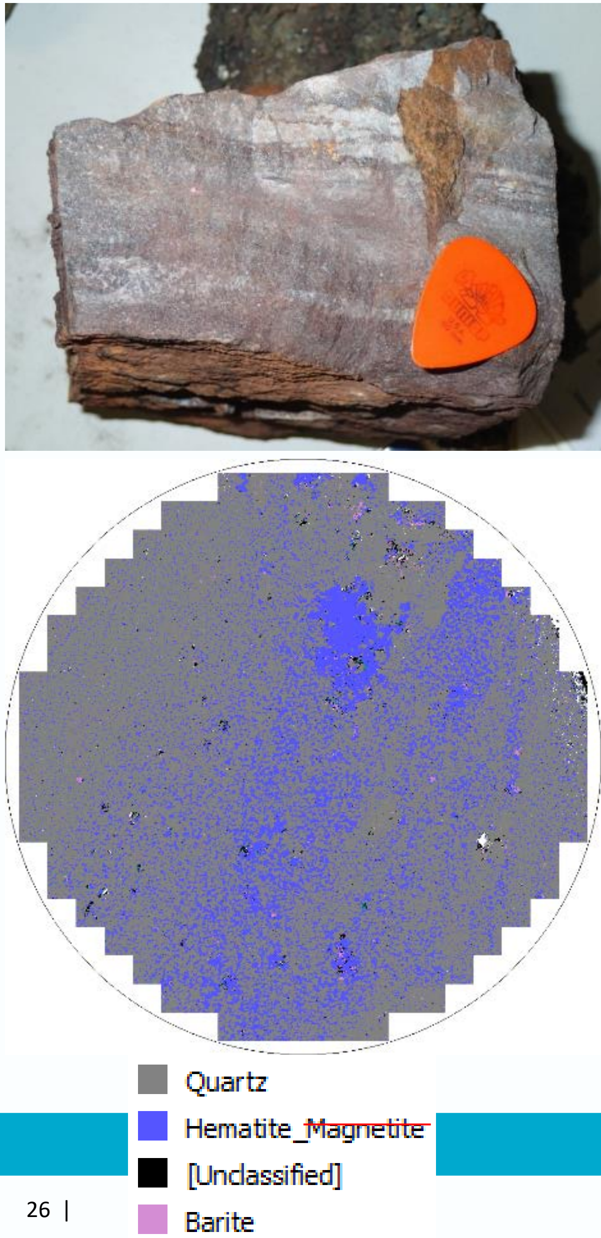


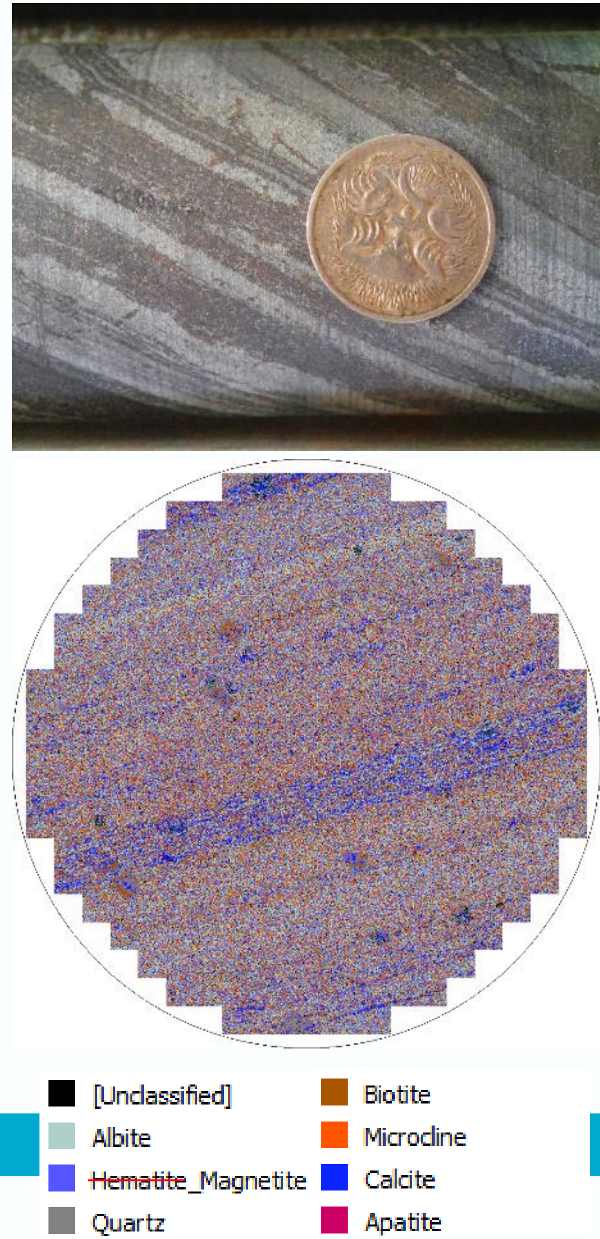
Fault zones are associated with:

