Mineral chemistry – expanding the footprint of NWQ mineral systems

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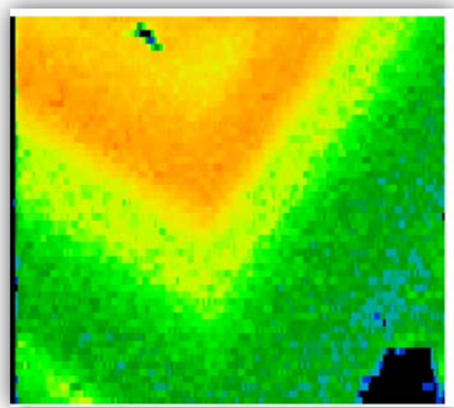
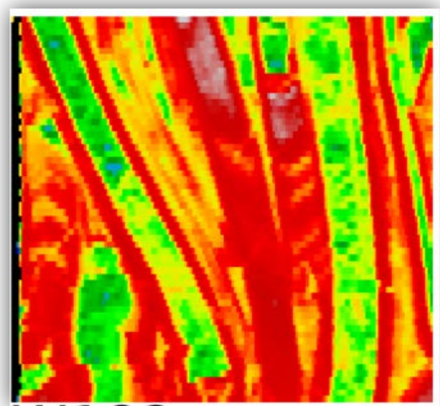
University of Tasmania





#Acknowledgements

- Geological Survey of Queensland through the Strategic Resources Exploration Program for funding
- CSIRO for providing access to archived samples
- CODES Analytical Laboratories Staff
- Wei Hong

Northwest Queensland mineral geochemistry vectoring project

- Sponsored by the Geological Survey of Queensland through the **Strategic Resources Exploration Program** **(SREP)**
  - Dept. of Natural Resources, Mines, and Energy (DNRME) given **$27M over 4 years** to revitalize the North West Minerals Province (i.e., Mount Isa)
- **Our aims:**
  1. **Deposit 'fingerprinting'** – trace element characterization of hydrothermal alteration minerals proximal to known ore deposits
     - CSIRO sample set – 145 polished mounts from 21 deposits/prospects in the Cloncurry belt
  2. **Deposit 'footprints'** – delineating mineral chemistry alteration footprints for IOCG and sediment-hosted Pb-Zn-Ag deposits
  3. **Age dating of non-traditional datable minerals (i.e., calcite, epidote, etc.)**

Strategic Resources Exploration Program

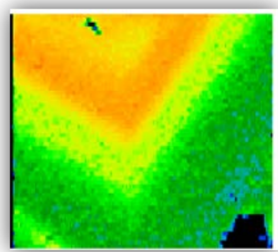
We are investing $27.125 million through the 4-year Strategic Resources Exploration Program to boost exploration and support for resource development projects.

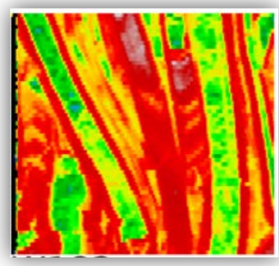
The program funding is helping to expand resource exploration and development for gas and minerals in North West Queensland.

Initiatives funded under the program include:

- $3.6 million to drive exploration for gas in the Georgina, South Nicholson and Isa Super Basins.
- $4.275 million for mineral geophysics to pinpoint the locations of potential new mineral prospects over wide areas.
- $1.45 million for mineral geochemistry programs to identify the type of potential mineral deposits (e.g. copper, lead, zinc) identified from geophysical programs using surface samples.
- $4.95 million for mineral synthesis to develop a comprehensive and integrated understanding of the geology of the North West Minerals Province
- $925,000 to support national research into advanced techniques used in the discovery of mineral deposits in frontier regions.
- $7.125 million for the Geoscience Data Modernisation Program, to modernise legacy systems and enable data driven exploration and resource development opportunities for Queensland

Today's talk





- Why mineral chemistry?
- Overview of previous mineral chemistry studies by CODES
- NWQ mineral chemistry studies
  - Lady Loretta overview of pyrite chemistry
  - IOCG – initial results from magnetite and pyrite
- What next?

