CSIRO MINERAL RESOURCES – MULTIPHYSICS TEAM
www.csiro.au

Geophysical, Structural and Mineralogical Signatures of the Cloncurry Mineral System

Jim Austin|
21 March 2019

+ Ben Patterson, John Walshe, Renee Birchall, Monica leGras, Michael Gazley, Vladimir Lisitsen, Courteney Dnararham, Paul Donchak + UQ +CODES.

Queensland Government
Department of Natural Resources and Mines

Ground we'll cover today

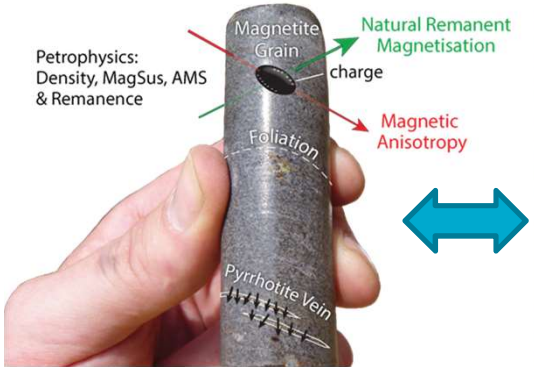
- To give you all an idea of the approach we're taking with the Cloncurry Mineral System.

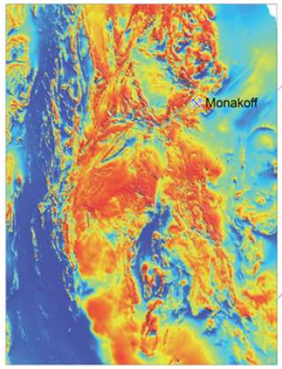
  1. Overarching Goals
  2. Sampling Conducted thus far
  3. Techniques being used
  4. Preliminary Results

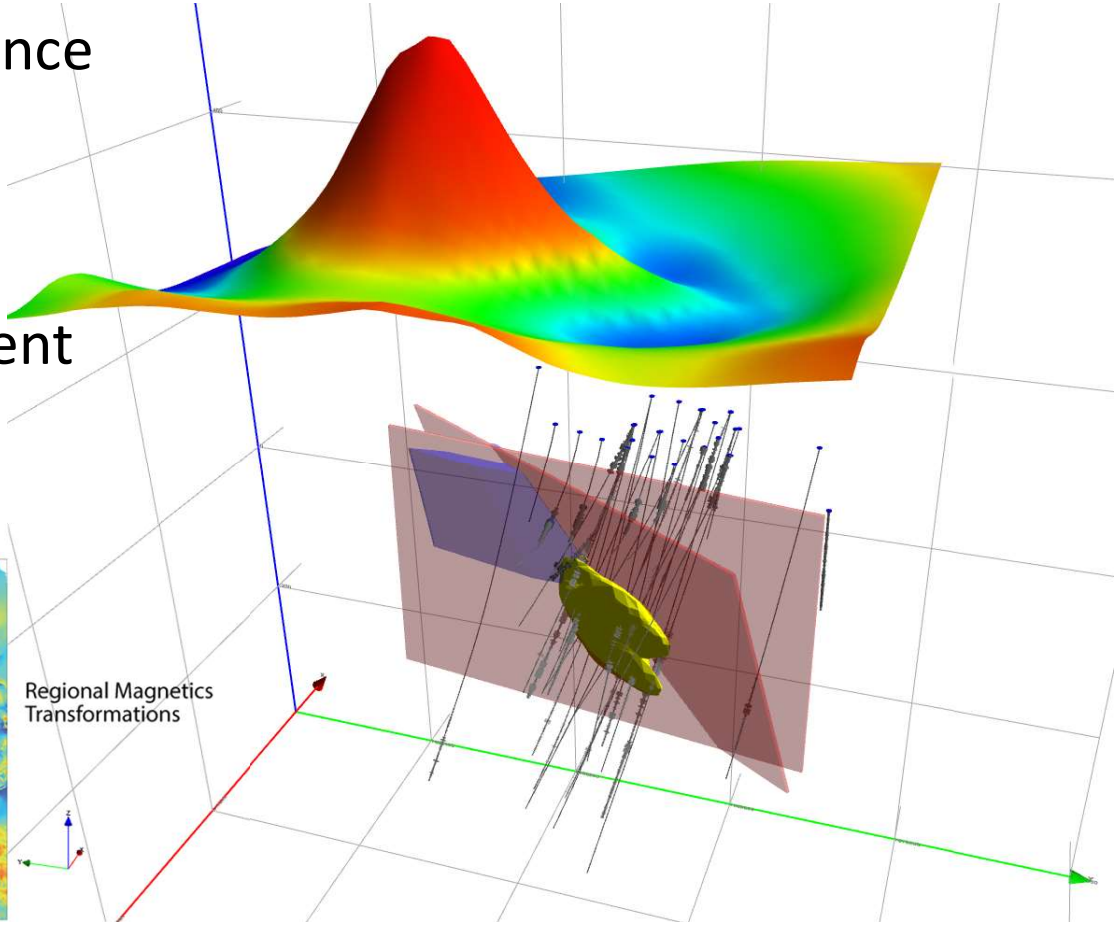
Data “Integration”

- We’re entering a new era of data-driven “science”, but
- we have huge problems with data integration in geoscience
- Our datasets were never designed to be integrated
- Geoscientific data is different from most other data:

- **Main issues**
  1. dimensionality,
  2. scale and scalability.
  3. spatial resolution





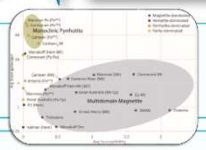


INTEGRATED PETROPHYSICS

1500 point samples | ~80 samples per deposit | 25 x Deposits / Prospects | 1 x Mineral System

NRM

AGICO JR-6 Magnetometer



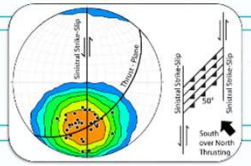
Q ratio can be used as a proxy Redox in Mt<->Po

NRM vector, intensity, stability & Q Ratio

AMS

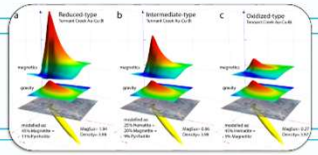
AGICO MFK-1 Magnetometer

Proxy for fabric: used to quantify fabrics and structural controls



3 Eigenvectors & ratios that describe ellipsoid

MagSus



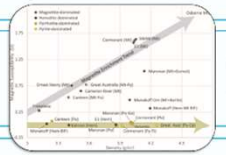
Magnetic Mineralogy

Susceptibility & Q Ratio

Density

Metler-Toledo MS201TS Balance

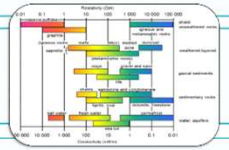
Density-MagSus ratio used as a proxy Redox in Mt<->Hem



Density, Mt: Hem #

EM

KT-20 Conductivity-Susceptibility Meter



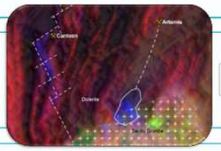
Used with Q ratio to discriminate pyrrhotite from other sulphides

Conductivity / resistivity (± chargeability)

Radio-metrics

RS330 Gamma-Ray Spectrometer

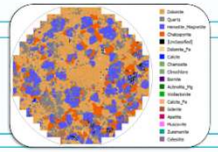
IOCG Alteration ????



K, Th, U, Total Count, Ternary & various ratios

Min

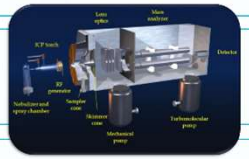
Tescan Integrated Mineral Analyser (TIMA)



IOCG/ not IOCG ?%#!

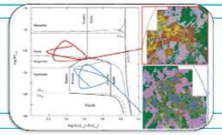
≤ 85 different minerals + rock textures

Geo-chem



Laser Ablation ICP-MS

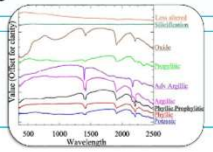
Can we predict mineralogy from Geochemistry??



≤ 75 different elements

Hyper-spectal

Hylogger Mark III



Used to discriminate mineral species

≤ 80 different minerals, 10 alteration proxies

FOR FURTHER INFORMATION

Jim Austin - Team Leader Multiphysics
e james.austin@csiro.au
P 02 9490 8876 m: 0459 886 302
a 11 Julius Ave, North Ryde, 2113, NSW
w https://confluence.csiro.au/display/cmfr/Home

CSIRO

Queensland Government
Department of Natural Resources and Mines

Progress

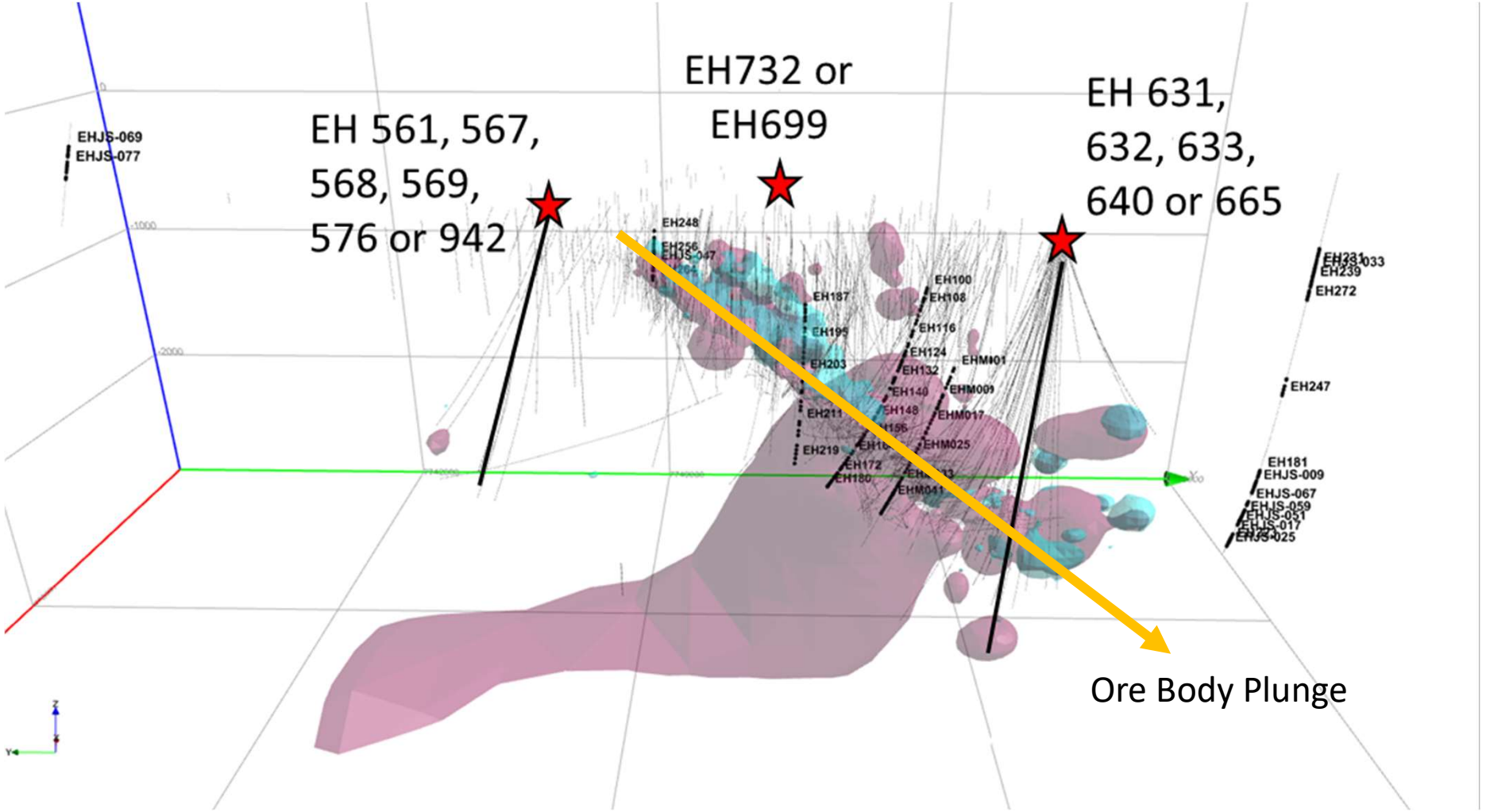
Petrophysics – Legacy Data

DEPOSIT	Num of Specimens	Conductivity		Num of Samples	Radiometrics	
		KT10	KT20 (100kHz)		RS-332	
Altia	59	Y	Y	30	Y	P
Artemis	56	Y	Y	22	Y	P
Barbara	21	Y	Y	7	Y	P
Brumby	72		Y	38	Y	P
Cam River	84	Y	Y	42	Y	P
Canteen	96	Y	Y	48	Y	P
Cormorant	117	Y	Y	45	Y	P
E1	36	Y	Y	18	Y	P
E1-Surface	80		Y	34	Y	P
EHM	81	Y	Y	41	Y	P
Great Aus	59	Y	Y	22	Y	P
Kalman	45	Y	Y	21	Y	P
Kulthor	56	Y	Y	28	Y	P
Little Eva	22	Y	Y	11	Y	P
Maronan	66	Y	Y	33	Y	P
Merlin	31	Y	Y	16	Y	P
Monakoff	31	Y	Y	16	Y	P
Mt Colin	32	Y	Y	11	Y	P
Osborne	77		Y	34	Y	P
Starra	52		y	26	Y	P
SWAN	125	Y	Y	49	Y	P
Trekelano	44	Y	Y	22	Y	P

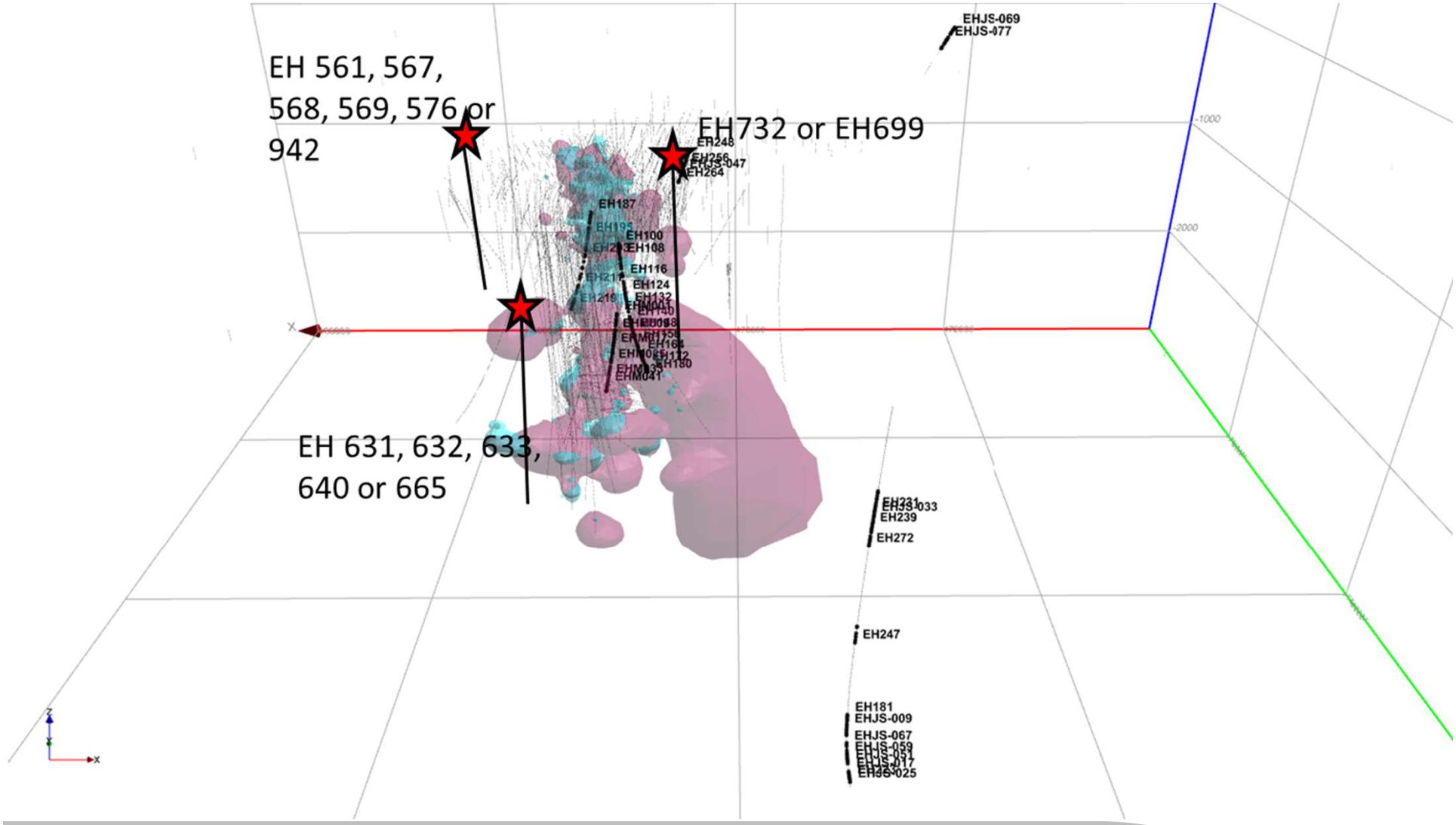
In Progress		
Completed		
Y	Data imported to spreadsheet	
P	Partial import	

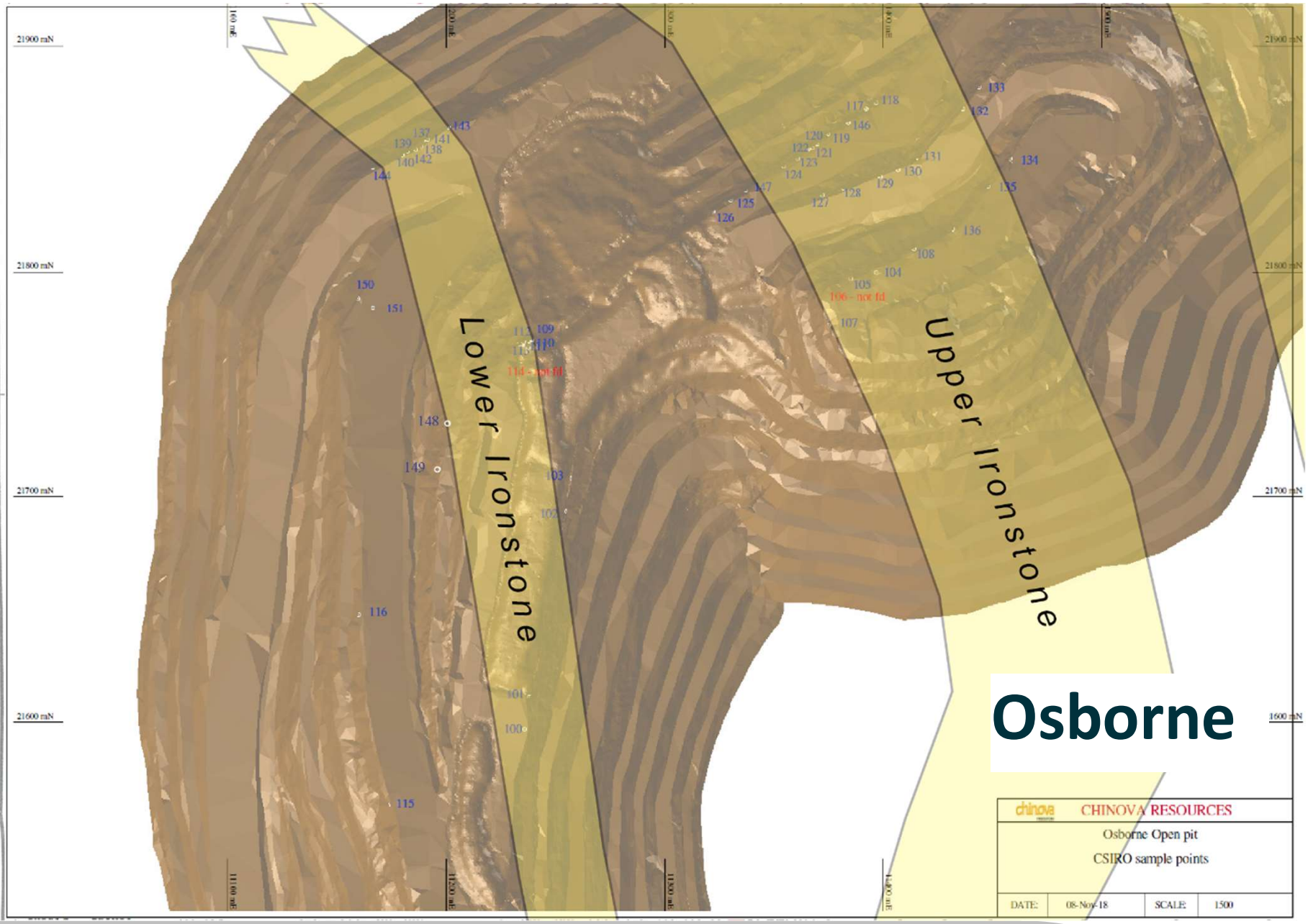
1935	786	Total Number of Specimens/Samples @ North Ryde
1342	0	Number to be Measured (total - OSB,STA,EH/EHM)
1265	786	Currently Measured
94%	**100%**	**% Complete**
CONDUCTIVITY	RADIOMETRICS	