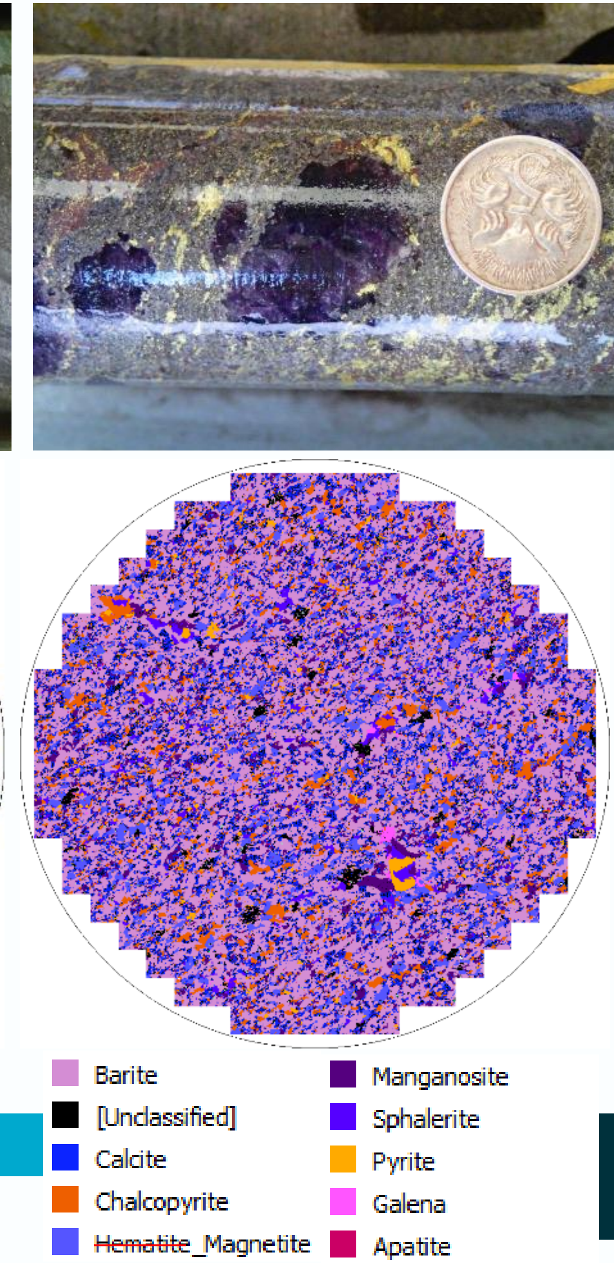
- Potassic Alteration
- Mt-destructive (oxidising)
- Associated with Copper