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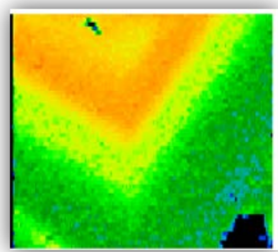
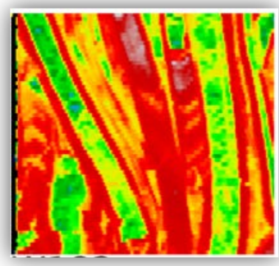
Mineral geochemistry vectoring





- Many gangue minerals in hydrothermal alteration assemblages are sensitive to changes in fluid chemistry and temperature
  - Sulfides (e.g., pyrite and pyrrhotite)
  - Silicates (chlorite, epidote, quartz)
  - Oxides (hematite, magnetite)
  - Carbonates (dolomite, calcite)
  - Phosphates (apatite)
- These characteristics enable us to provide “fingerprints” and “footprints” of deposits, and aid mineral exploration by measuring the chemistry of individual mineral species

Why laser ablation?

- Mineral trace element geochemistry is not a new discipline (e.g., Loftus-Hills and Solomon, 1967)
- Early methods: Electron microprobe and solution ICPMS
    - Problems – high detection limits (microprobe) and no spatial context (solution ICPMS)
- Later developments: proton microprobe; SIMS and TIMS
    - Pros: low detection limits; spatial context preserved
    - Cons: Very expensive
- **Laser ablation combined with ICPMS dealt effectively with the ‘cons’ while enhancing the ‘pros’**
    - **Particularly imaging**

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Hem-py vein cutting mt-kfs-py-ap breccia, DDH EH550 (942.3m)

CODES – world leaders in mineral chemistry

- Through a series of AMIRA projects over 15 years, CODES has demonstrated the utility of mineral chemistry in porphyry-epithermal exploration
- Particular focus on the "green rock" environment – vectoring within propylytic alteration
- IOCG and sediment-hosted deposits have large alteration footprints
- How can we use mineral chemistry to vector within these?

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Hem-py vein cutting mt-kfs-py-ap breccia, DDH EH550 (942.3m)

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Epidote chemistry

$Ca_2(Al,Fe^{3+})_3Si_3O_{12}(OH)$

Epidote 'supergroup' minerals

Name	Formula
Epidote group	
Epidote	$Ca_2Al_2Fe^{3+}[Si_2O_7][SiO_4]O(OH)$
Epidote-(Sr)	$CaSrAl_2Fe^{3+}[Si_2O_7][SiO_4]O(OH)$
Epidote-(Pb)	$CaPbAl_2Fe^{3+}[Si_2O_7][SiO_4]O(OH)$
Clinozoisite	$Ca_2Al_3[Si_2O_7][SiO_4]O(OH)$
Clinozoisite-(Sr)	$CaSrAl_3[Si_2O_7][SiO_4]O(OH)$
Mukhinite	$Ca_2Al_2V^{3+}[Si_2O_7][SiO_4]O(OH)$
Piemontite	$Ca_2Al_2Mn^{3+}[Si_2O_7][SiO_4]O(OH)$
Piemontite-(Sr)	$CaSrAl_2Mn^{3+}[Si_2O_7][SiO_4]O(OH)$
Piemontite-(Pb)	$CaPbAl_2Mn^{3+}[Si_2O_7][SiO_4]O(OH)$
Manganipiemontite-(Sr)	$CaSrMn^{3+}AlMn^{3+}[Si_2O_7][SiO_4]O(OH)$
Allanite group	
Allanite-(Ce), -(La), -(Y), -(Nd)	$Ca(REE)^{3+}Al_2Fe^{2+}[Si_2O_7][SiO_4]O(OH)$
Vanadoallanite-(La)	$CaLa^{3+}V^{3+}AlFe^{2+}[Si_2O_7][SiO_4]O(OH)$
Dissakisite-(Ce), -(La)	$Ca(REE)^{3+}Al_2Mg[Si_2O_7][SiO_4]O(OH)$
Ferriallanite-(Ce), -(La)	$Ca(REE)^{3+}Fe^{3+}AlFe^{2+}[Si_2O_7][SiO_4]O(OH)$
Manganiandrosite-(La), -(Ce)	$Mn^{2+}(REE)Mn^{3+}AlMn^{2+}[Si_2O_7][SiO_4]O(OH)$
Vanadoandrosite-(Ce)	$Mn^{2+}Ce^{3+}V^{3+}AlMn^{2+}[Si_2O_7][SiO_4]O(OH)$
Dollaseite group	
Dollaseite-(Ce)	$CaCe^{3+}MgAlMg[Si_2O_7][SiO_4]F(OH)$