Ernest Henry Sampling (east)

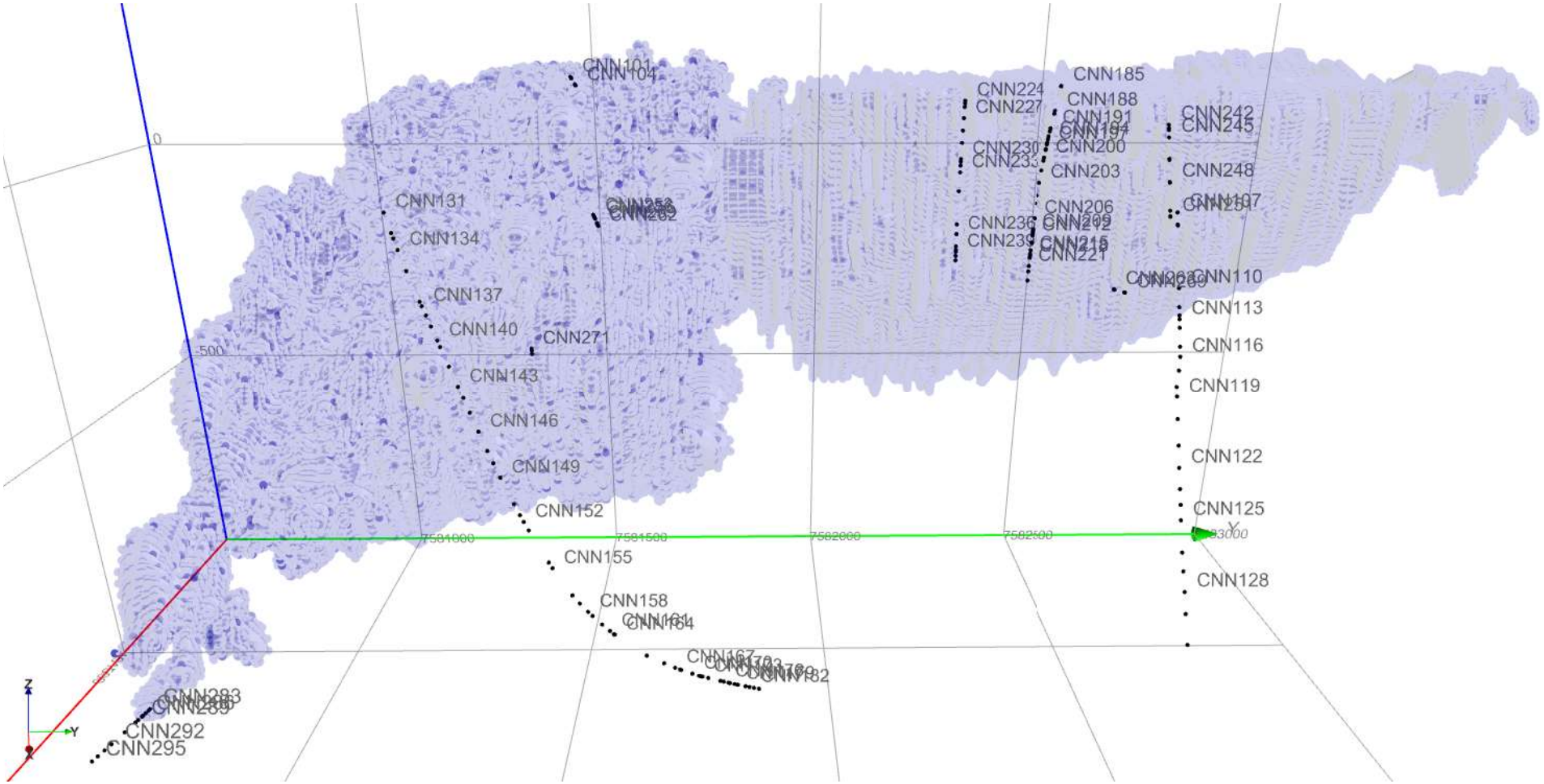


Ernest Henry Sampling (south)

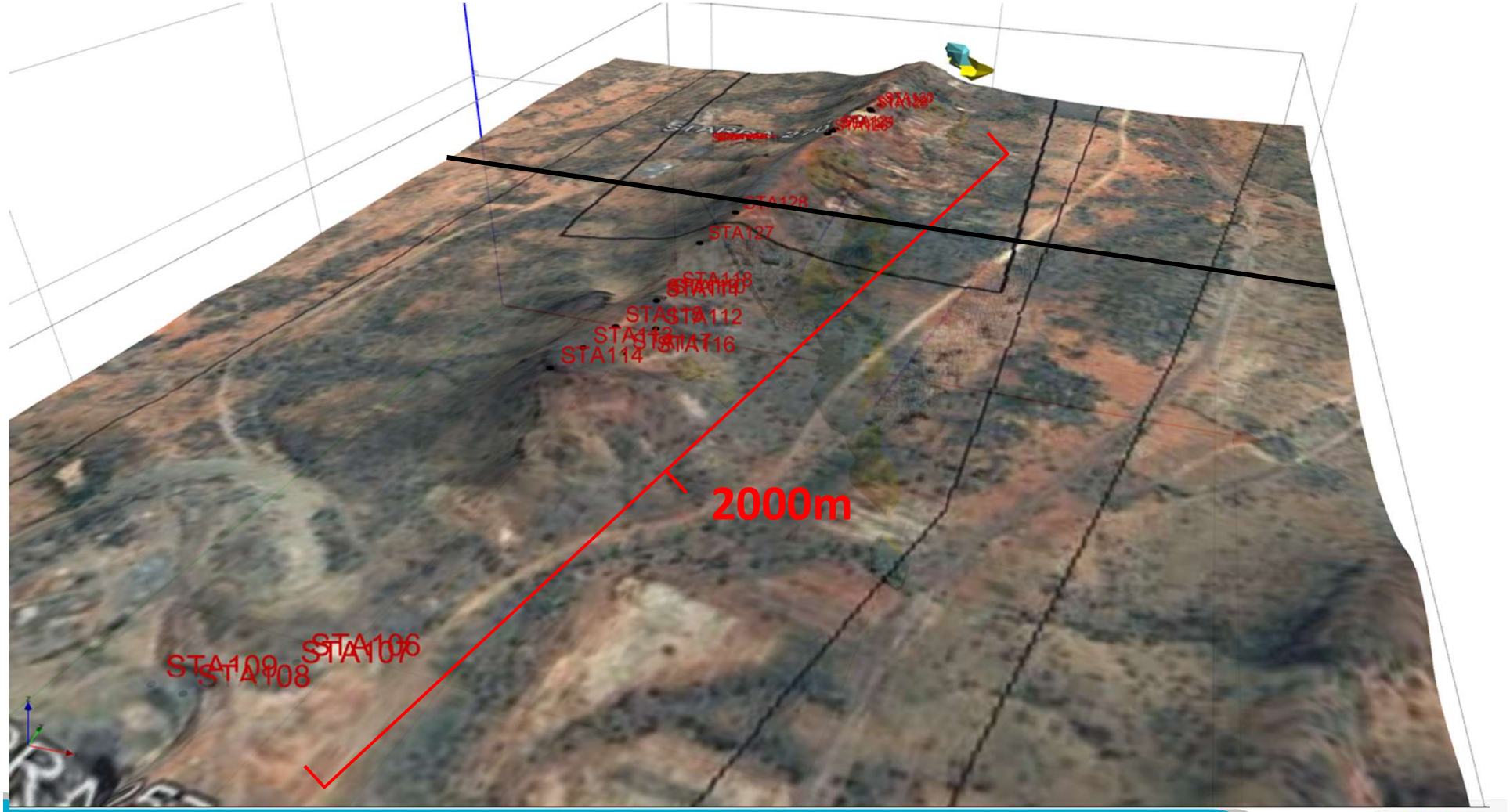



Lower Ironstone
Upper Ironstone
Osborne
CHINOVA RESOURCES
Osborne Open pit
CSIRO sample points
DATE: 08-Nov-18
SCALE: 1500

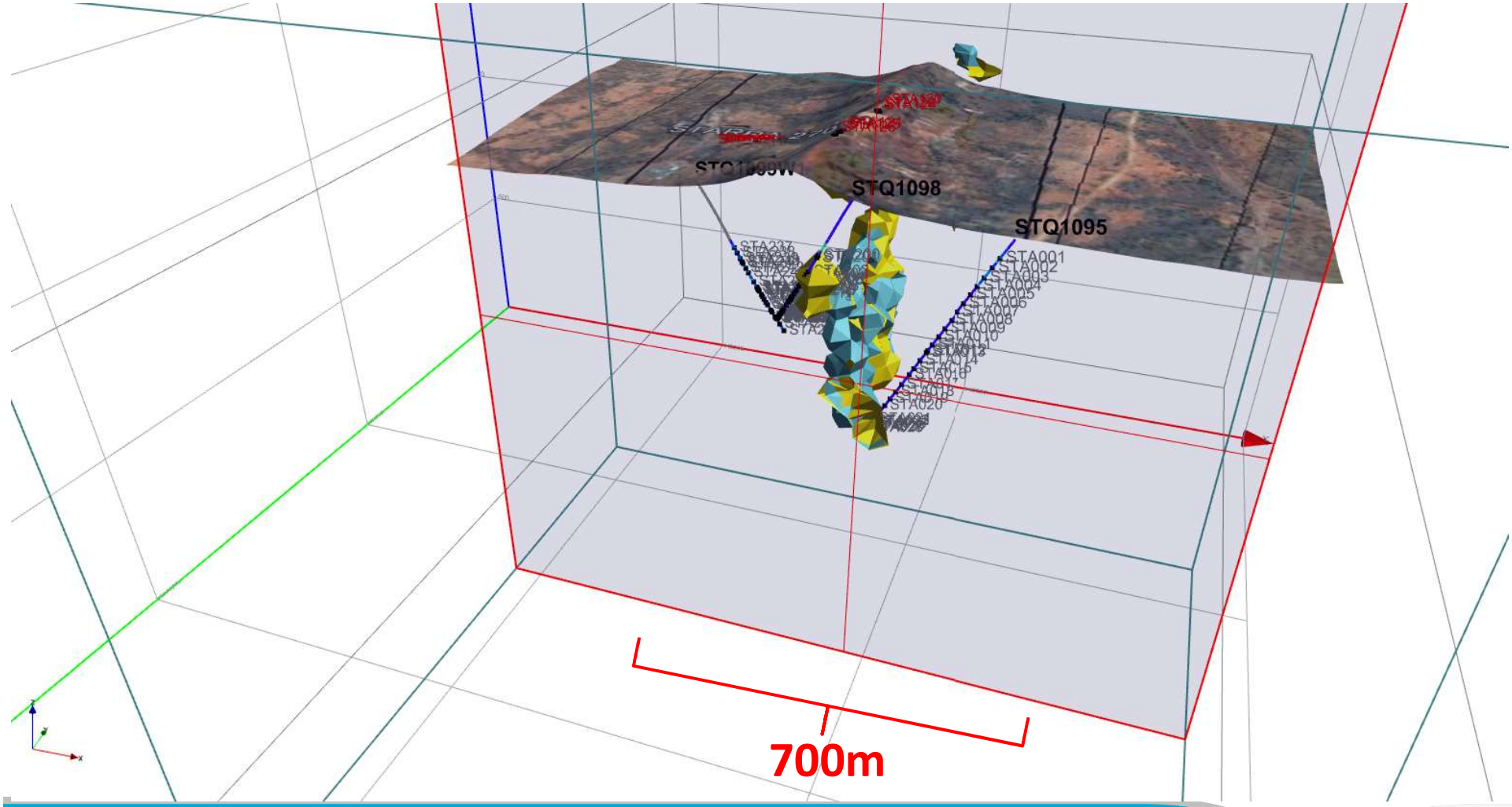
Cannington Downhole Sampling (east)

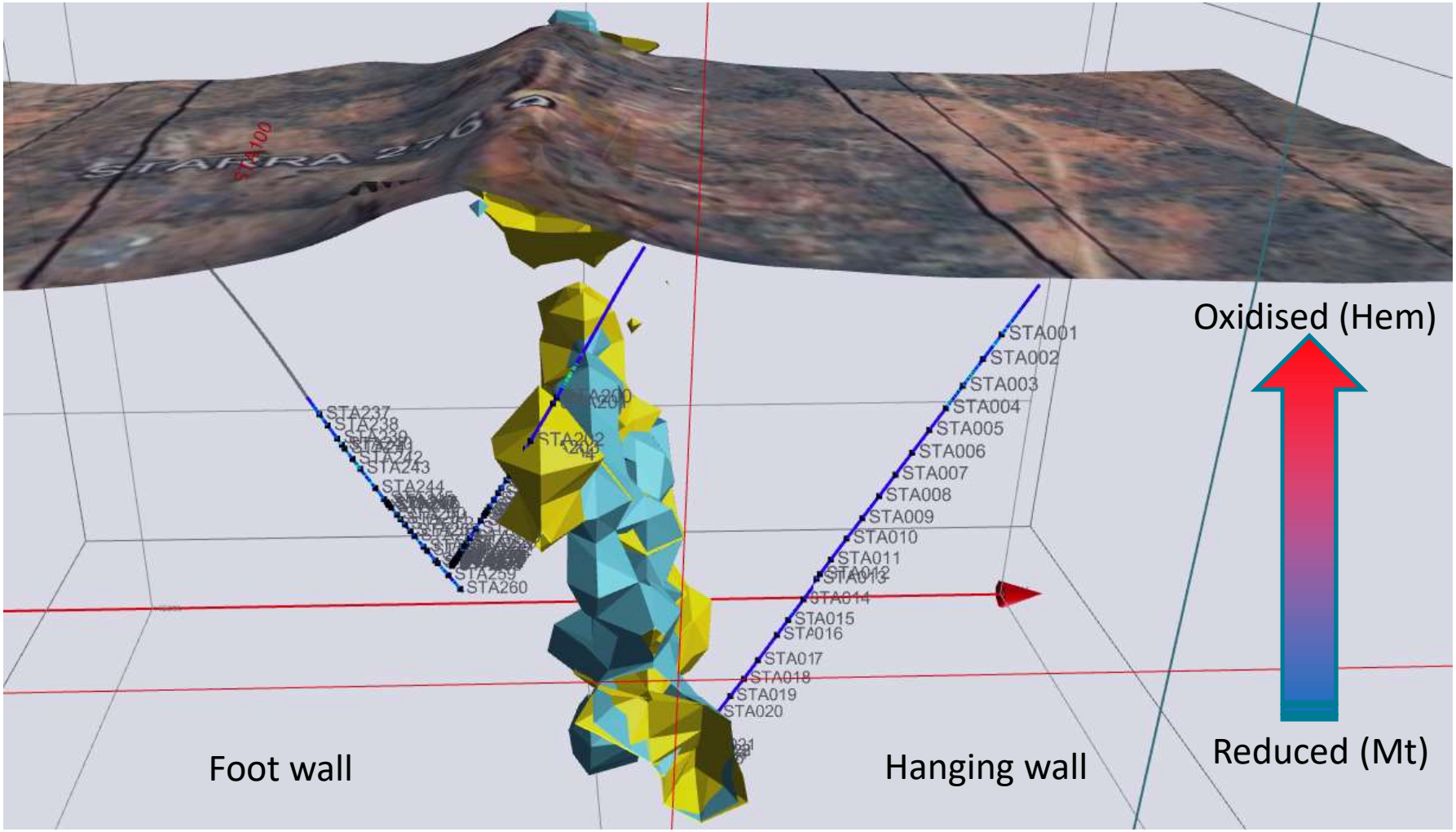


Starra Surface sampling



Starra Downhole sampling



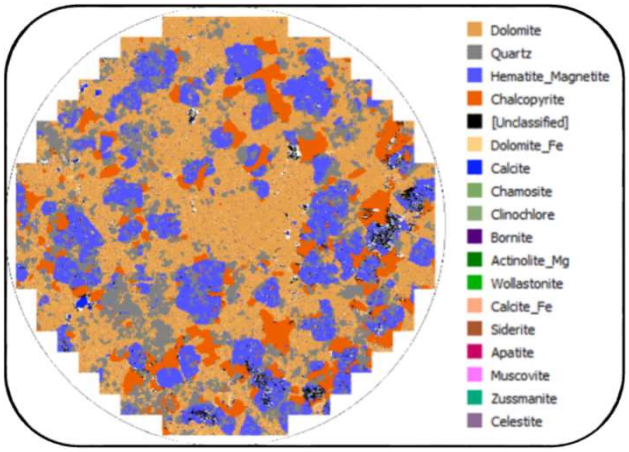

Oxidised (Hem)
Reduced (Mt)
Foot wall
Hanging wall
Background
Distal
Proximal
Ore
Proximal
Distal
Background
Reduced (Mt)
Oxidised

Techniques

Mineralogy with integrated Textural/Fabric Mapping

Correlating Structure with Fabric & Mineralogy

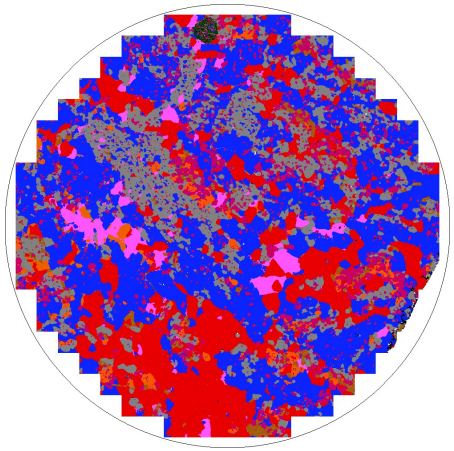
TIMA (Tescan Integrated Mineral Analyser)



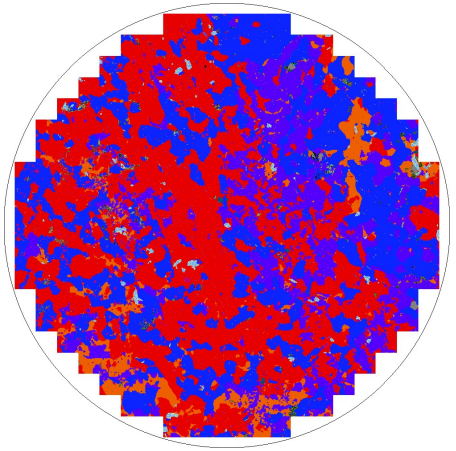
- The best way is to image the mineralogy and the texture of the same sample you've measured