Pb-Zn-Ag Sedex/BHT system

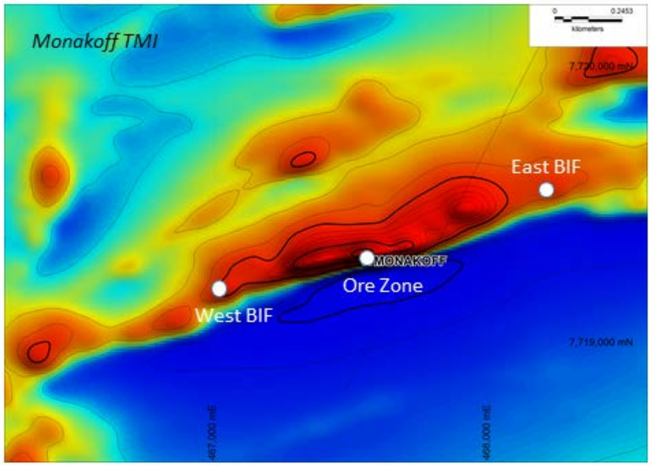
Redox zonation

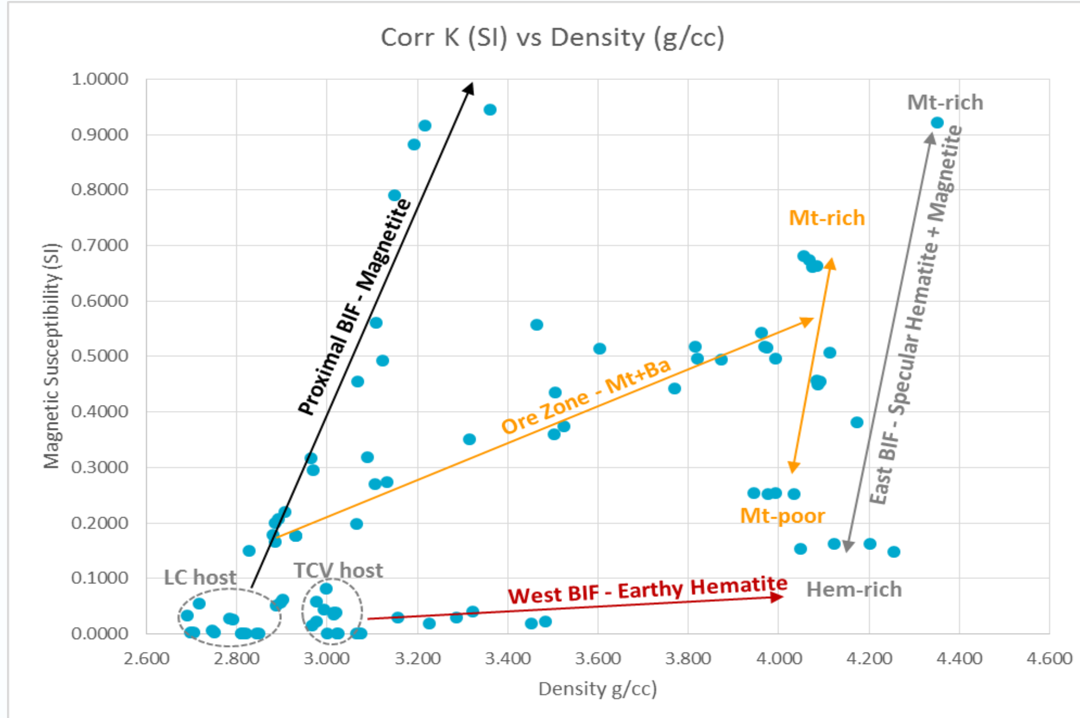




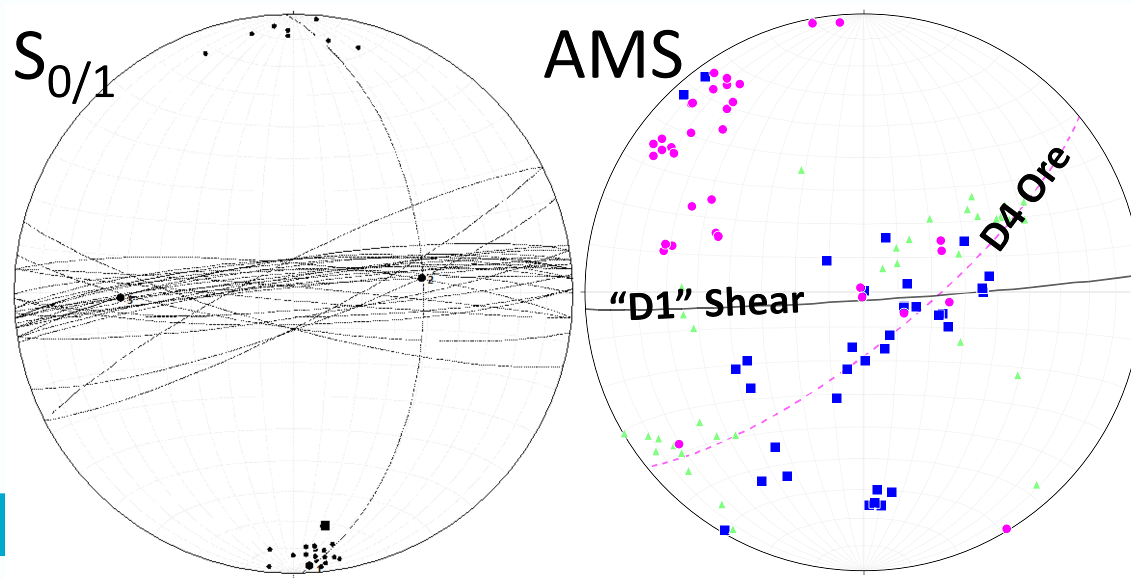


Petrophysical Zonation



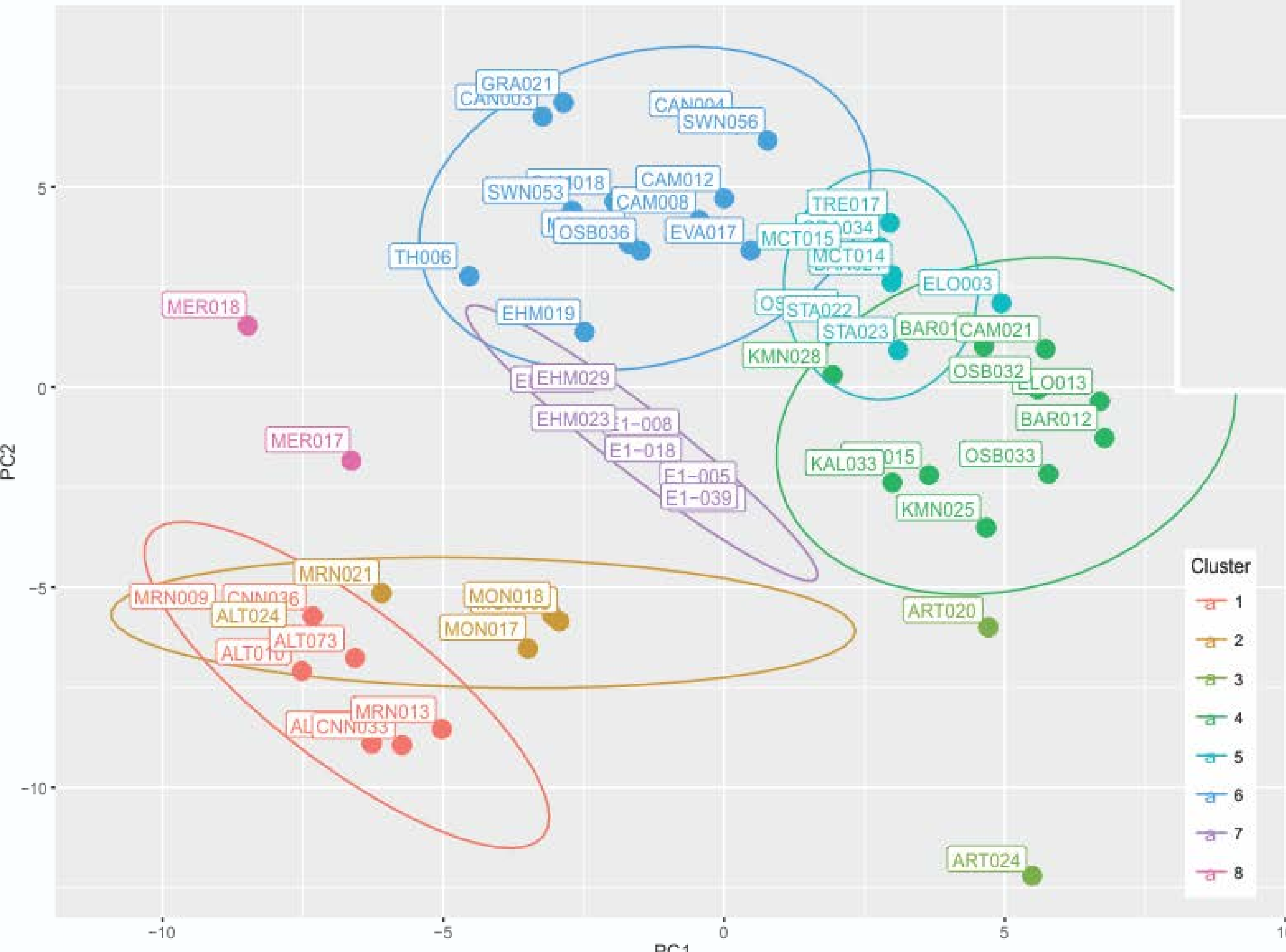


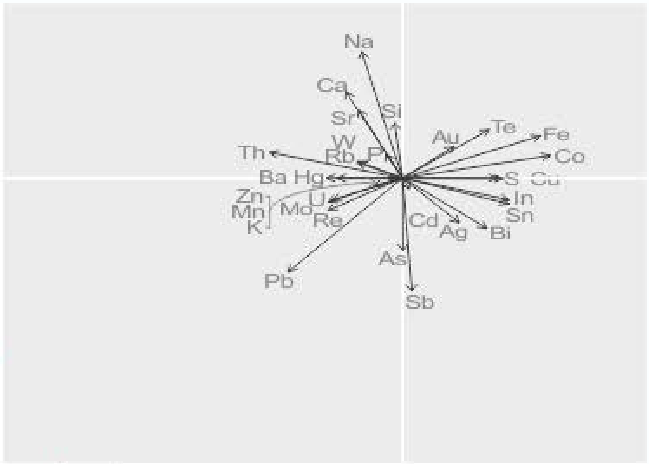
Rock type	Density (g/cm³)	Mag Sus K (SI)	Koenigsberger Ratio (Q)	Anisotropy (P)	Fabric Type