Table reproduced from Cooke et al. (2014)

Typically detected by electron microprobe

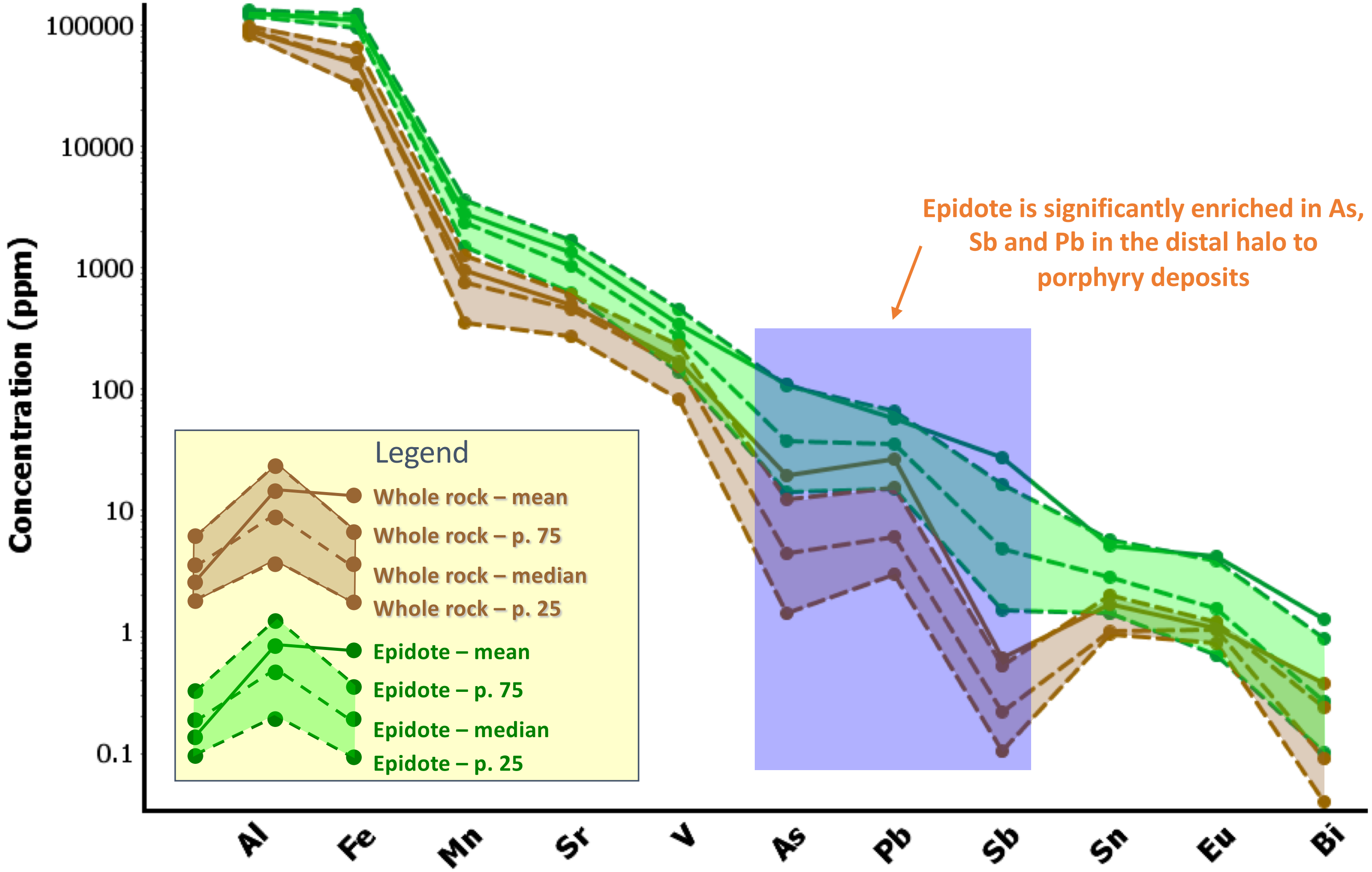
- Concentrations > 1 wt %
  - *Ca, Fe, Al, Si, O, H*
- Typically between 1,000 ppm and 1 wt %
  - *Mn, Sr*
- 100 to 1,000 ppm
  - *Ti, Mg, V*