BHT/Sed-hosted

Maronan Pb-Zn

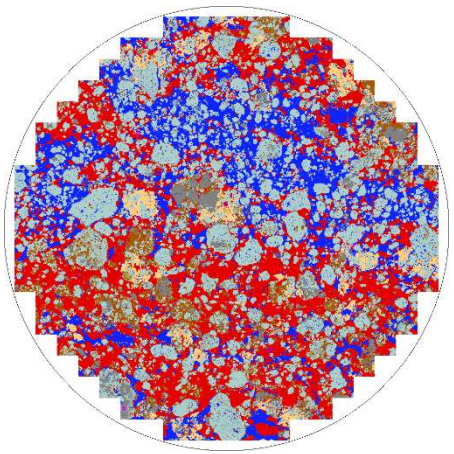


Artemis Cu-Zn

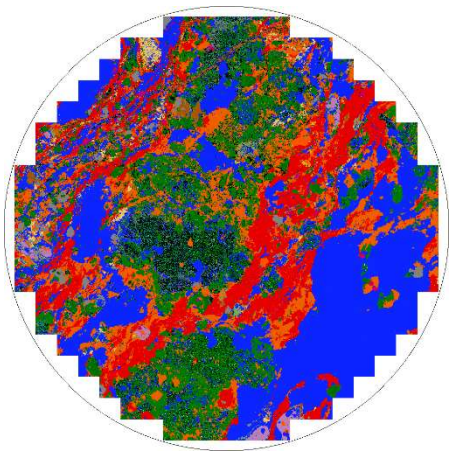


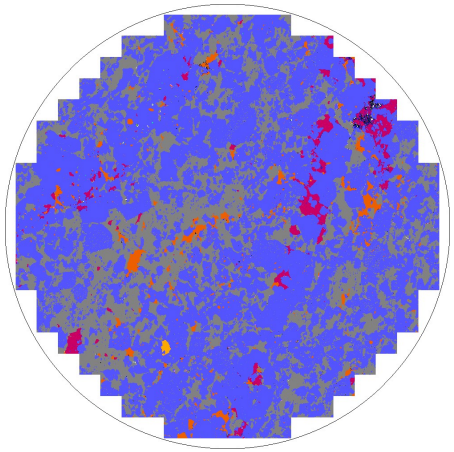
Calcite+Po SKARN

Canteen Cu-Au

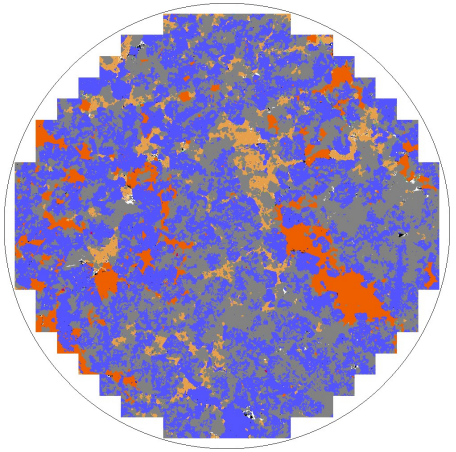


Mt Colin Au-Cu



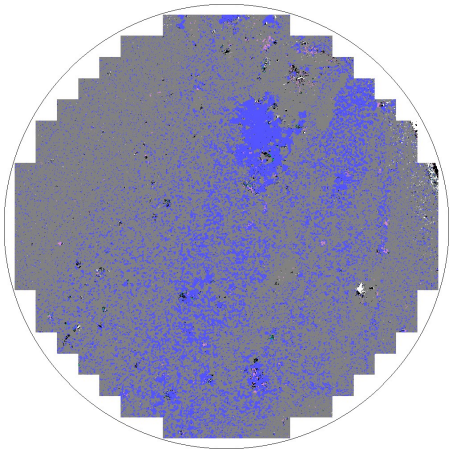


Osborne Cu-Au



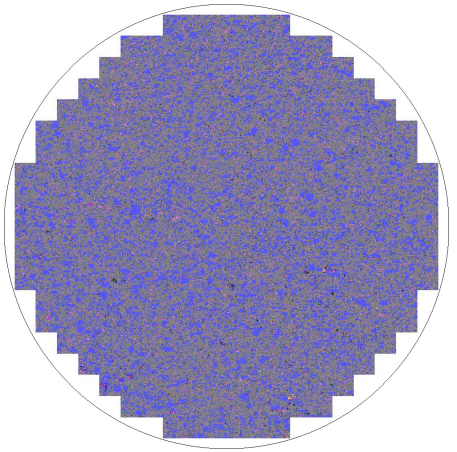
Starra Cu-Au

IOCG??



Monakoff Cu-Au

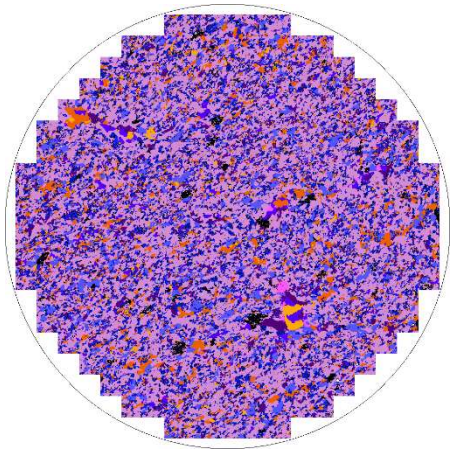
Sed-hosted (Distal)



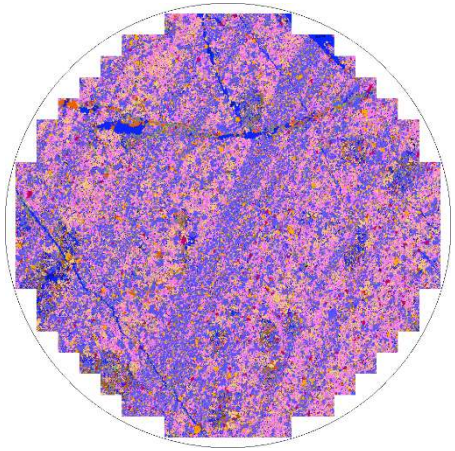
E1 Cu-Au

Magnetite-Barite-Fluorite

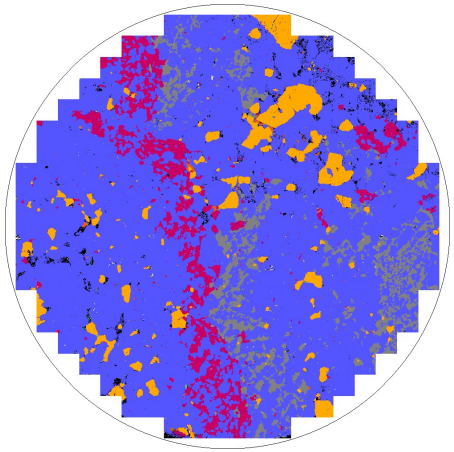
Monakoff Cu-Au



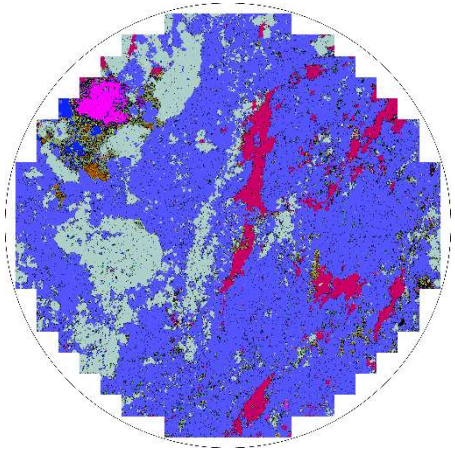
E1 Cu-Au



Osborne Cu-Au

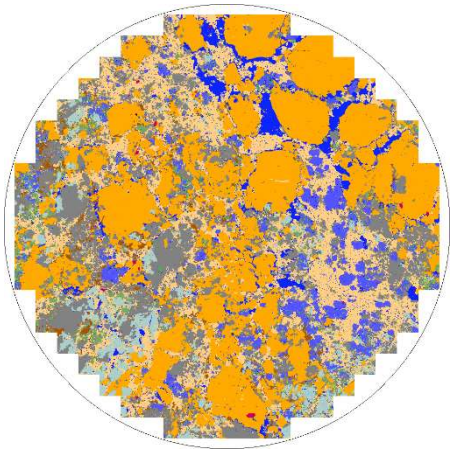


Ernest Henry Cu-Au

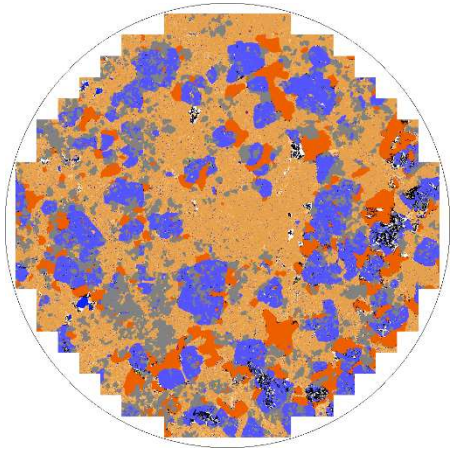


Dolomite-Pyrite-Mt-Qtz

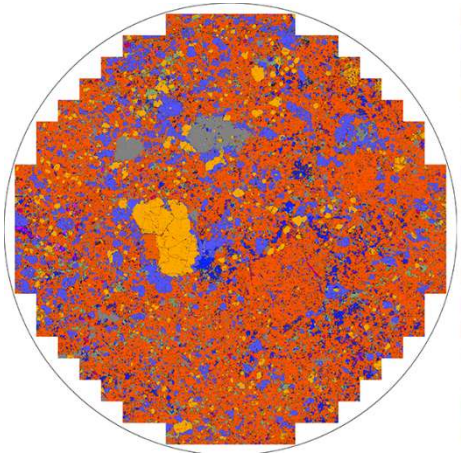
Canteen Cu-Au



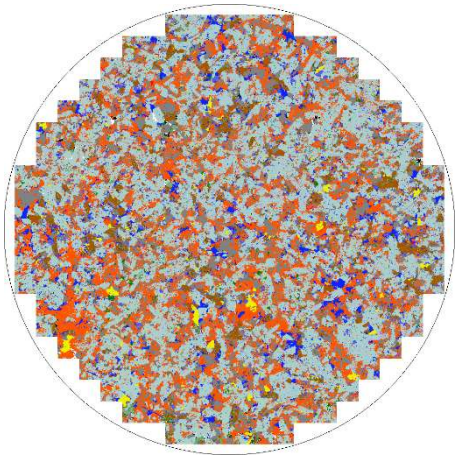
Starra Cu-Au



Ernest Henry Cu-Au



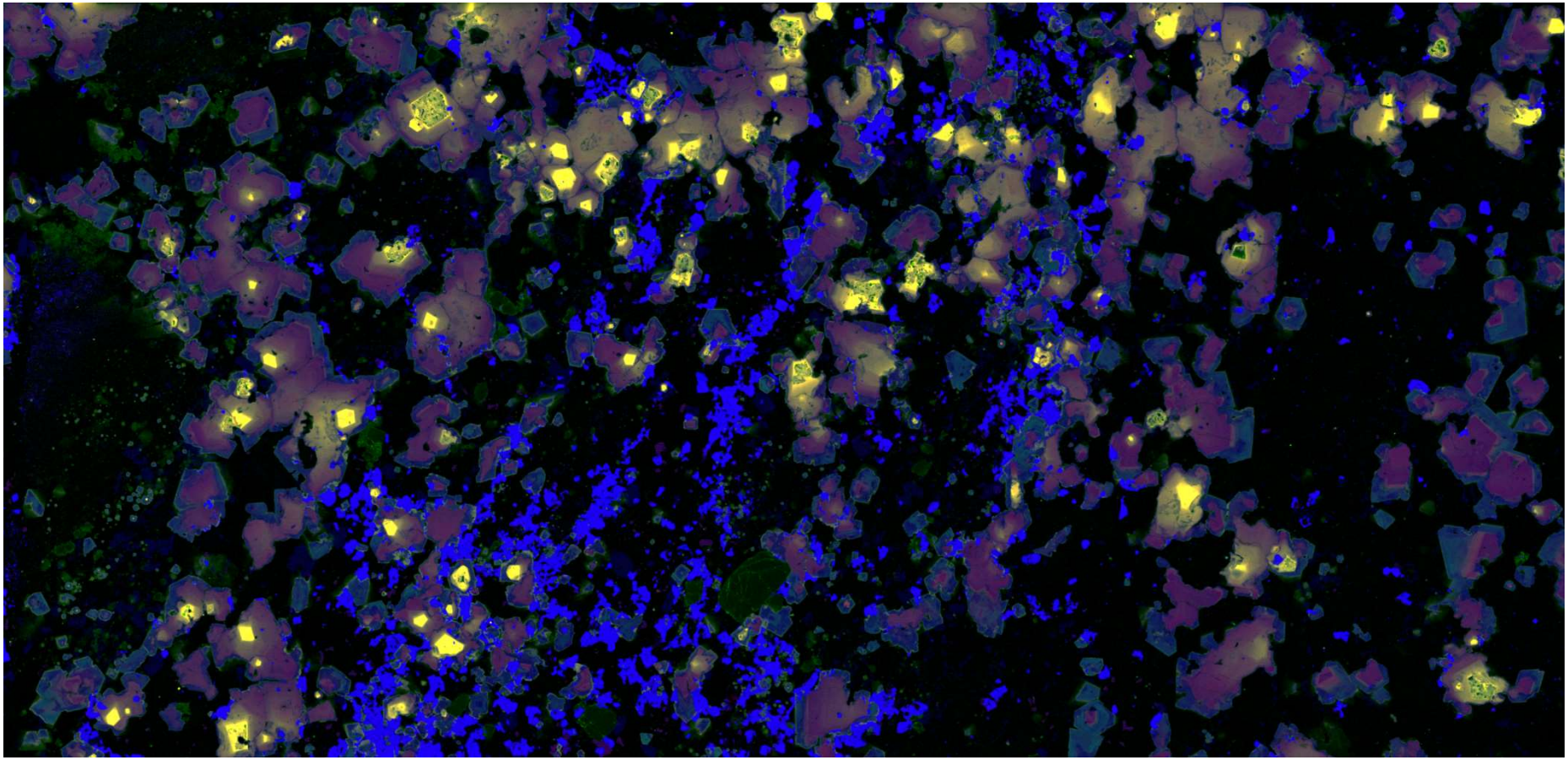
SWAN Cu-Au



Magnetite-Apatite

Potassic Breccias

MAIA Mapper Data



Co in Red, As in Green and Fe in blue

Explanation

You can see that the As and Co go together for much of the history resulting in the pink colour (red + blue). There are some really bright spots in the middle of the pyrites which are probably cobaltite (CoAsS) around which it looks like the pyrites have nucleated.

Louise and I had a go at inventing a story last week and it goes something like this (using the colours from the Co As Fe image):
Growth of cobaltite and possibly arsenopyrite (some of the internal, yellow, zones of high Co and As look a bit like arsenopyrite crystal shapes)
Cooling destabilises arsenopyrite to pyrite + As so the As (+Co) bearing pyrite is grown (with decreasing As content – yellow à red pyrite)
Continued cooling results in magnetite being stable at the expense of pyrite, perhaps with a change in S/O fugacity – we'd need to draw a phase diagram! This is when the red pyrite is resorbed to produce the tatty looking edges on that zone
Breakdown of amphibole produces releases Fe and Ni (in the As Ni Co image there are bright green phases that we think are actinolite) which allows (with sufficient S present already) the growth of the new, euhedral Ni-bearing pyrite (blue and green zoning in the CoAsFe image).

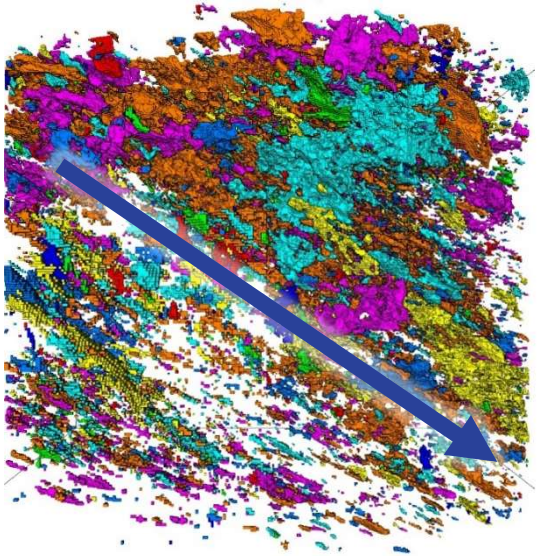
This is our working story but it would need some further investigation.

Also relevant for your meeting is that this sample was one of the ones that I took to Maia Map before Jeff lasered it so we can work together with CODES on this. I would be interested on any feedback that they have.

Quantifying Strain Conditions

AMS (Anisotropy of Magnetic Susceptibility)

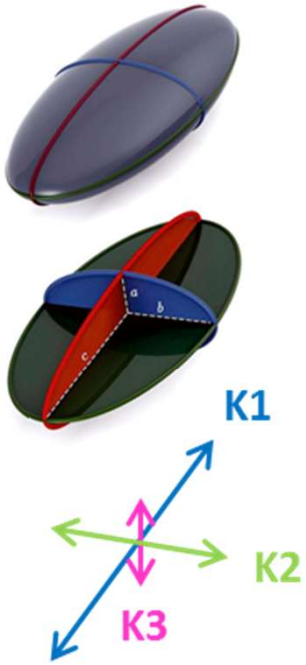
- Measureable petrophysical property of rock
- Preferred orientation of crystallographic axes of magnetite /pyrrhotite.
  - i.e., the magnetic fabric.
- Can be used to Define strain distribution prior to mineralisation



µCT image of ART16C

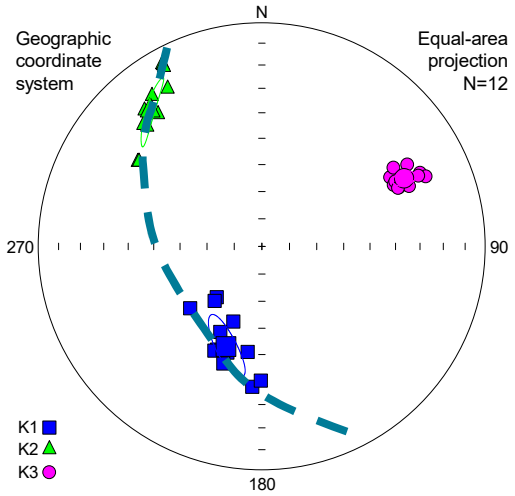
Isotropic
(random)

Anisotropic

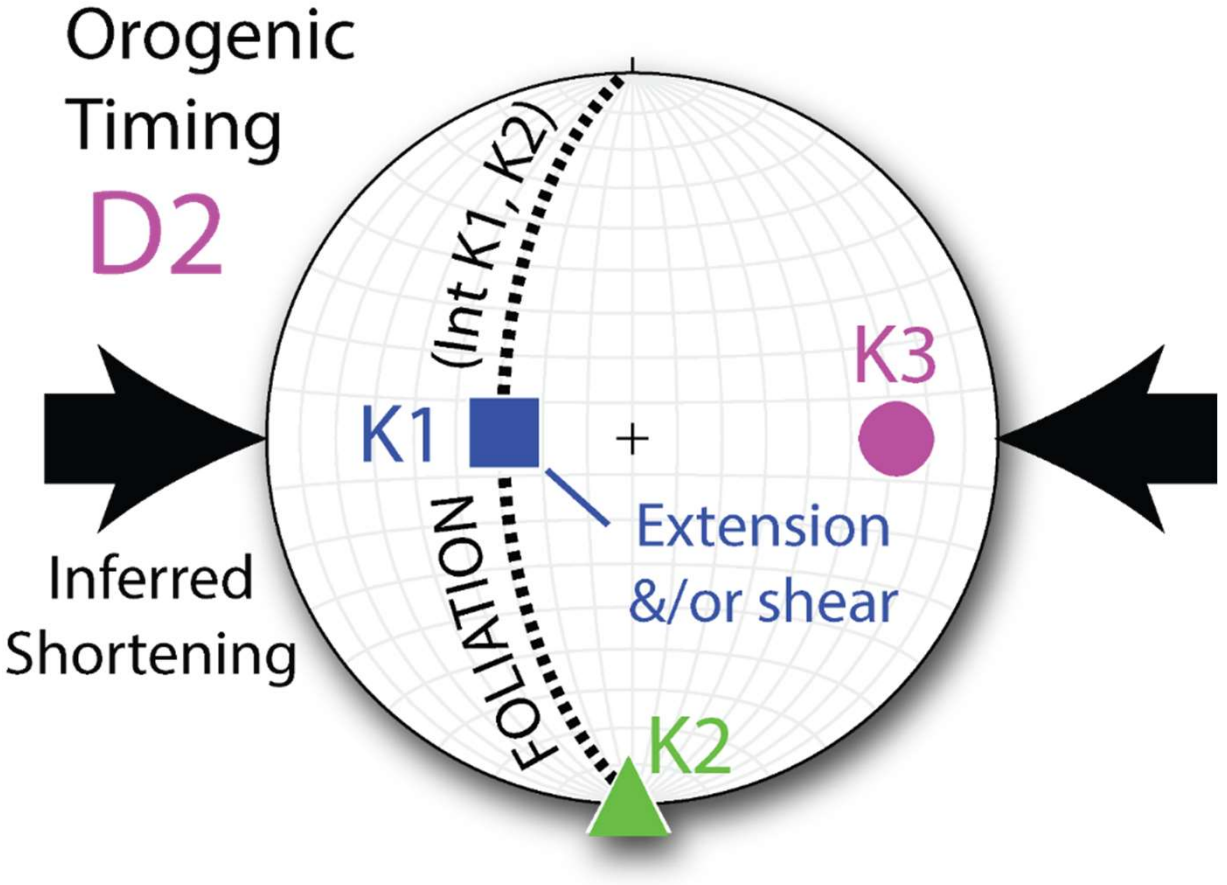


AMS can provide information about:

- **Strain Fabrics**
- **Shearing**
- Veining (Dilation)
- Sedimentary Banding
- Magma Flow
- Magmatic Settling
- So you need to know about the mineralogy and the texture to use it effectively

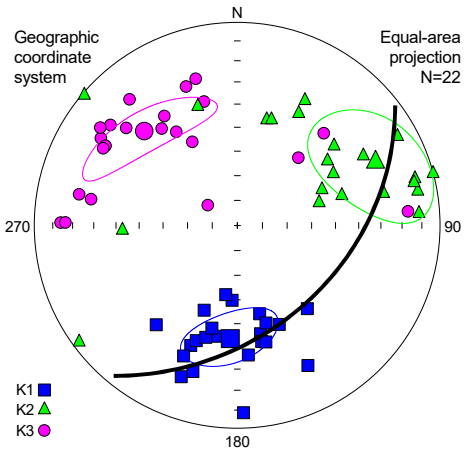


AMS (Anisotropy of Magnetic Susceptibility)

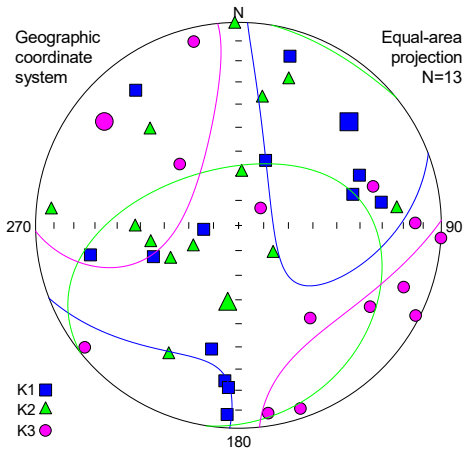


Ernest Henry Structural Controls

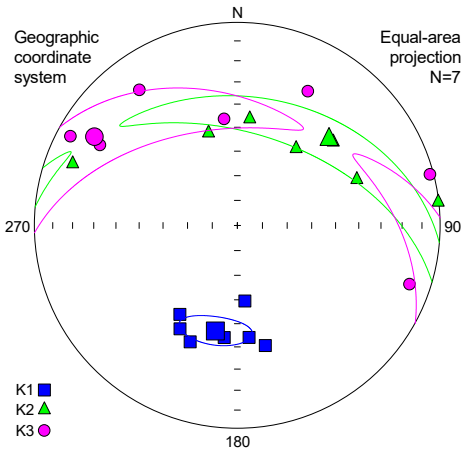
Hanging Wall AMS

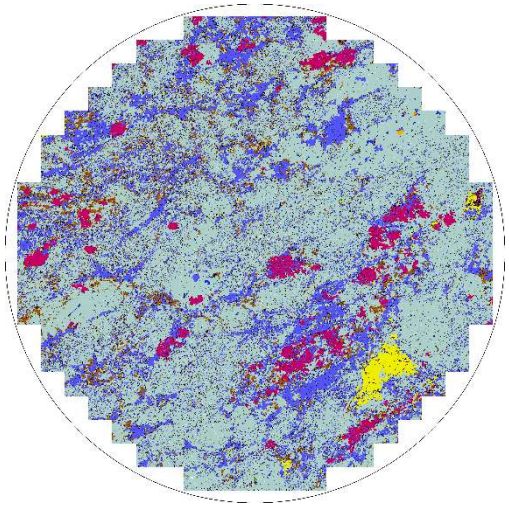


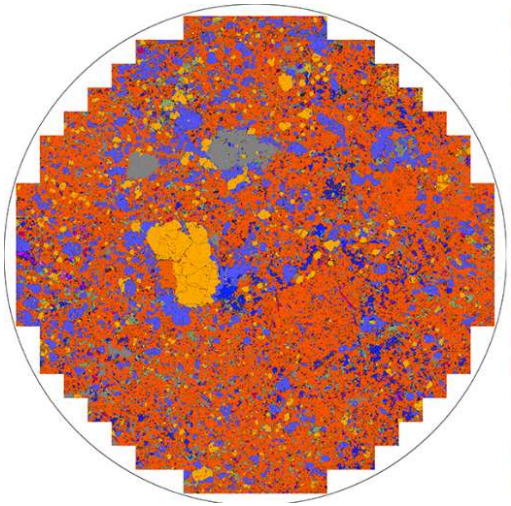
Breccia AMS

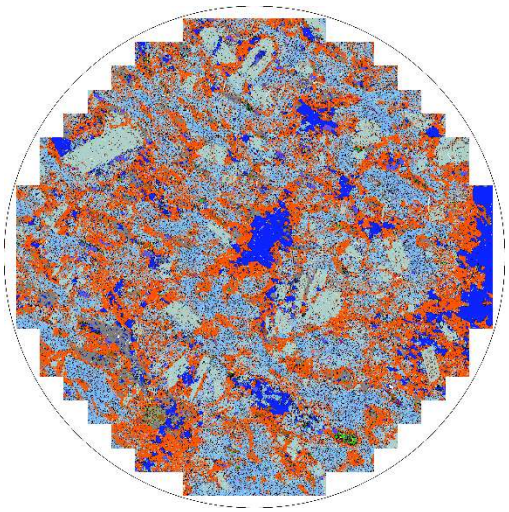


Foot Wall AMS

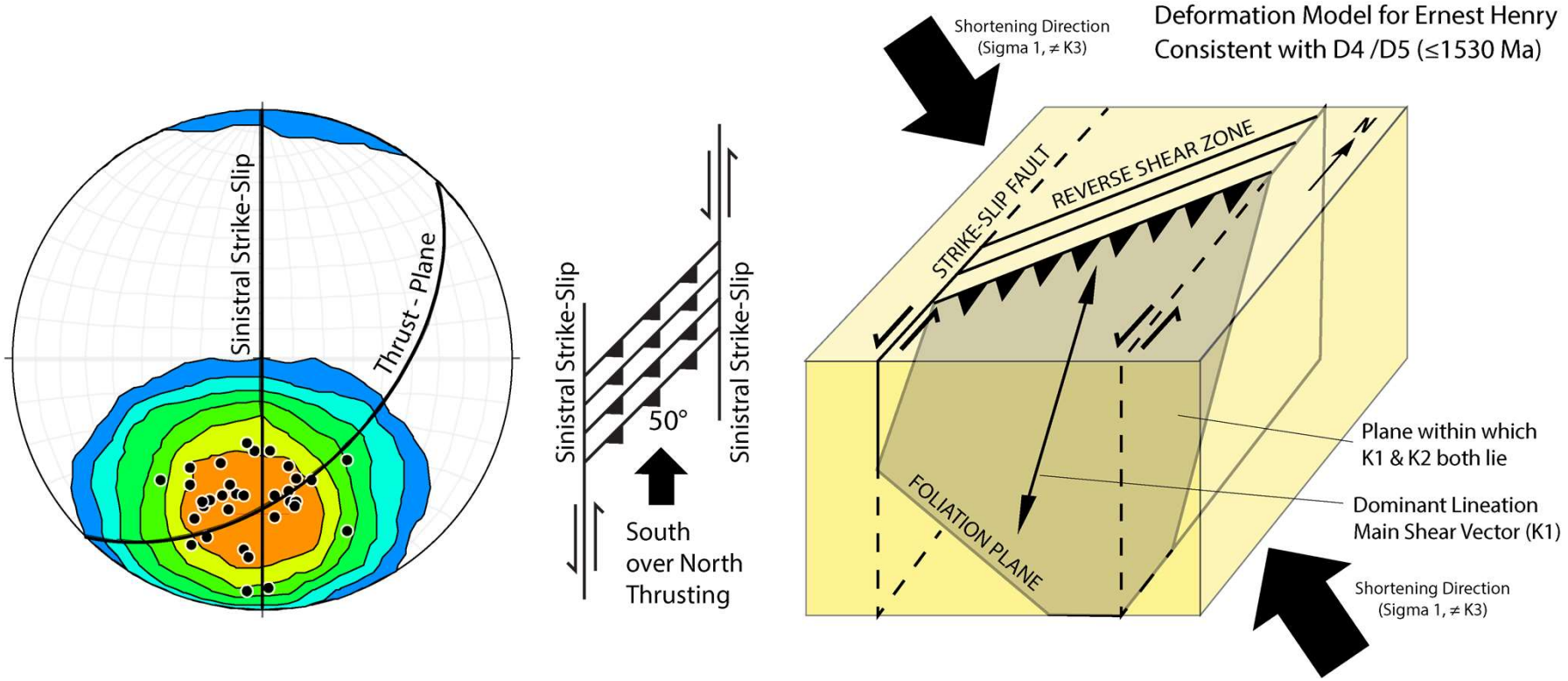








Thrust-Jog Model

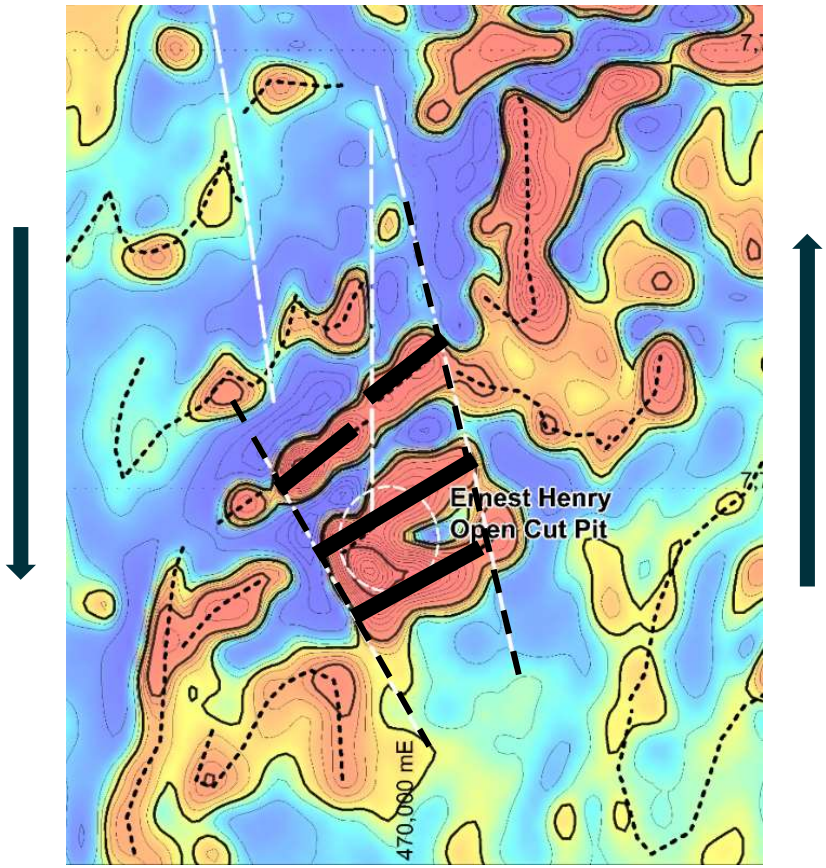


- This is really telling us about the pre-mineralisation rheology
- The magnetite post-dates the shearzone (metasomatic replacement)
- Shearzone localises magnetite, but not an active structural control on metal
- Structural controls were upright N-S features that formed in brittle conditions

Structural Controls

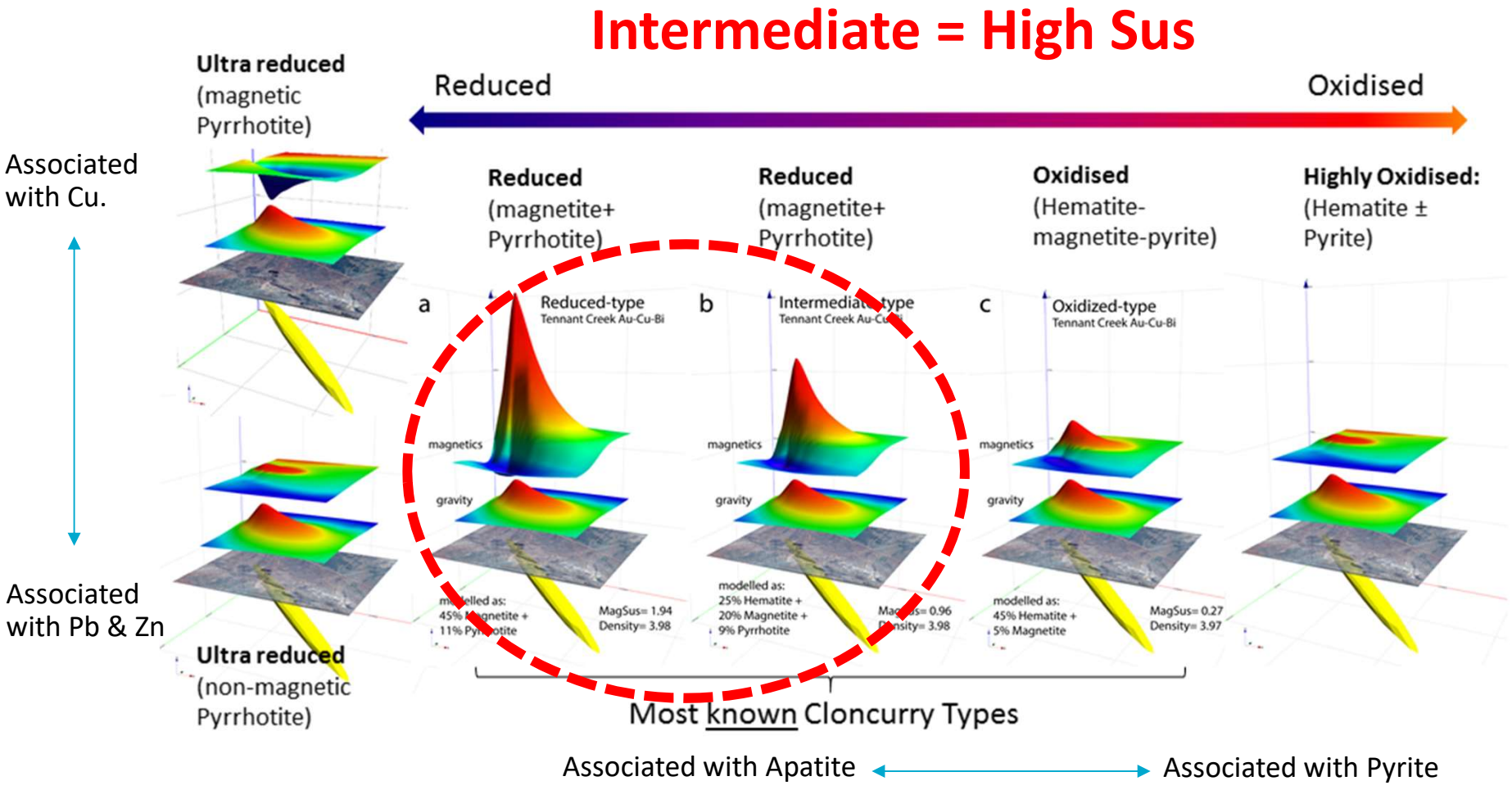
- Fluid Pathway(s)
  - from deep crust/mantle
  - Surface oxidized fluids
- Host
  - Structurally weak zone
  - Permeable Horizon
- Plumbing System
  - Pressure Valves
  - Facilitate precipitation