Intact laminated siltstone	2.81	0.0014	-	1.05	Isotropic
Altered Toole Ck Volcanics	2.81	0.072	0.2	1.07	Isotropic
Mt + Chl Altered Metasedimentary	2.96	0.25	0.15	1.35	Foliation/ Lineation
BIF West (Qtz-Hem)	3.19	0.03	12.27	1.02	Isotropic
BIF East (Qtz-Mt-Hem)	4.19	0.32	1.54	1.02	Isotropic
Magnetite BIF + Mt Alteration	3.36	0.51	0.08	1.48	Lineation/ Foliation
Ore Zone (Mt-Cp-Py)	3.99	0.48	0.16	1.58	Lineation/ Foliation



Principal Component Analysis (PCA)

Compares samples, or bits of systems, to allow us to see what may be related.





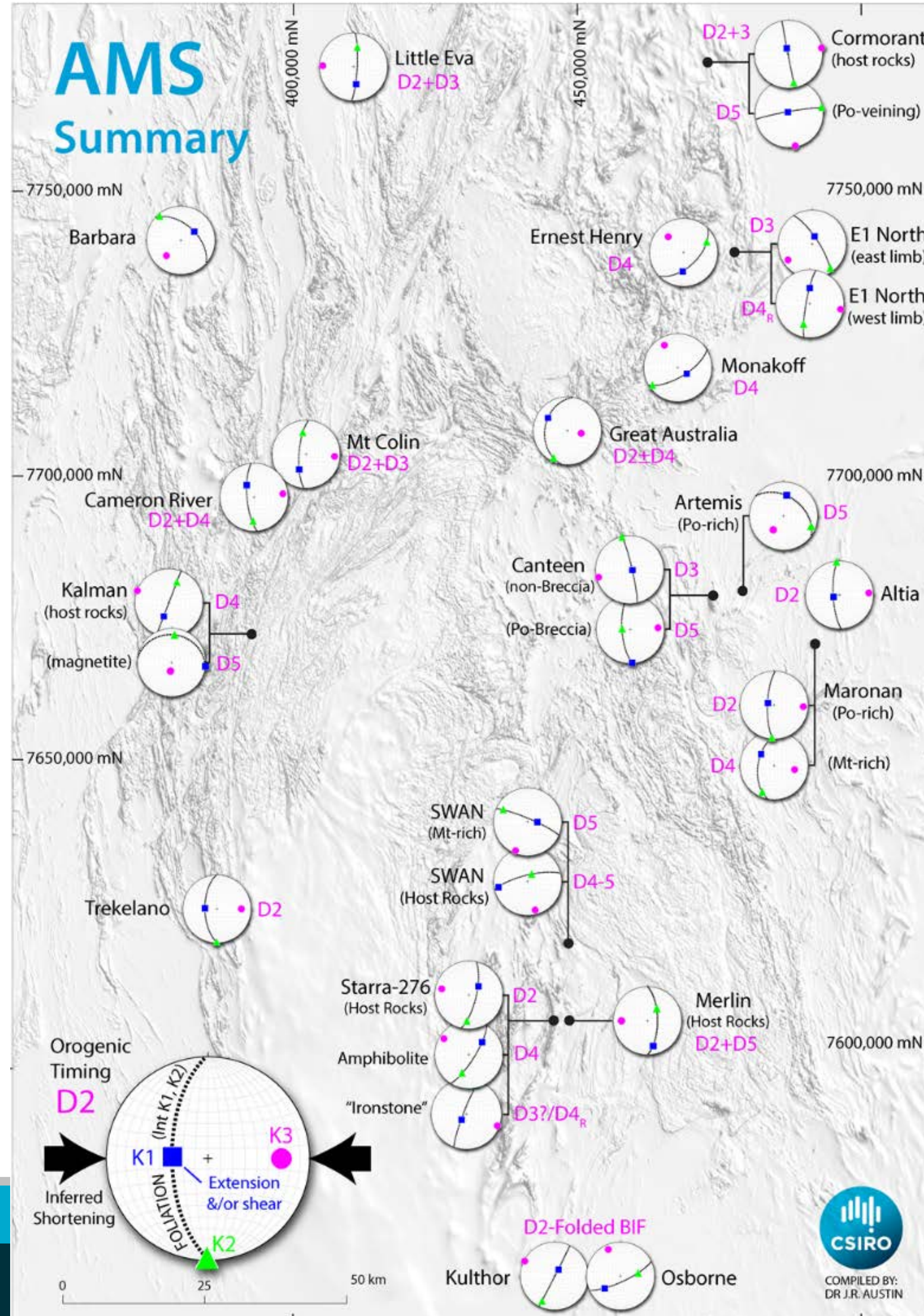
- 57 samples
- 30 elements
- <LOD substituted 50% LOD
- CLR for closure issues
- 61.03% summarised by PC5
- Bayesian mixture-modelling cluster