Only detected by LA-ICPMS, except in rare cases

- 10 to 100 ppm
  - *Pb, As, Zn, Na, K, Y, Ga, Ce, Cr*
- < 10 ppm
  - *Cu, Mo, Sn, Bi, Au, Co, Sb, Ba, Th, U, Zr, La, Pr, Nd, Sm, Eu, Dy, Er, Yb, Lu, Hf*

Piemontite, Picuris District, New Mexico, USA; source: http://www.mindat.org/photo-281671.html

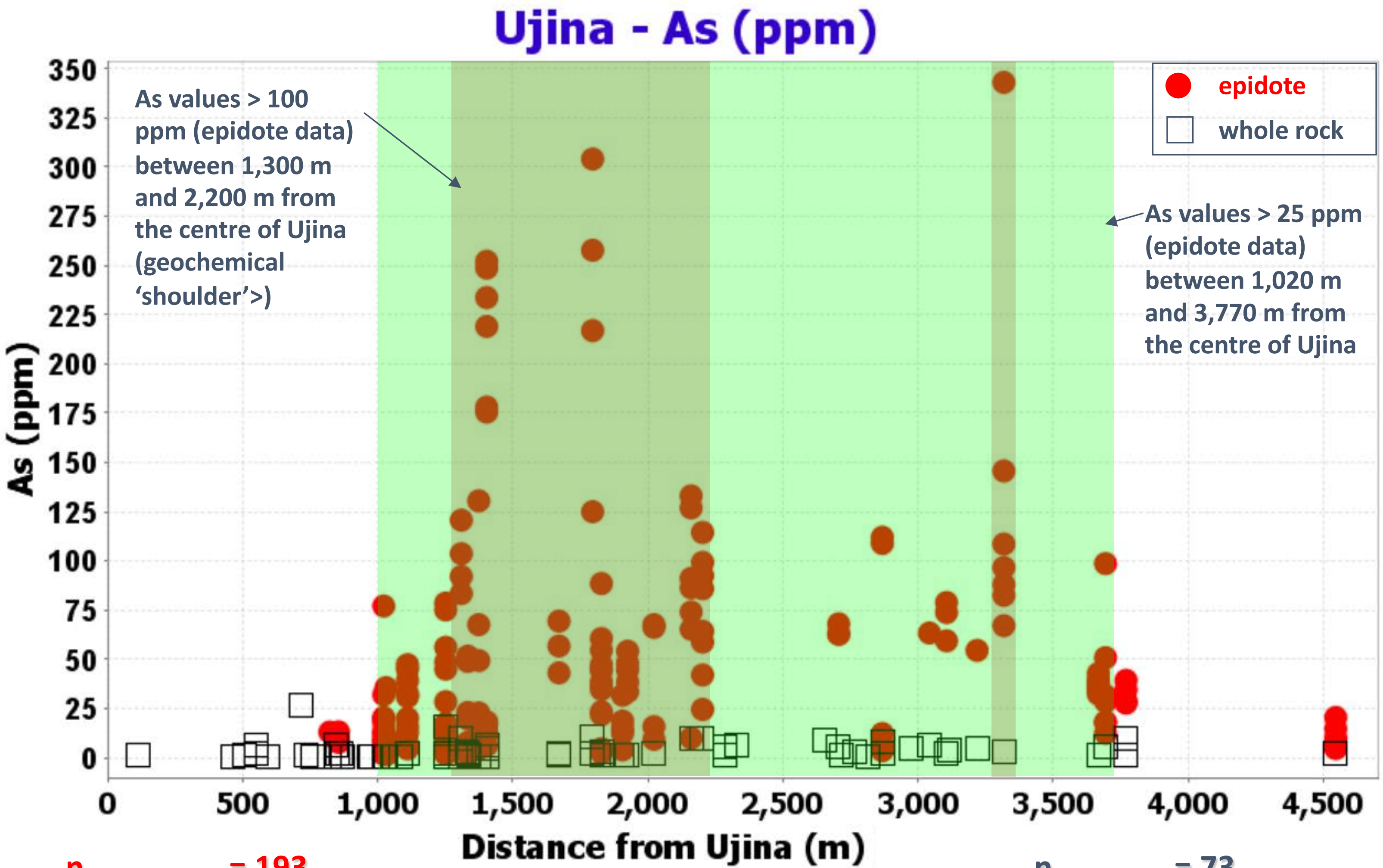
Elements enriched in epidote relative to host rocks