- Must consider rheological context
- Must consider permeability

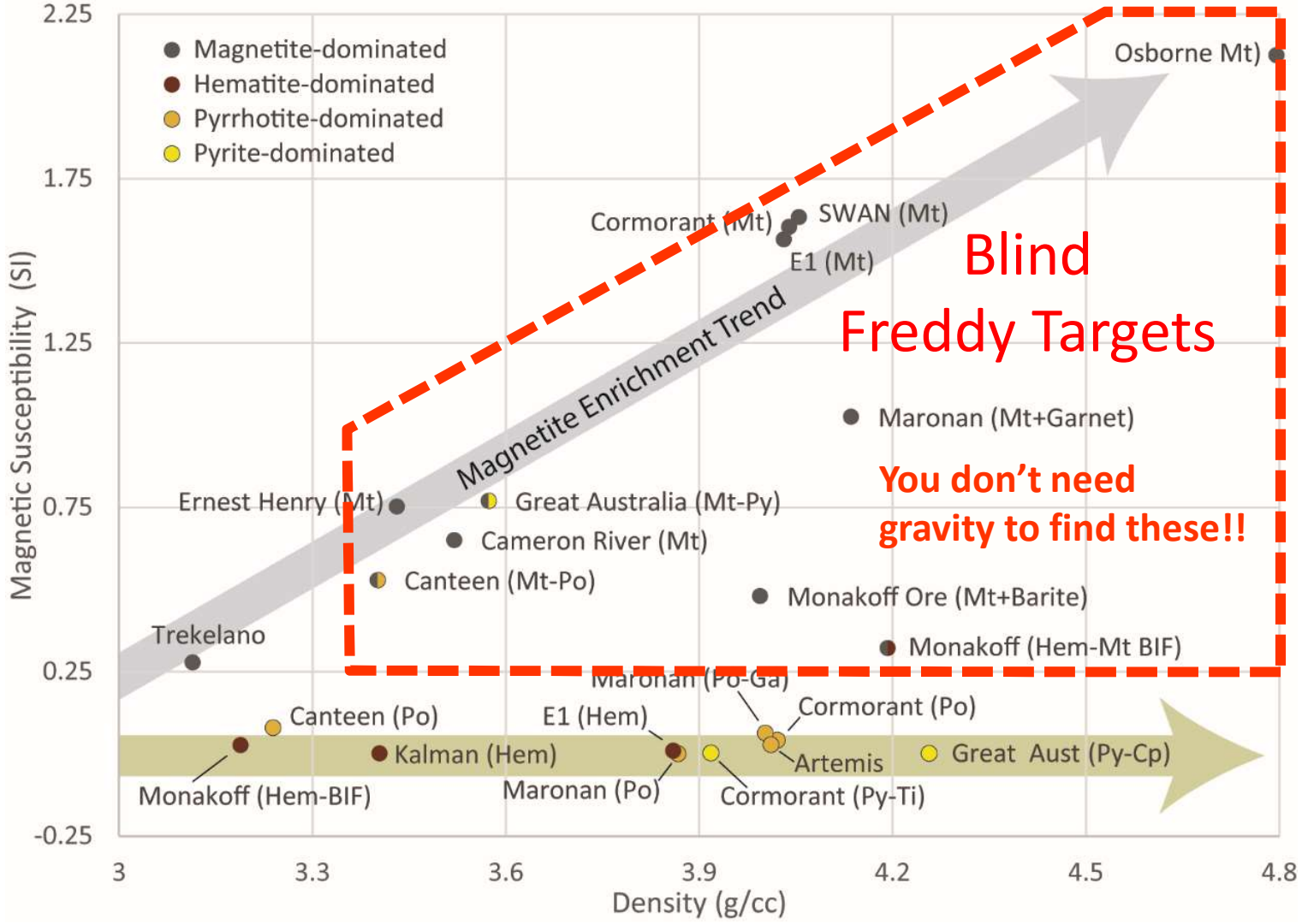


Mapping Redox Gradients… with Geophysics

Redox & Geophysics

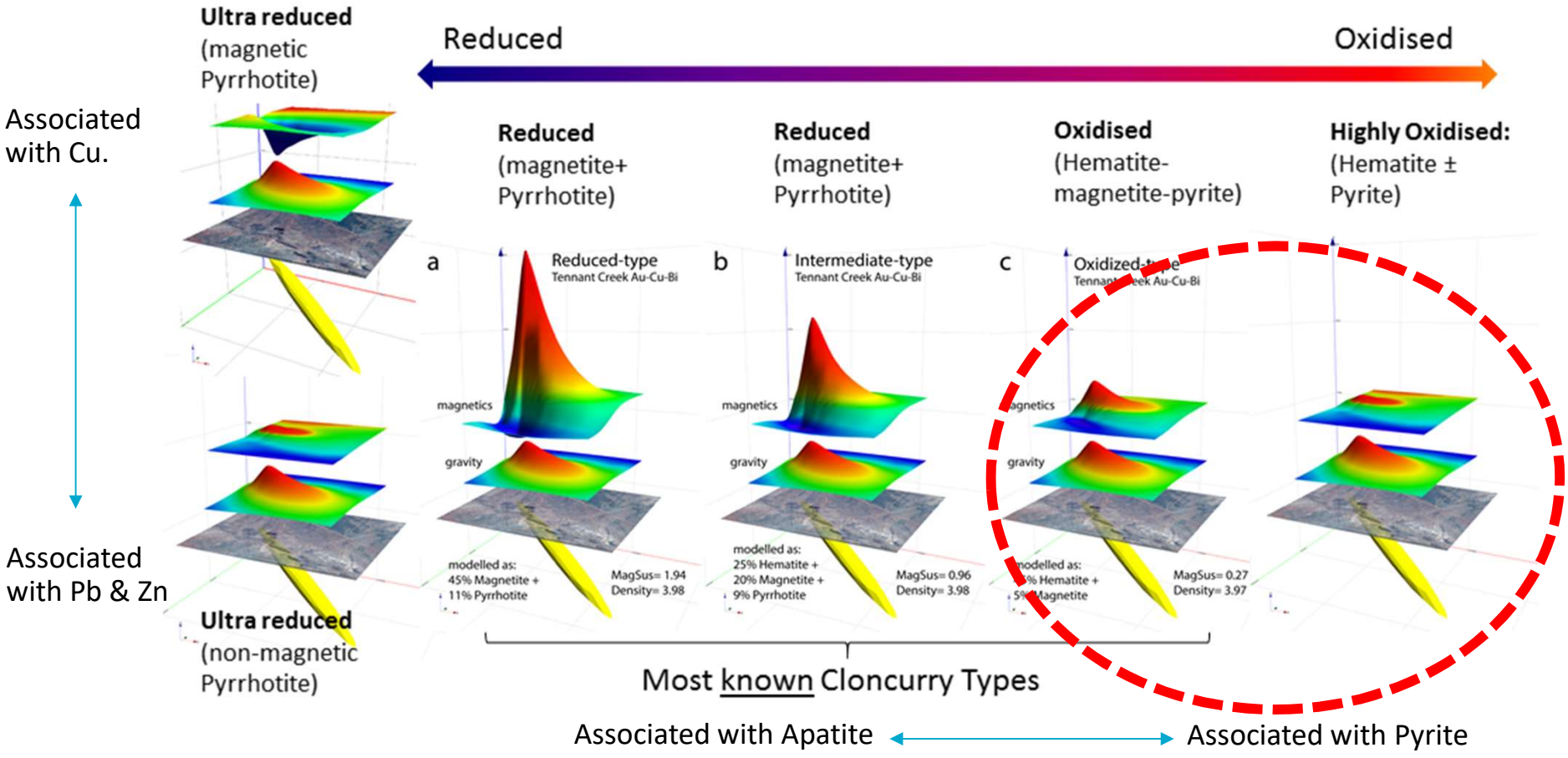


Geophysical Variability – Sus vs Density

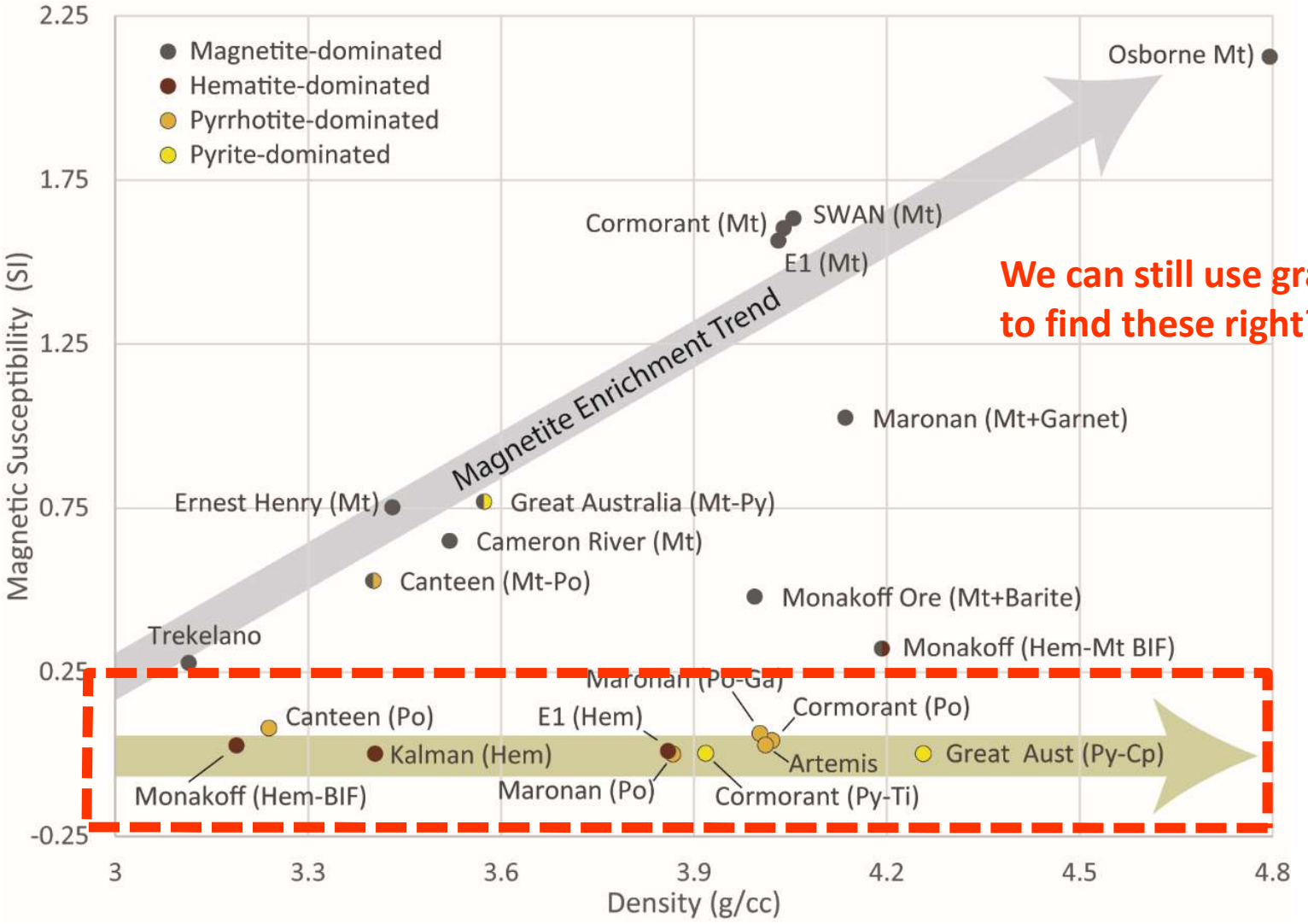


Redox

Low Susceptibility

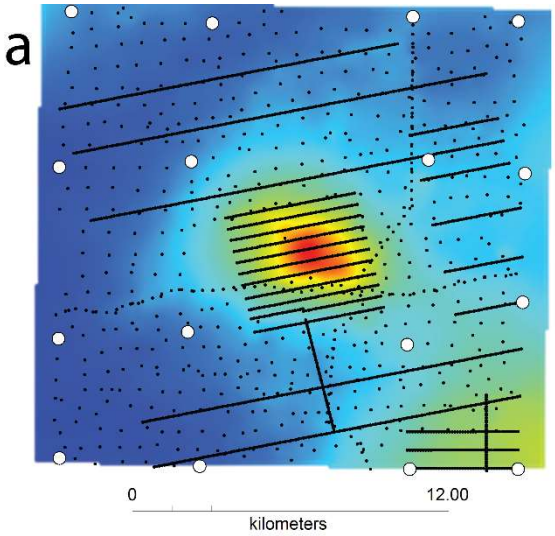


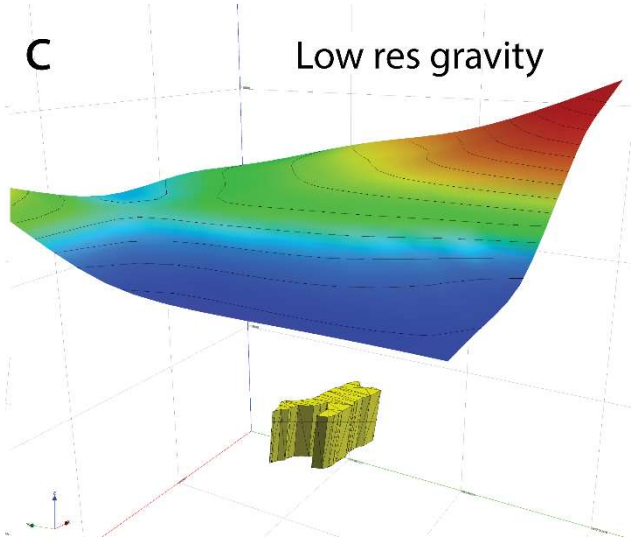
Blind Targets – (non-weakly magnetic)



We can still use gravity to find these right??

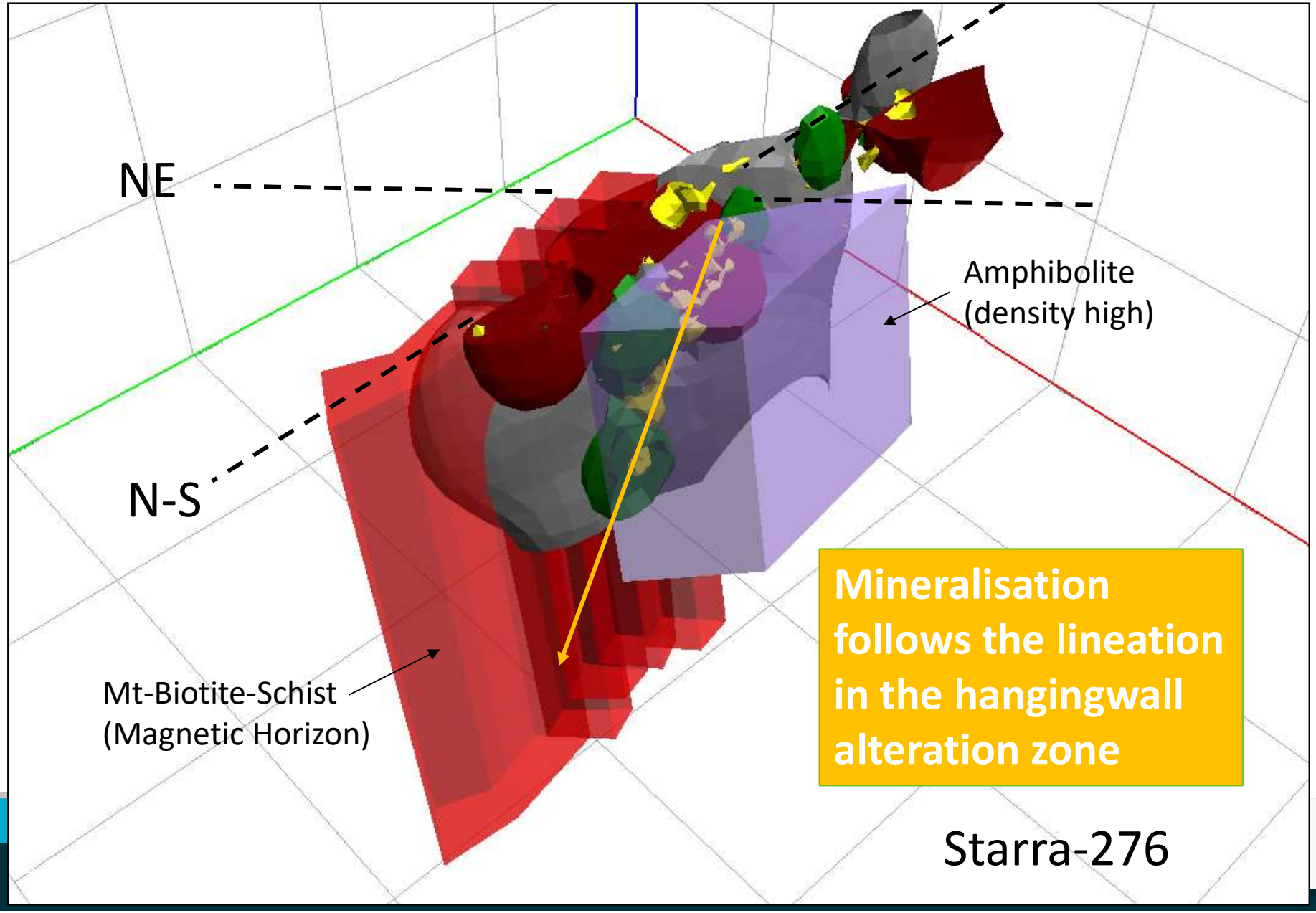
Influence of data resolution





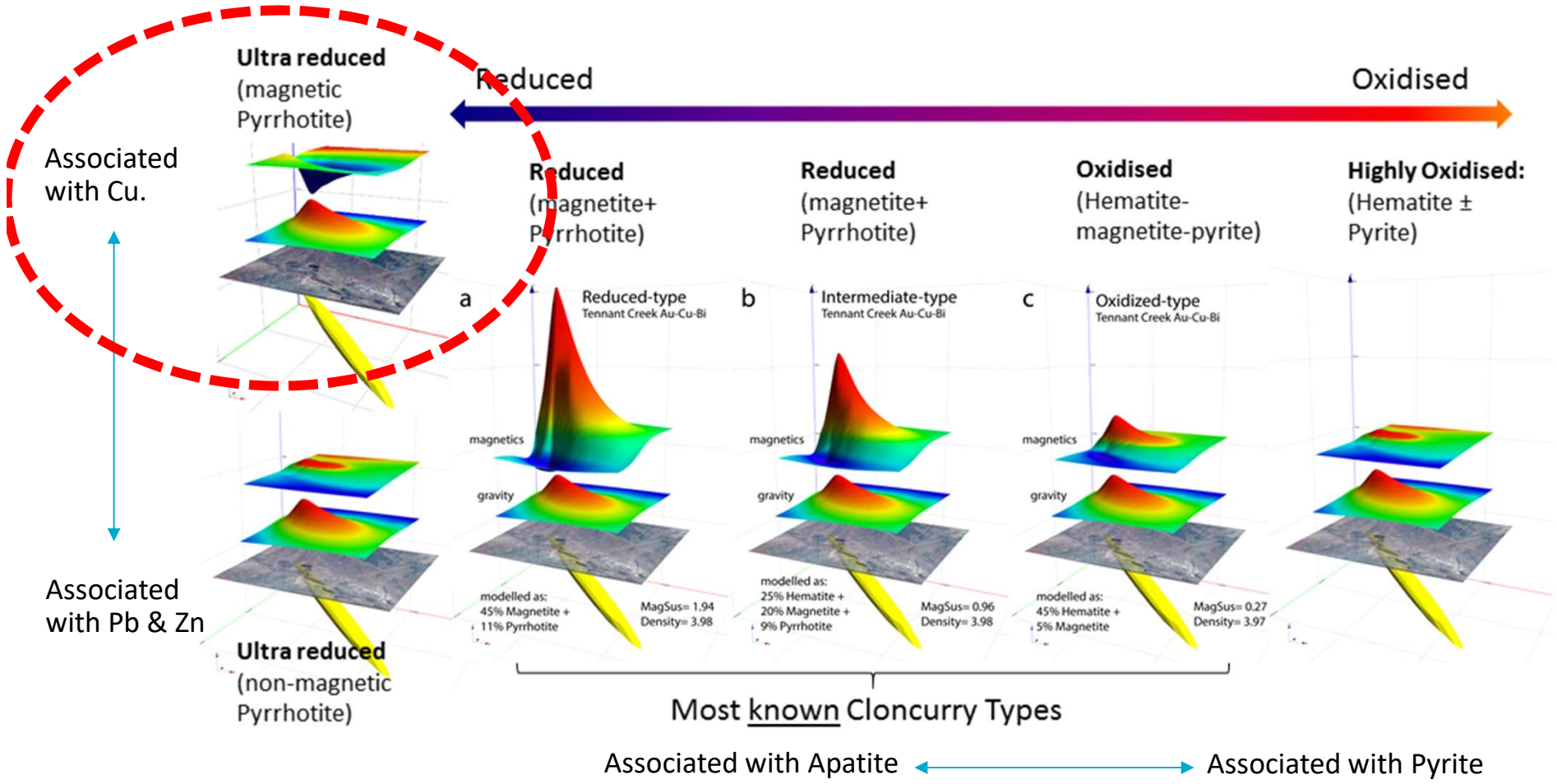
- How many deposits can we hide in 2km spaced gravity????