How can we use it??
- Future Research directions


793C

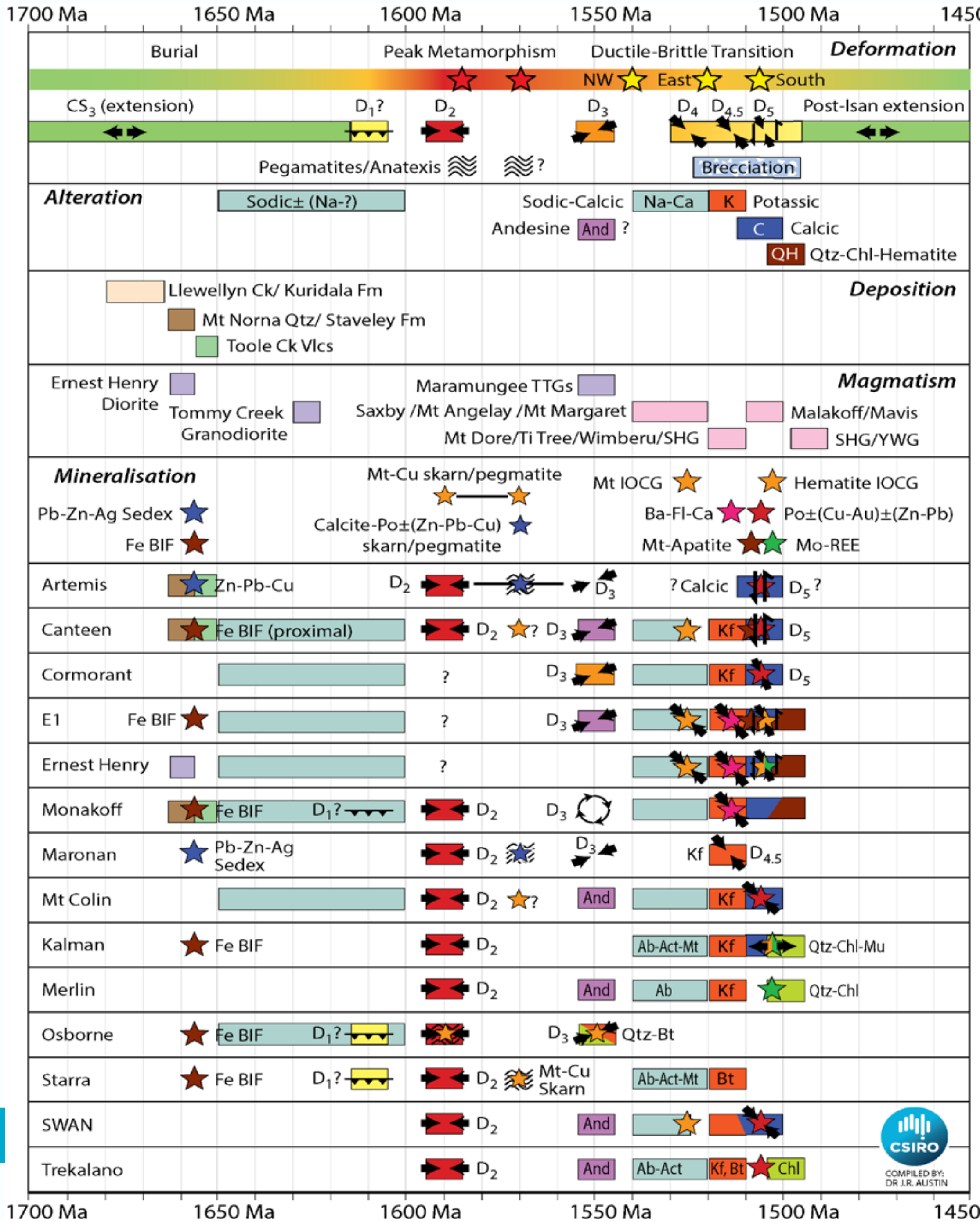
Structural Framework

- Mapped strain in 16 deposits across the Inlier
- Well clustered results
- N-S “D2” fabrics dominant