Cooke et al. (2014)

$n_{(max)\ epidote}$ = 3,521 $n_{(max)\ whole\ rock}$ = 985

Extending the geochemical footprint using epidote

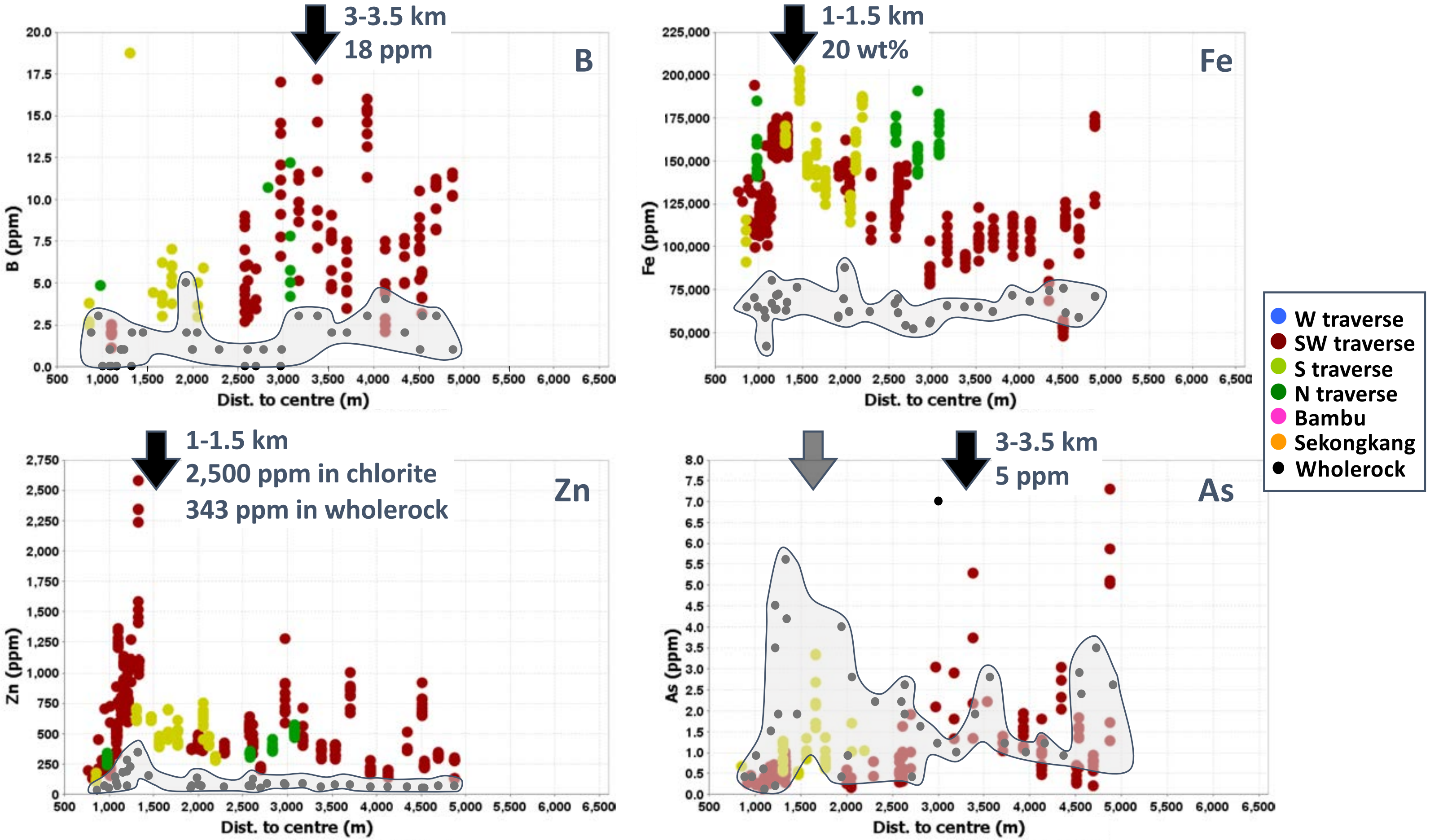


$n_{(max)\ epidote} = 193$

$n_{whole\ rock} = 73$

Epidote anomalies defined for samples where two or more spots exceed the threshold value