Structural–Geochemical–Geophysical Model



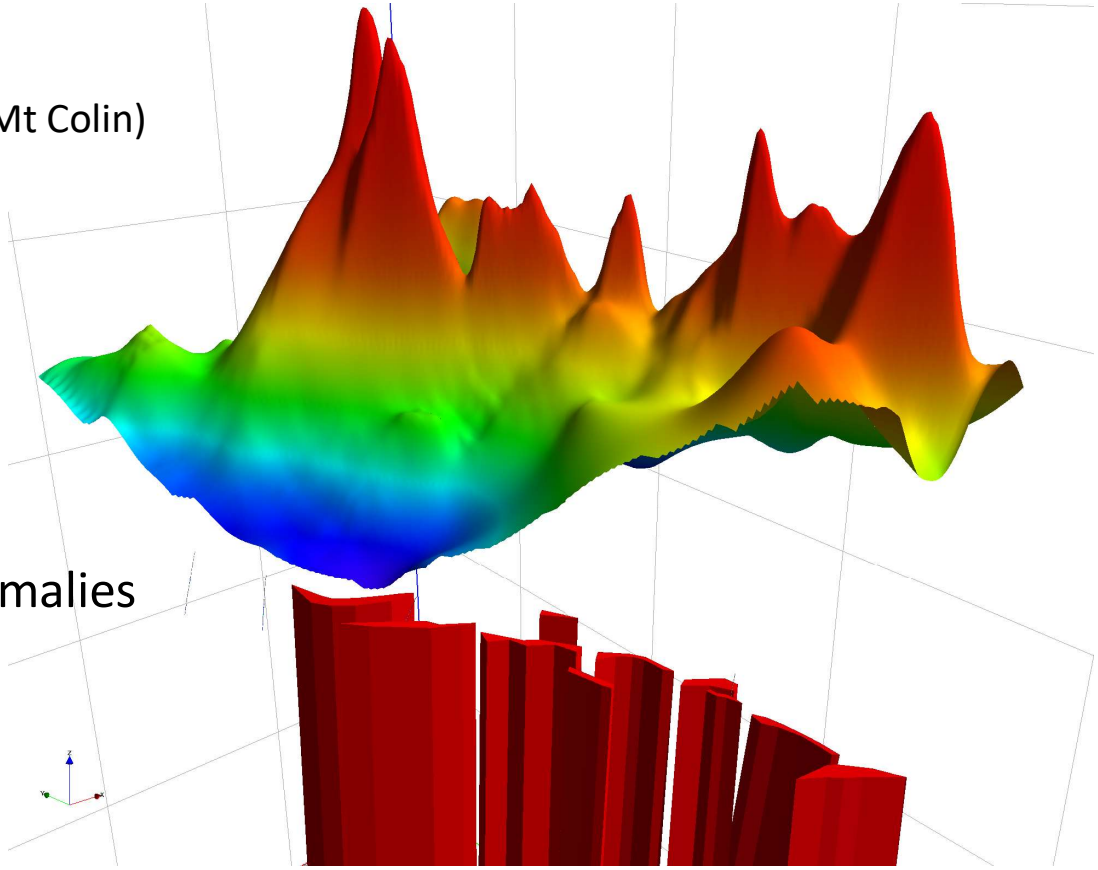
Redox

Reduced = High Remanence

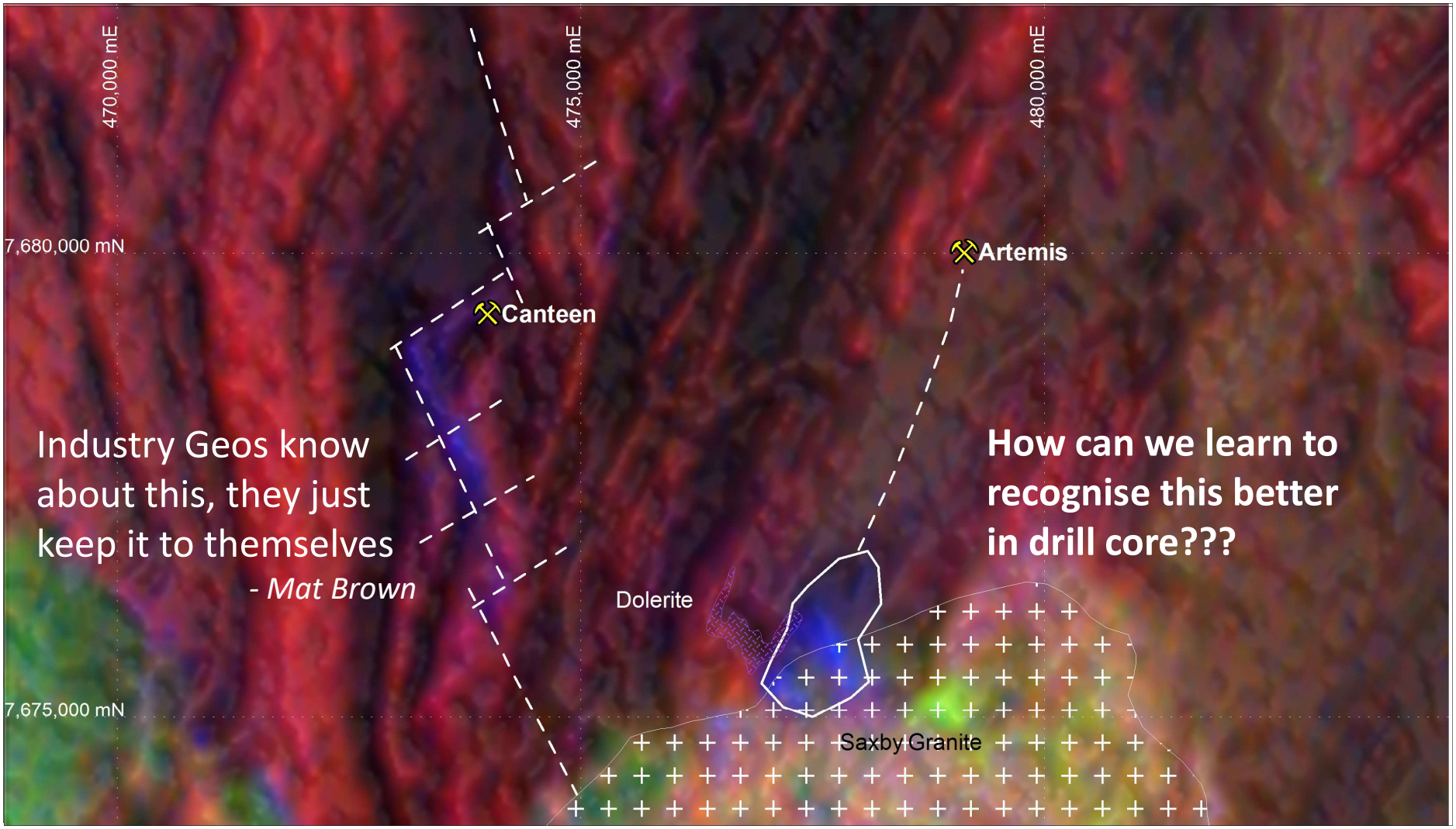


Issues using remanence to map Pyrrhotite

- Monoclinic pyrrhotite is associated with high Koenigsberger ratios.
  - (e.g., Canteen, Cormorant, Maronan, Mt Colin)
- remanence directions are
- sub-vertical upward in a similar orientation to the inducing Field.
- They look similar to induced anomalies

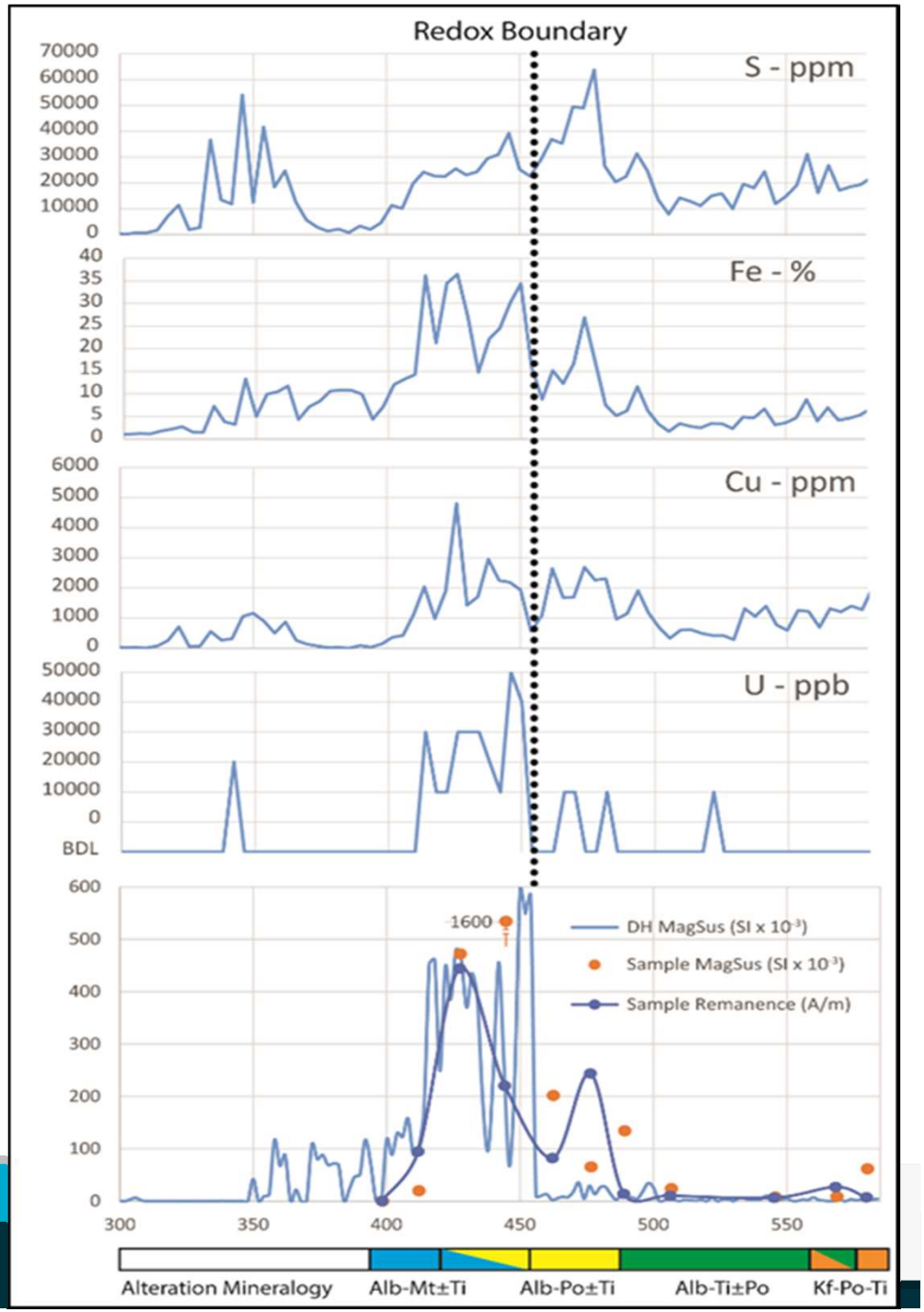


Ternary KTU radiometrics

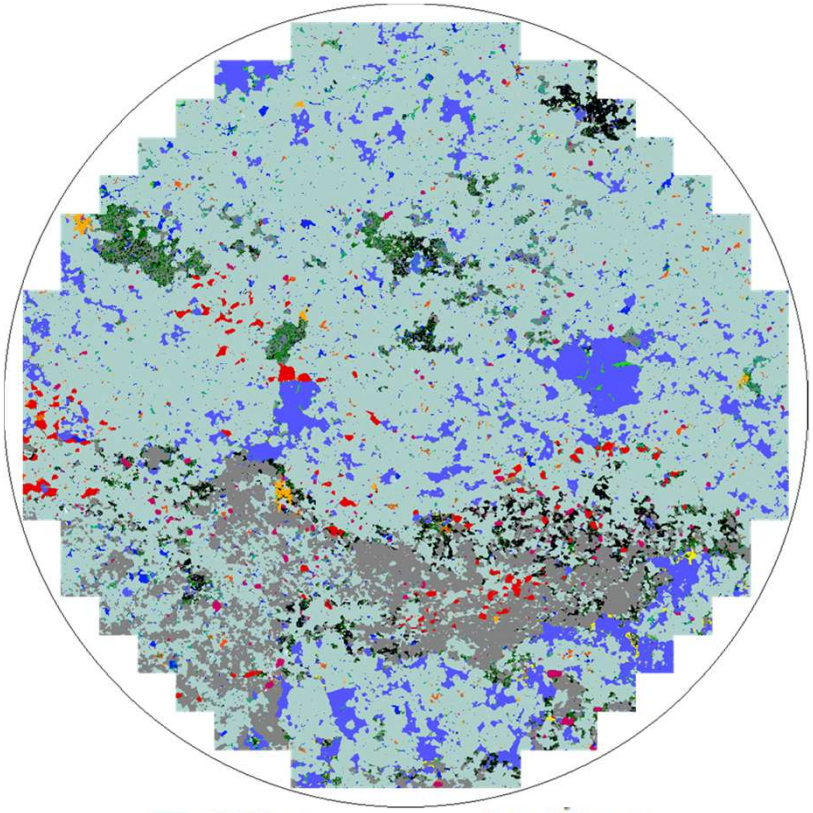


Redox Control on Cu

- Elevated Cu occurs either side of an apparent redox boundary
- transition from magnetite into magnetite-pyrrhotite
- U-rich alteration sits on more oxidized side

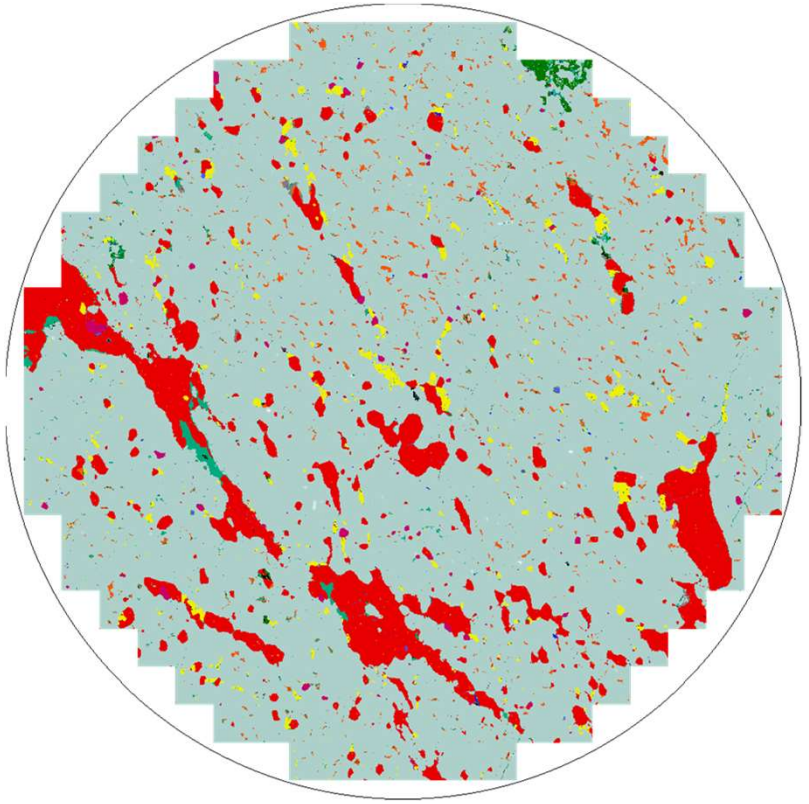


Uranium, assoc with Mt-dominant Sodic Alteration



Albite
Quartz
[Unclassified]
Hematite_Magnetite
Pyrrhotite
Calcite
Zussmanite
Apatite
Hornblende
Actinolite_Mg

REDOX BOUNDARY

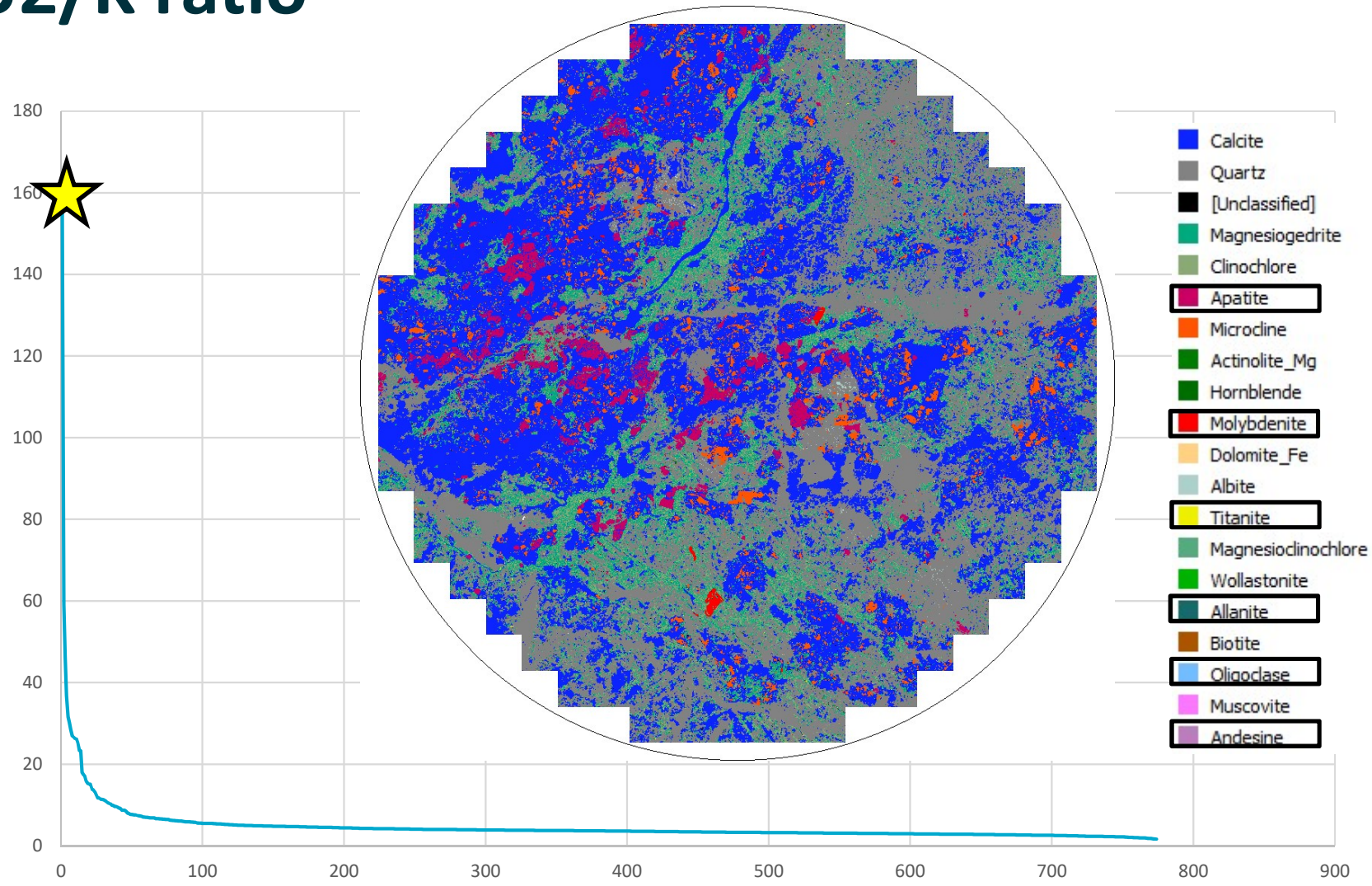


Albite
Pyrrhotite
[Unclassified]
Titanite
Microcline
Zussmanite
Apatite
Actinolite_Mg
Hornblende
Quartz