- Major deposits also have a D4, NE-SW- fabric
- Some deposits have late D5 fabrics (reactivation)



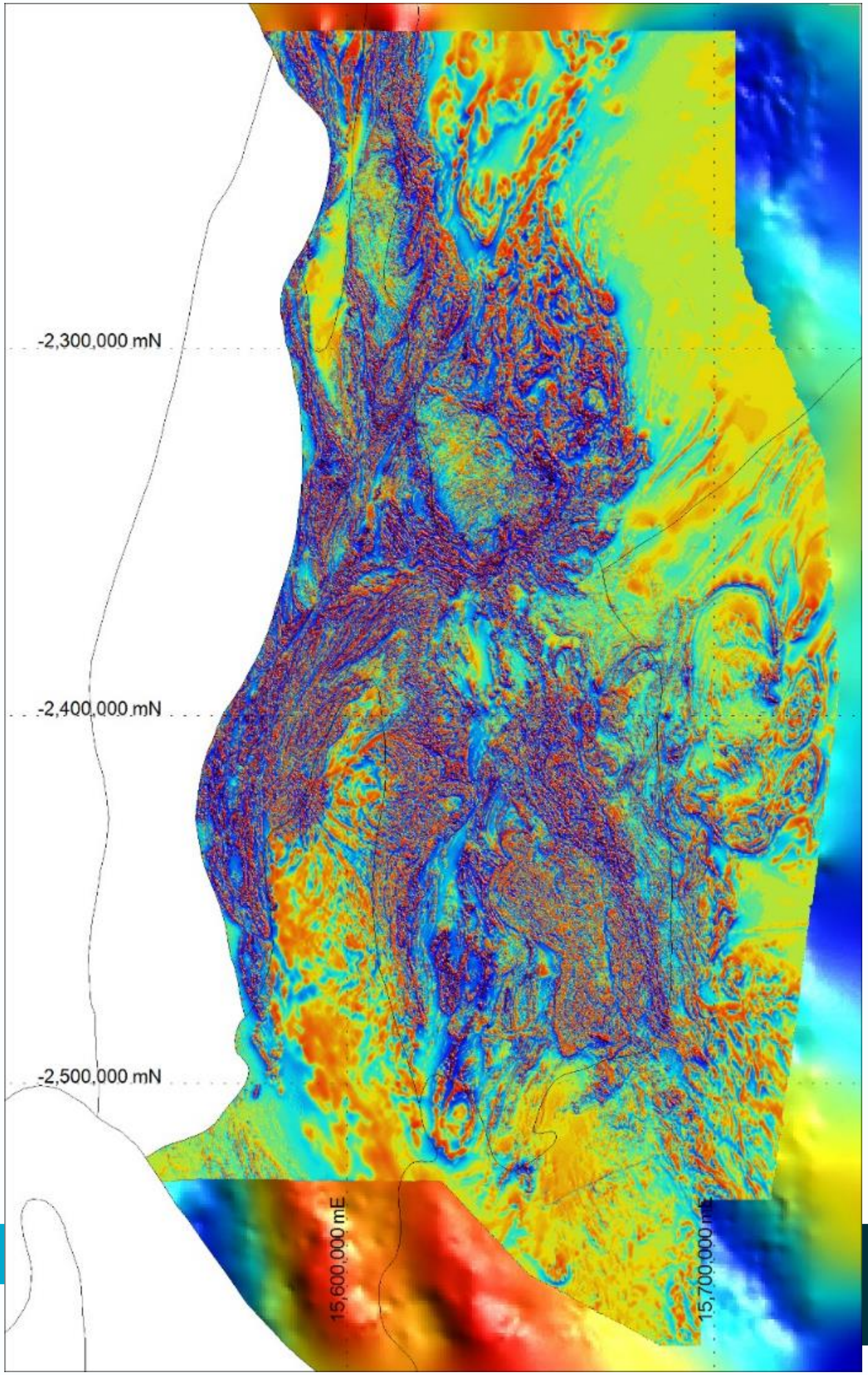
Tectonorthemal-metasomato-magmato-metallogenic Summary