New Radiometrics Data

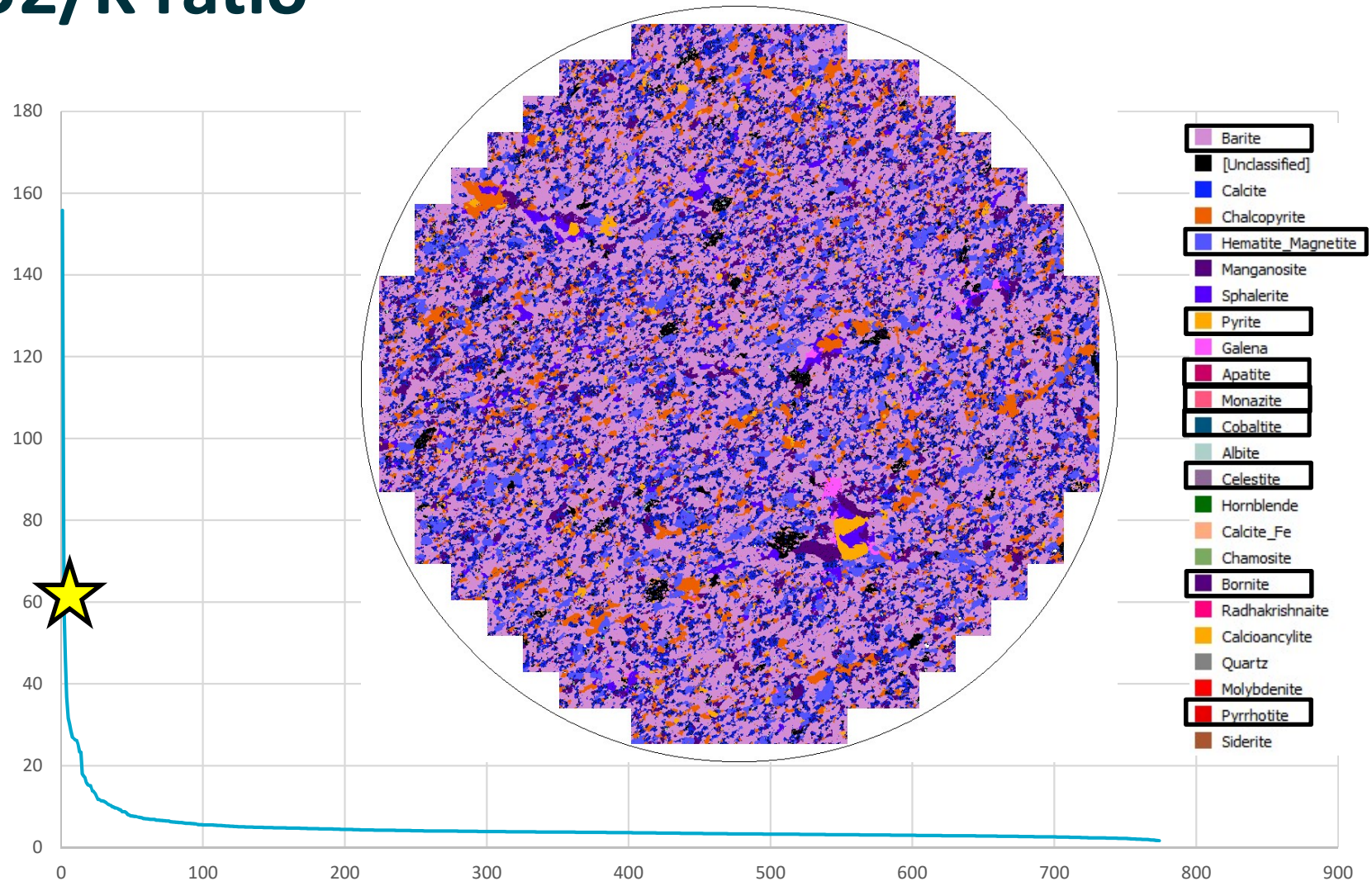
U2/K ratio

KAL009 - Kalman



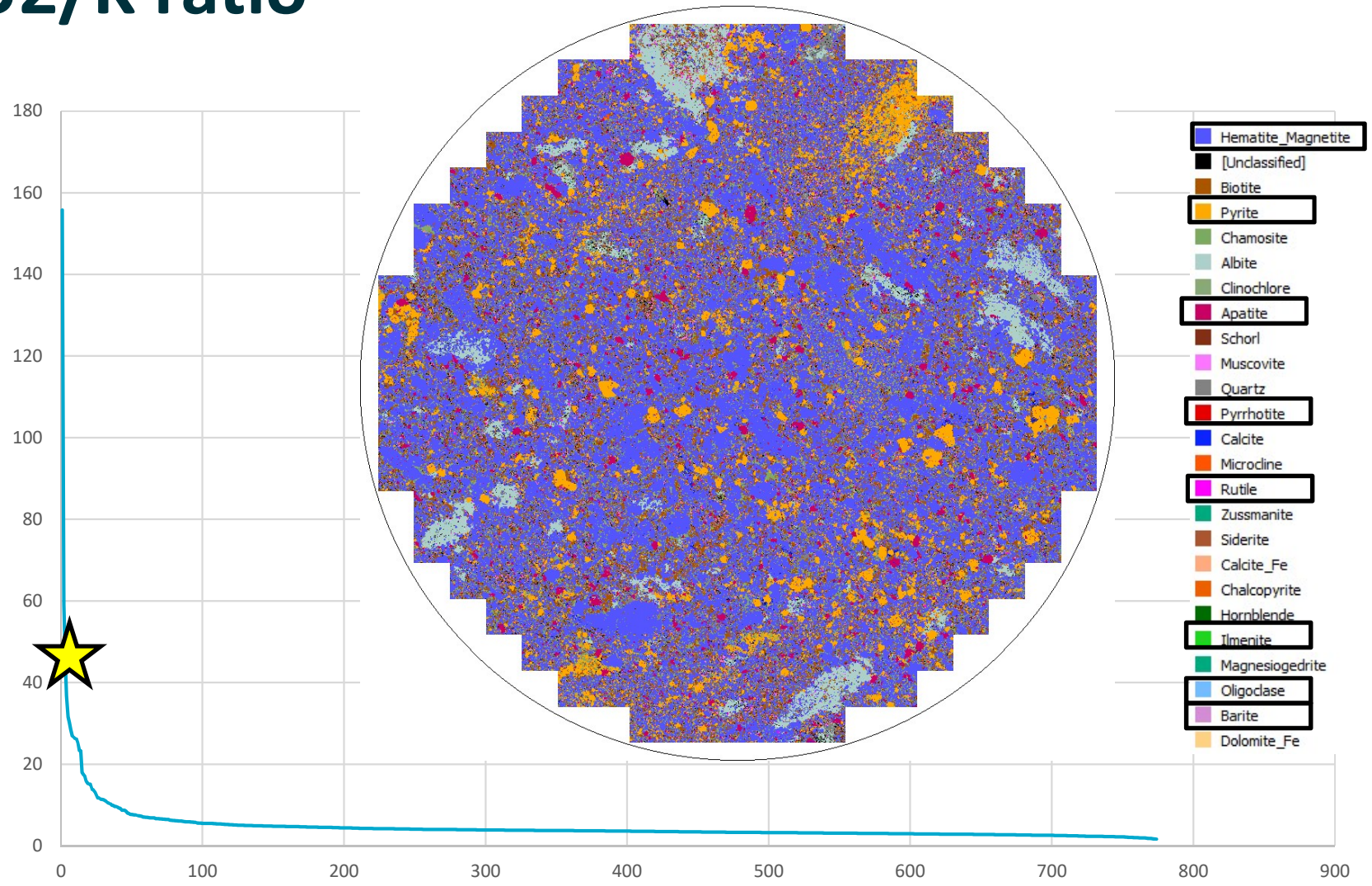
U2/K ratio

MK003 - Monakoff



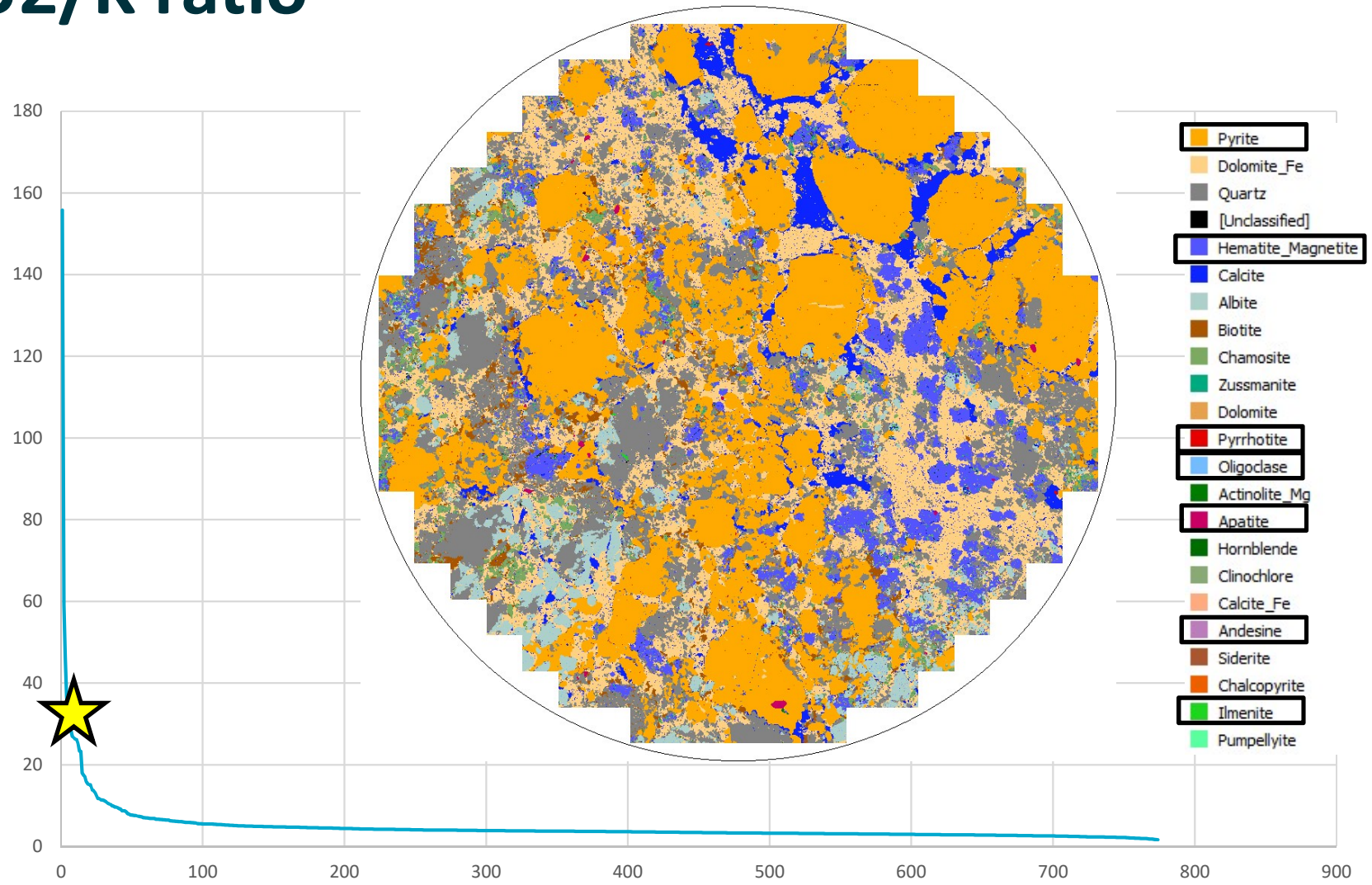
U2/K ratio

E1-039 – E1 North



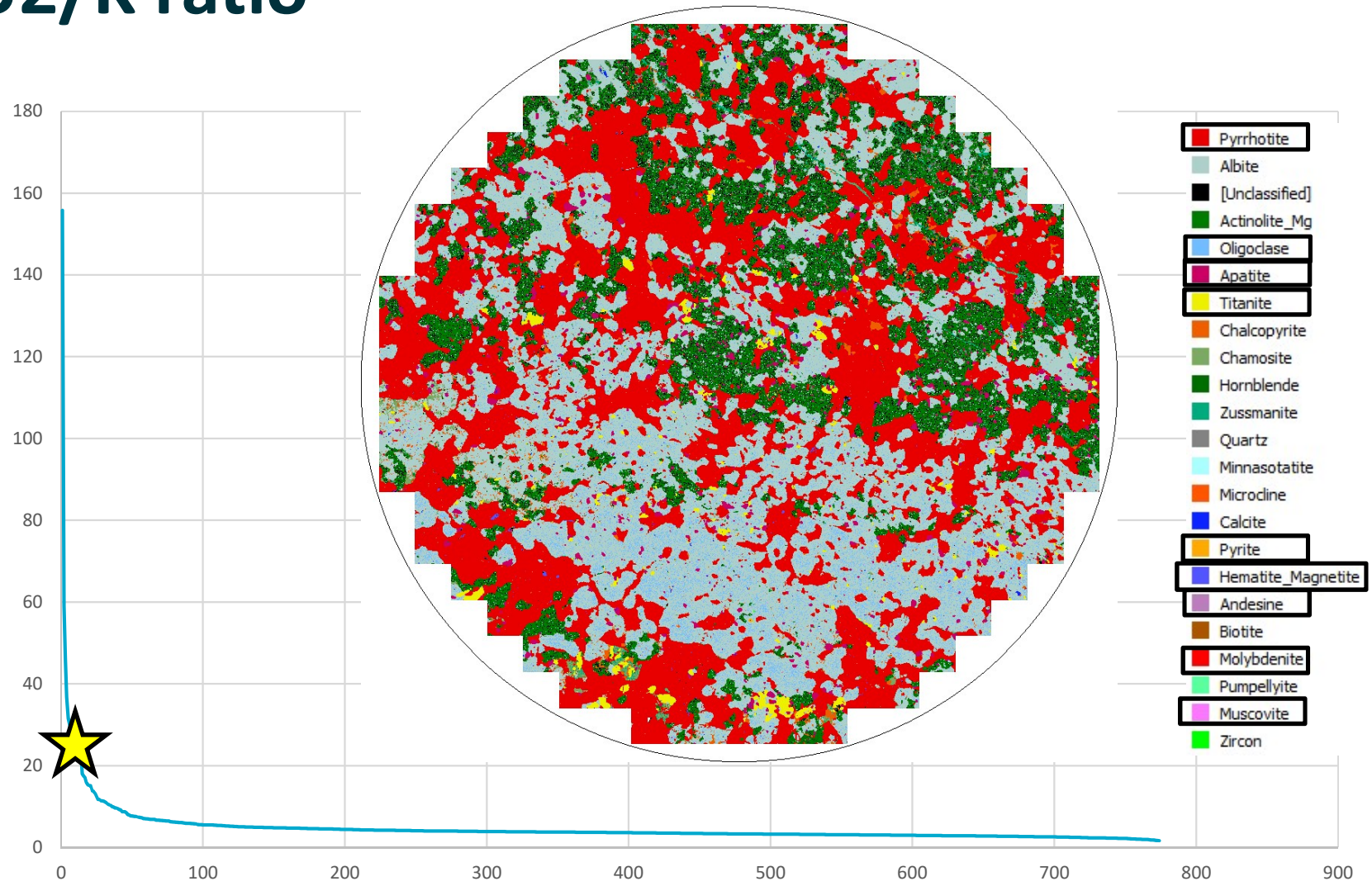
U2/K ratio

CAN043 – Canteen South



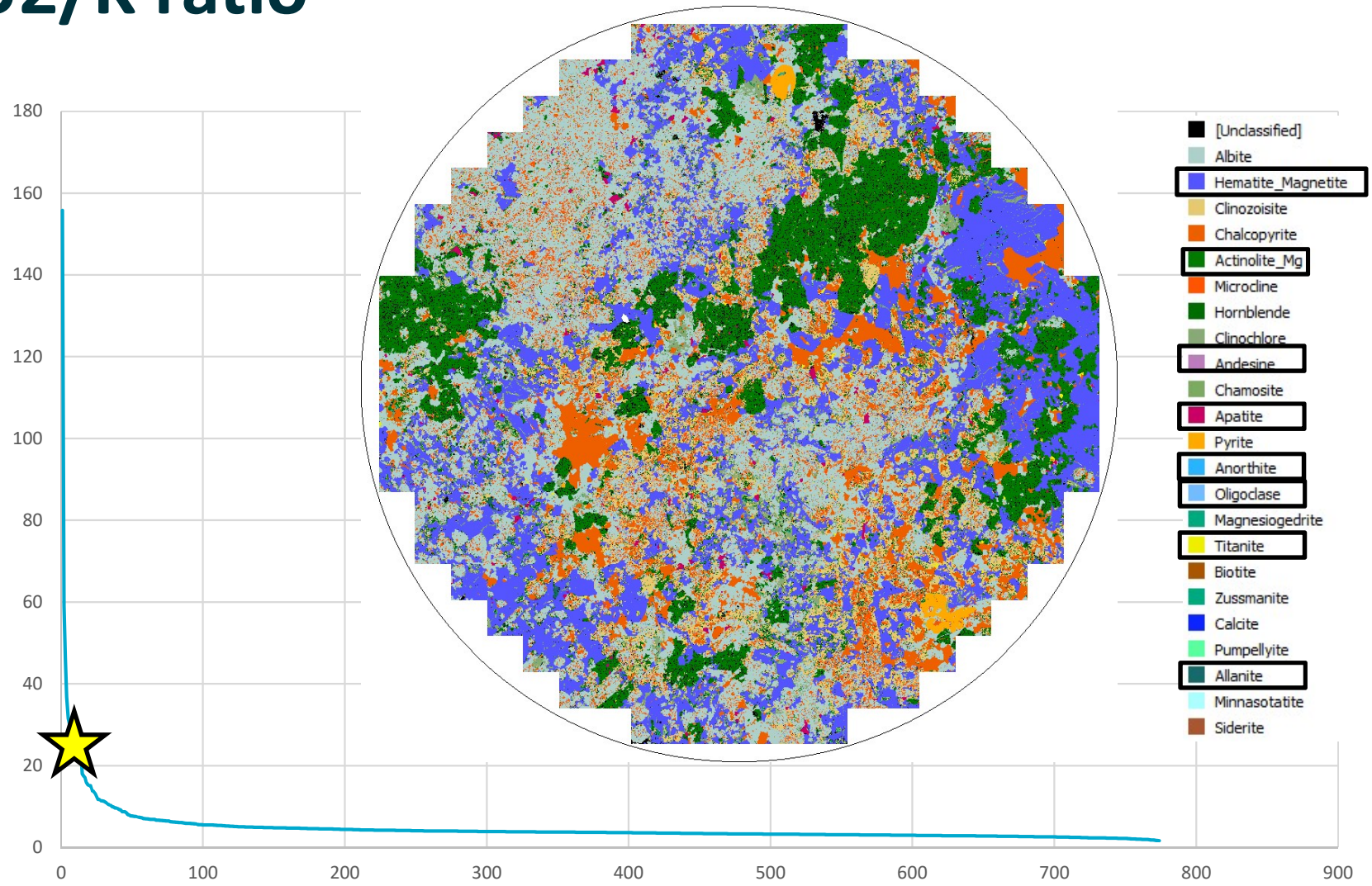
U2/K ratio

COR029 - Cormorant



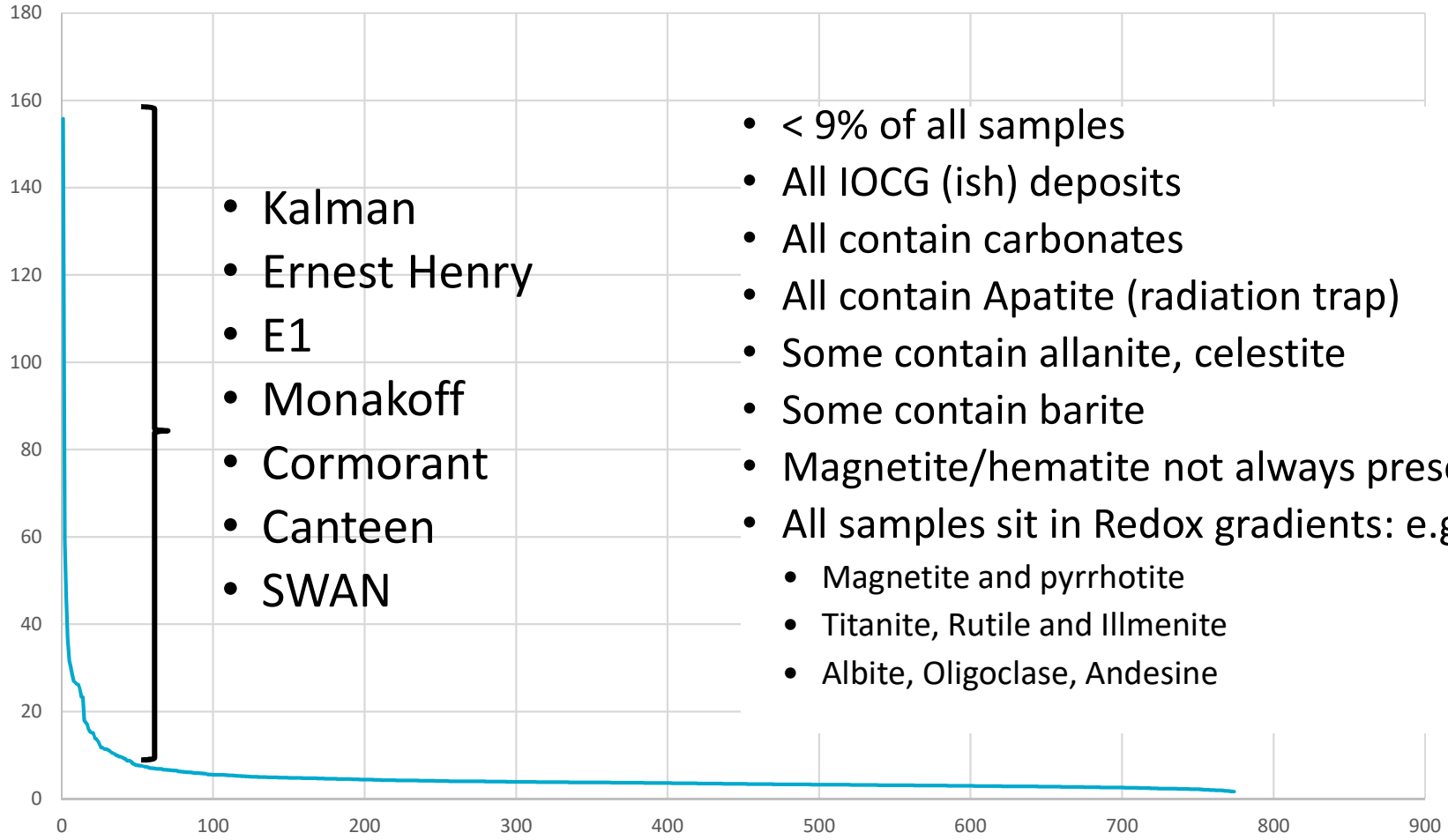
U2/K ratio

SWN013C - SWAN



U2/K ratio

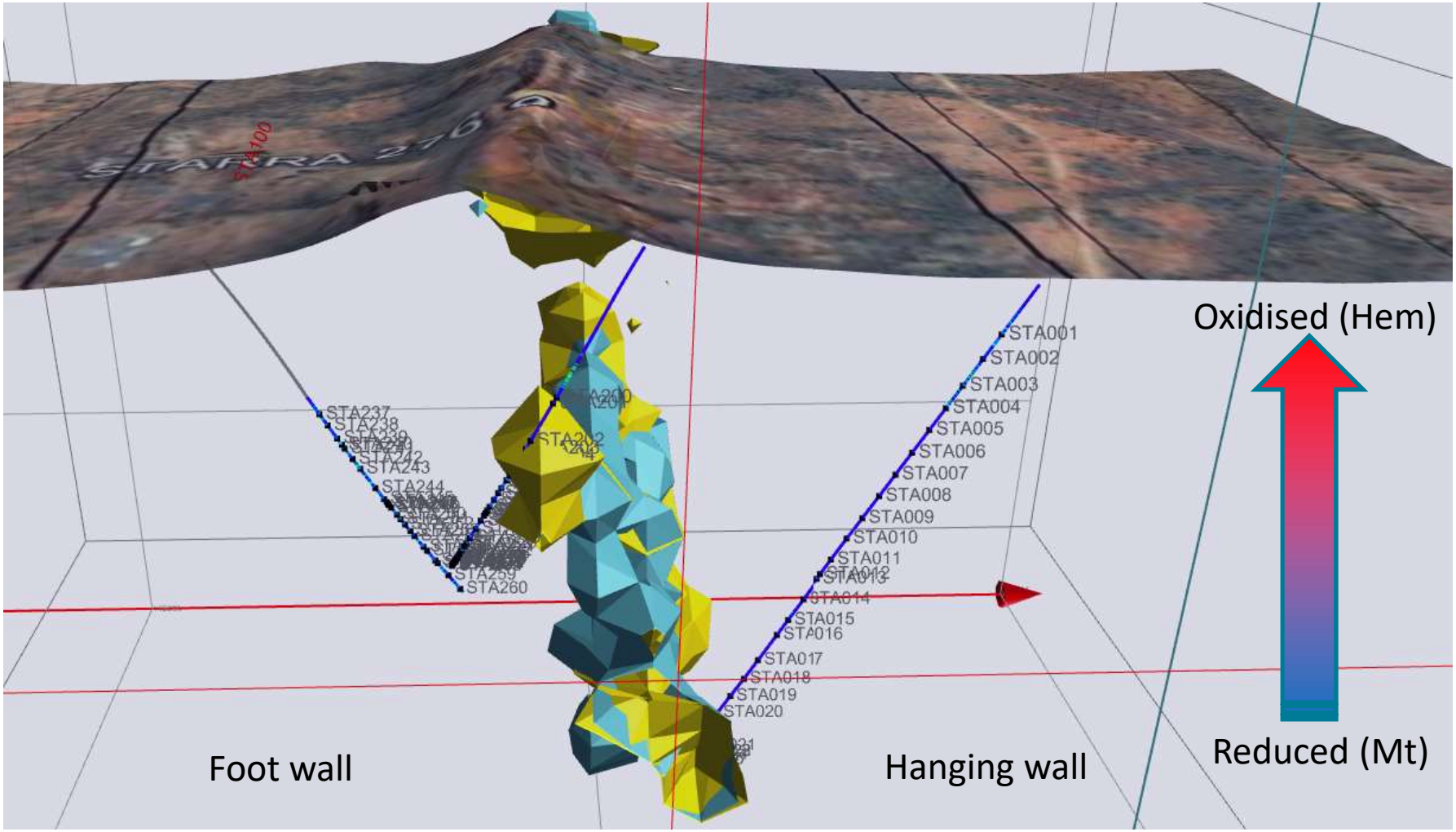
SWN013C - SWAN



- Kalman
- Ernest Henry
- E1
- Monakoff
- Cormorant
- Canteen
- SWAN

- < 9% of all samples
- All IOCG (ish) deposits
- All contain carbonates
- All contain Apatite (radiation trap)
- Some contain allanite, celestite
- Some contain barite
- Magnetite/hematite not always present
- All samples sit in Redox gradients: e.g.,
  - Magnetite and pyrrhotite
  - Titanite, Rutile and Illmenite
  - Albite, Oligoclase, Andesine

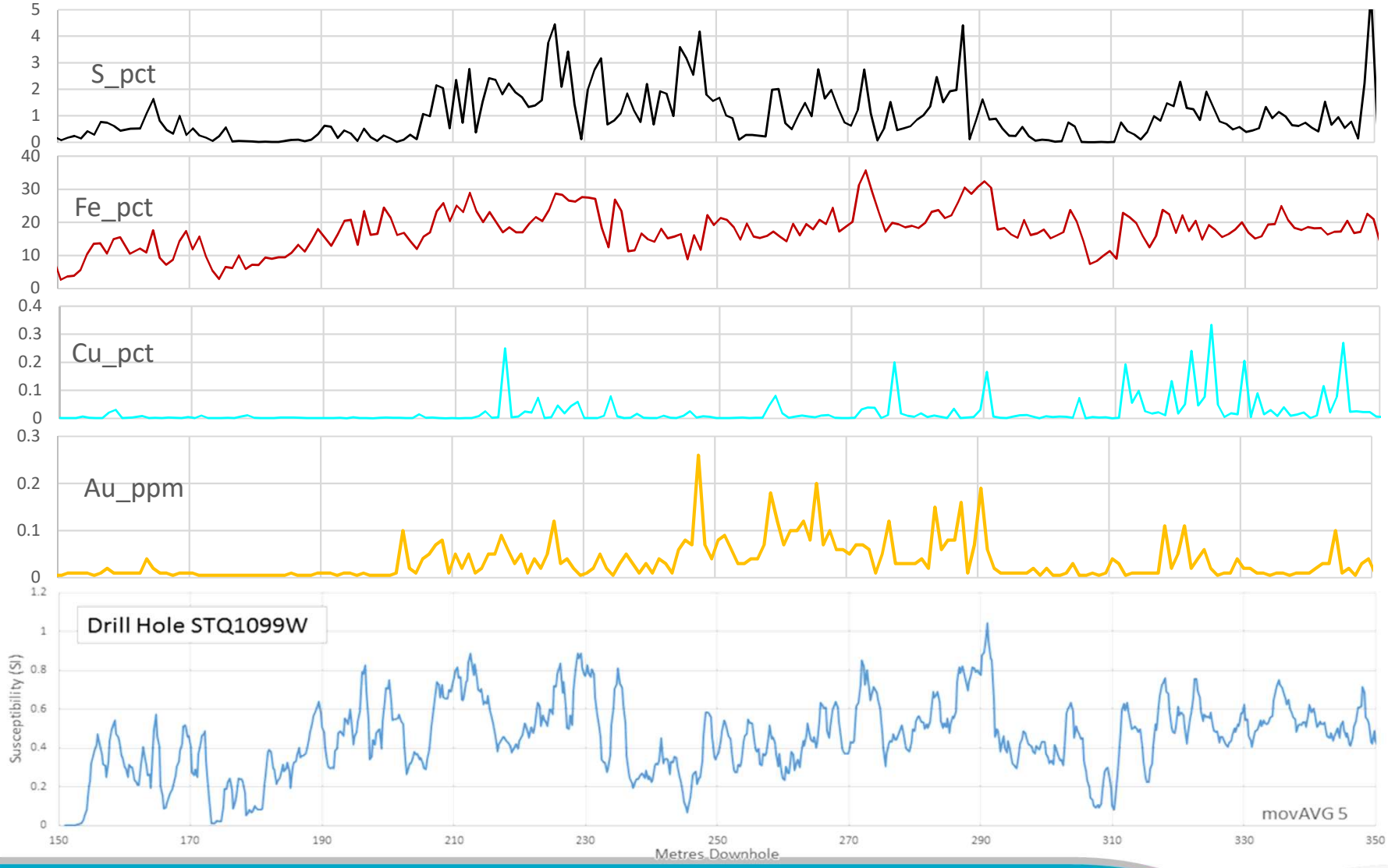
New Downhole Magnetic Data



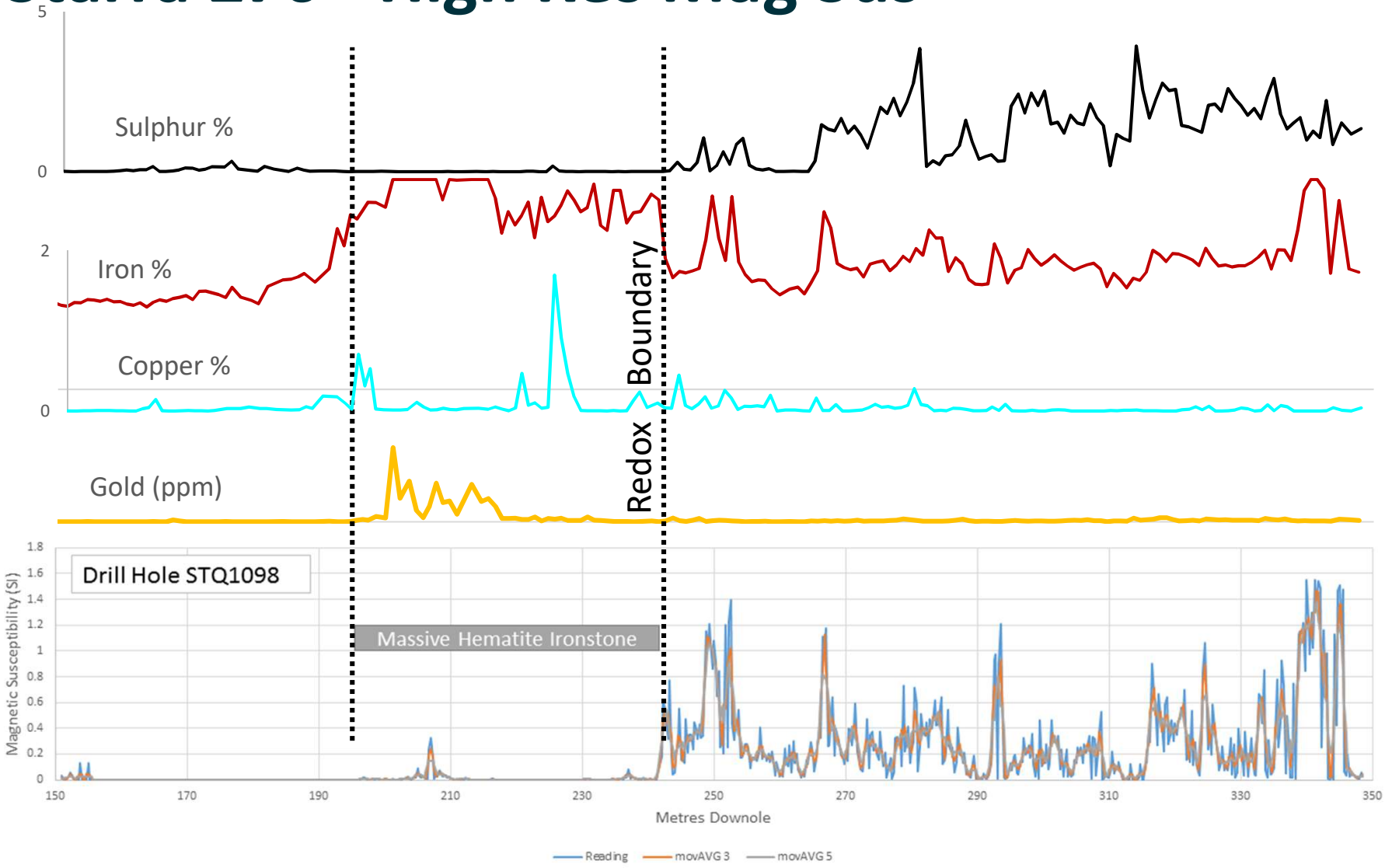
Background | Distal | Proximal | Ore | Proximal | Distal | Background

Reduced (Mt) → Oxidised ← Reduced (Mt)

Starra 276 - High Res Mag Sus

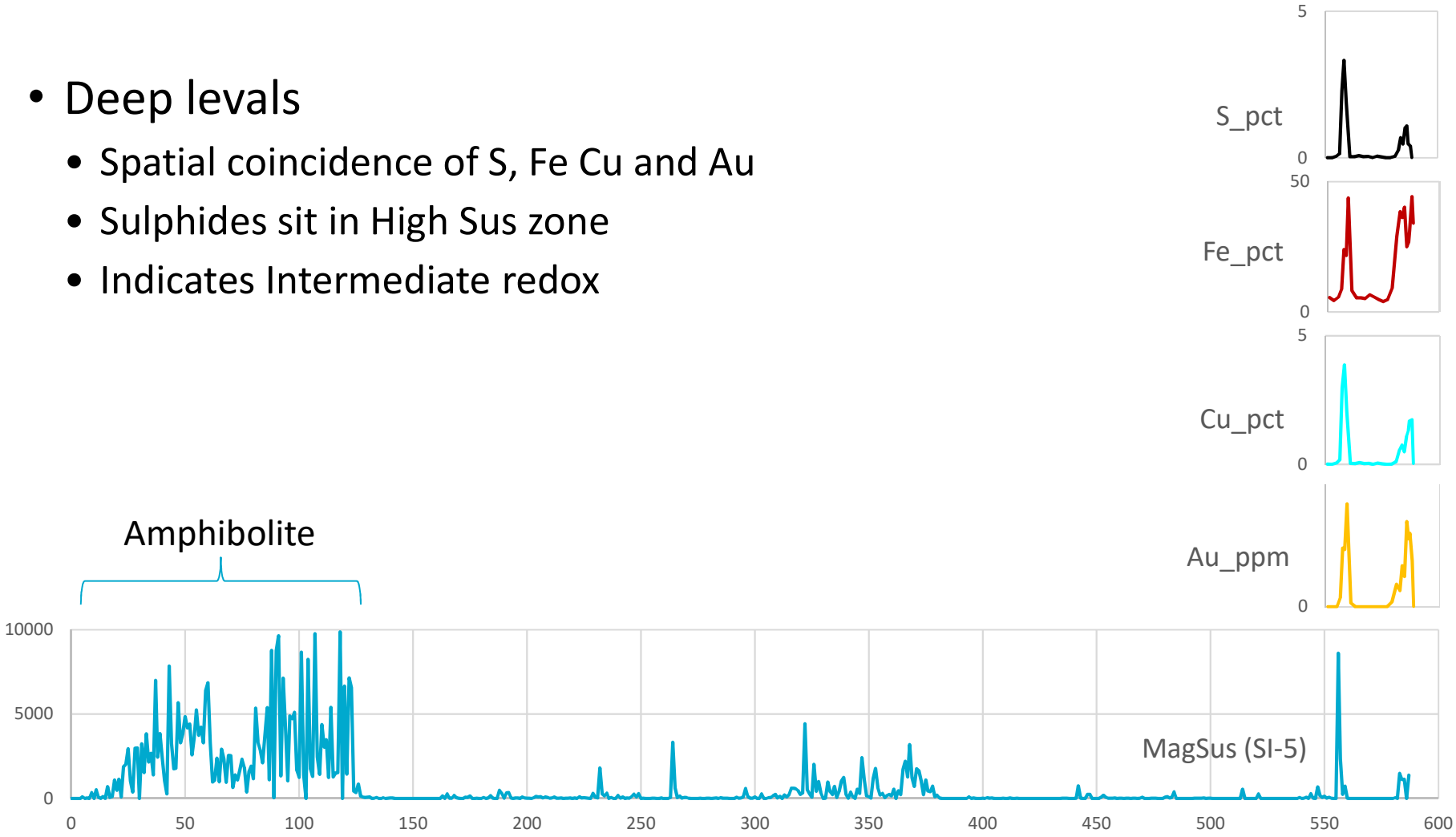


Starra 276 - High Res Mag Sus



STQ1095

- Deep levals
  - Spatial coincidence of S, Fe Cu and Au
  - Sulphides sit in High Sus zone
  - Indicates Intermediate redox



Summary

Petrophysics provides physical properties that can be placed in their structural, rheological, metasomatic and redox context.

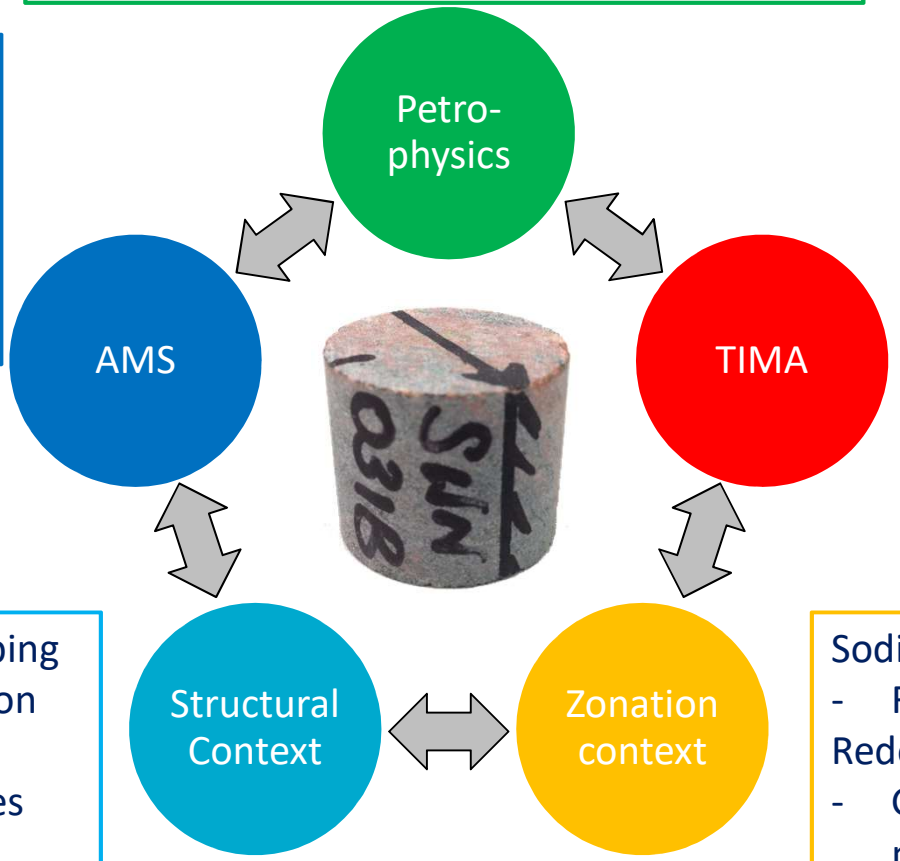
- Used to constrain geophysical models
- Used to ID distal signatures in core
- Used to ID gradients in basement chem

AMS Quantifies structure at the sample scale

- extrapolated using lineament mapping
- upscaled using geo-physical modelling

TIMA provides geological context

- Can relate Textures to magnetic fabric
- Can relate alteration to petrophysics



Pathway/trap/plumbing

- Relates to zonation

Ductile vs Brittle

- Rheology provides relative timing

Sodic/potassic/calcic/silicic

- Relates to structure

Redox gradient/zonation

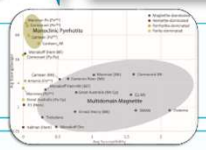
- Geophysical signature in magnetics, radiometrics…

INTEGRATED PETROPHYSICS

1500 point samples | ~80 samples per deposit | 25 x Deposits / Prospects | 1 x Mineral System

NRM

AGICO JR-6 Magnetometer



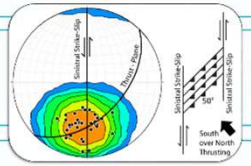
Q ratio can be used as a proxy Redox in Mt<->Po

NRM vector, intensity, stability & Q Ratio

AMS

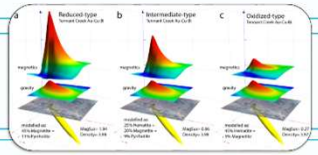
AGICO MFK-1 Magnetometer

Proxy for fabric: used to quantify fabrics and structural controls



3 Eigenvectors & ratios that describe ellipsoid

MagSus



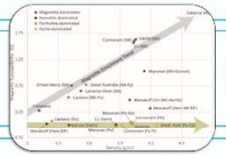
Magnetic Mineralogy

Susceptibility & Q Ratio

Density

Metler-Toledo MS201TS Balance

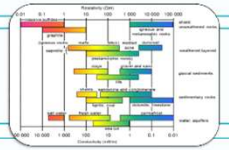
Density-MagSus ratio used as a proxy Redox in Mt<->Hem



Density, Mt: Hem #

EM

KT-20 Conductivity-Susceptibility Meter



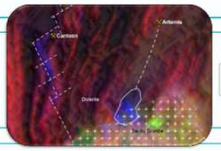
Used with Q ratio to discriminate pyrrhotite from other sulphides

Conductivity / resistivity (± chargeability)

Radio-metrics

RS330 Gamma-Ray Spectrometer

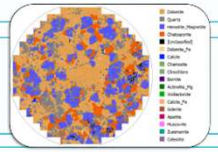
IOCG Alteration ????



K, Th, U, Total Count, Ternary & various ratios

Min

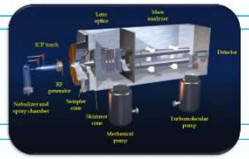
Tescan Integrated Mineral Analyser (TIMA)



IOCG/ not IOCG ?%#!

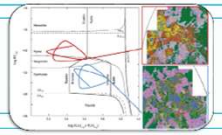
≤ 85 different minerals + rock textures

Geo-chem



Laser Ablation ICP-MS

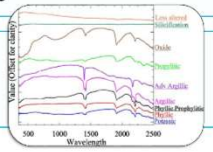
Can we predict mineralogy from Geochemistry??



≤ 75 different elements

Hyper-spectal

Hylogger Mark III



Used to discriminate mineral species

≤ 80 different minerals, 10 alteration proxies

FOR FURTHER INFORMATION

Jim Austin - Team Leader Multiphysics
e james.austin@csiro.au
P 02 9490 8876 m: 0459 886 302
a 11 Julius Ave, North Ryde, 2113, NSW
w https://confluence.csiro.au/display/cmfr/Home

CSIRO

Queensland Government
Department of Natural Resources and Mines

"In theory there is no difference between theory and practice.

In practice there is."

Yogi Berra