- Temporally Relates:
  - Thermal History
  - Tectonic Fabrics
  - Depositional Evets
  - Alterations Styles
  - Magmatic Events
  - Mineralisation Styles



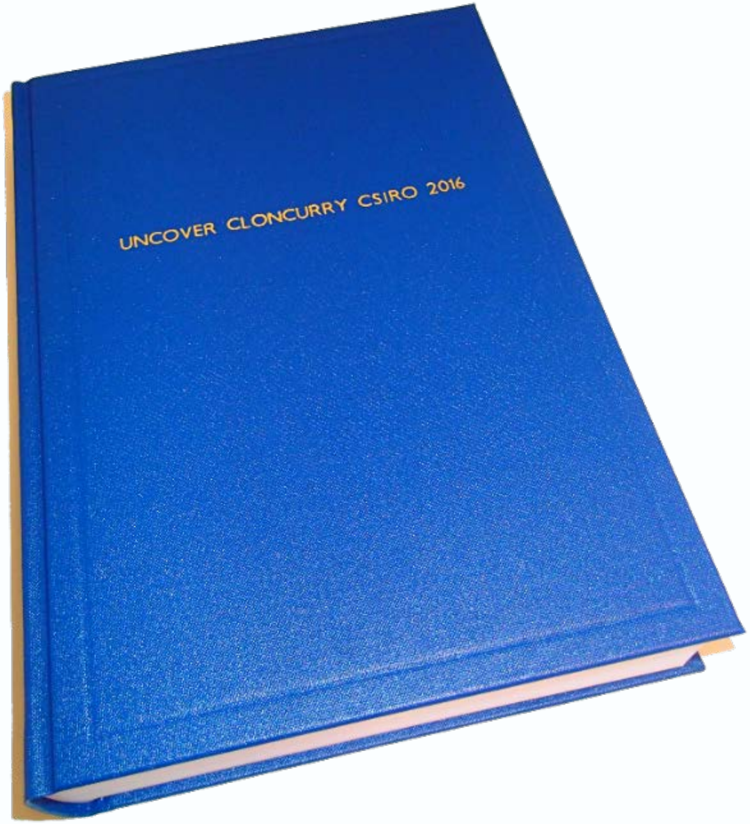
Exploring Undercover

- Don’t limit it to “undercover”
- There’s geophysically subtle targets left on the inlier too
- But possibly at deeper levels
- If drilling deep holes you need to get as much info as you can
- CSIRO has new technology to garner a lot of information from limited sampling
- We can build on these insights
- We hope to continue this work



Uncover Report – Summary Docs

- Integrated structural, metasomatic and metallogenic history of Cloncurry District.
- Geophysical Expressions of Cloncurry Mineral System.
- Chemical gradients in Cloncurry Mineral System: Vectors to grade?
- Multivariate analyses of geochemical data from Cloncurry deposits.
- Exploring for value: A geometallurgical perspective.
- Summary of methods.



QDEX Link: http://bit.ly/2jESB74

Deposit Reports >

- Altia Pb-Zn deposit.
- Artemis Zn-Cu deposit.
- Cameron River Cu prospect
- Canteen Cu-Au prospect.
- Cormorant Cu-Au Prospect.
- E1 Cu-Au deposit.
- Ernest Henry Cu-Au deposit.
- Kalman Mo-Re-Cu-Au deposit.
- Maronan Pb-Ag deposit.
- Merlin Mo-Re deposit.
- Monakoff Cu-Au-U deposit.
- Mount Colin Au-Cu deposit.
- Osborne Cu-Au deposit.
- Starra Cu-Au deposits.
- SWAN Cu-Au prospect.
- Trekelano Cu-Au Deposit