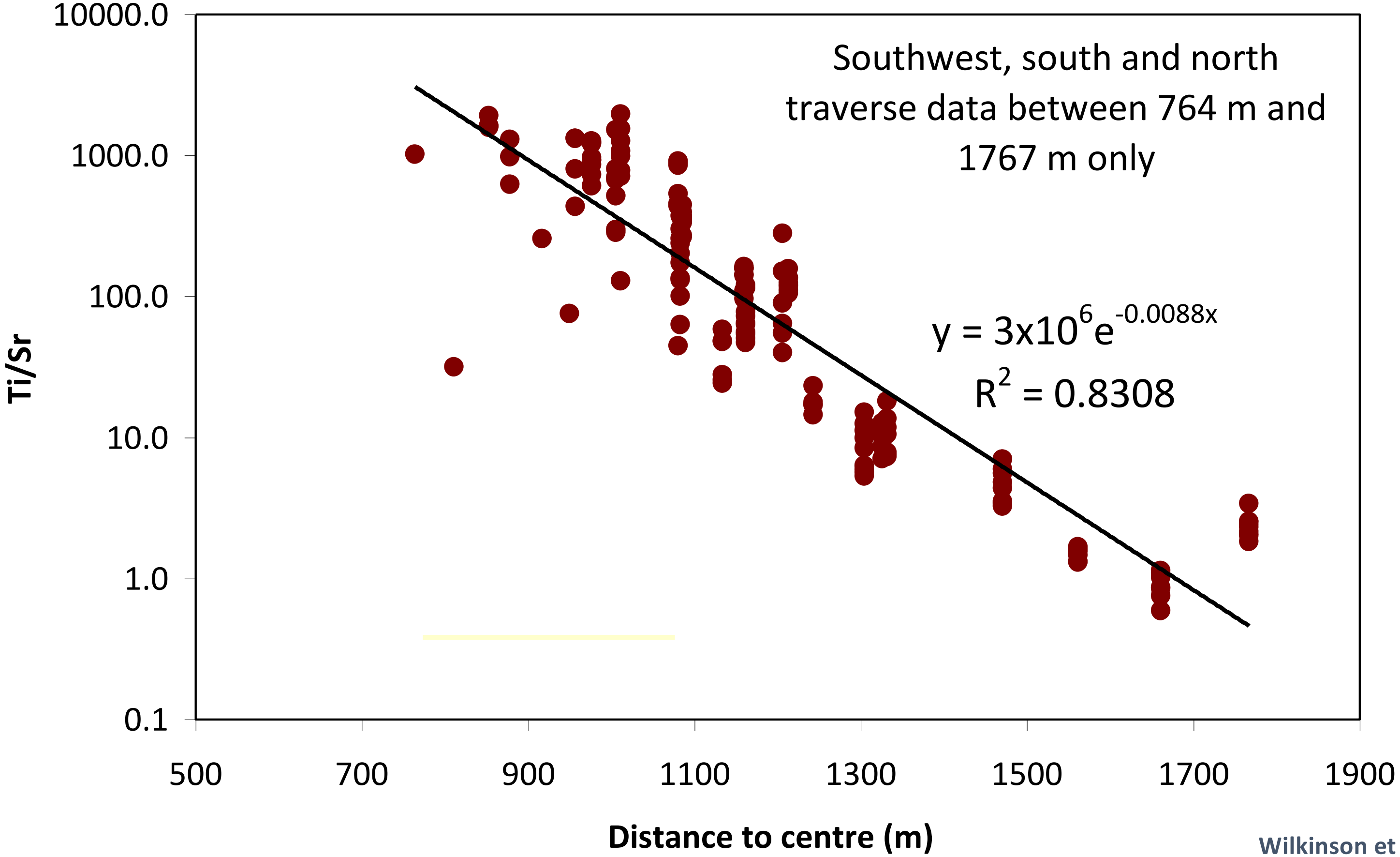
Chlorite 'halo' elements



Wilkinson et al. (2015)

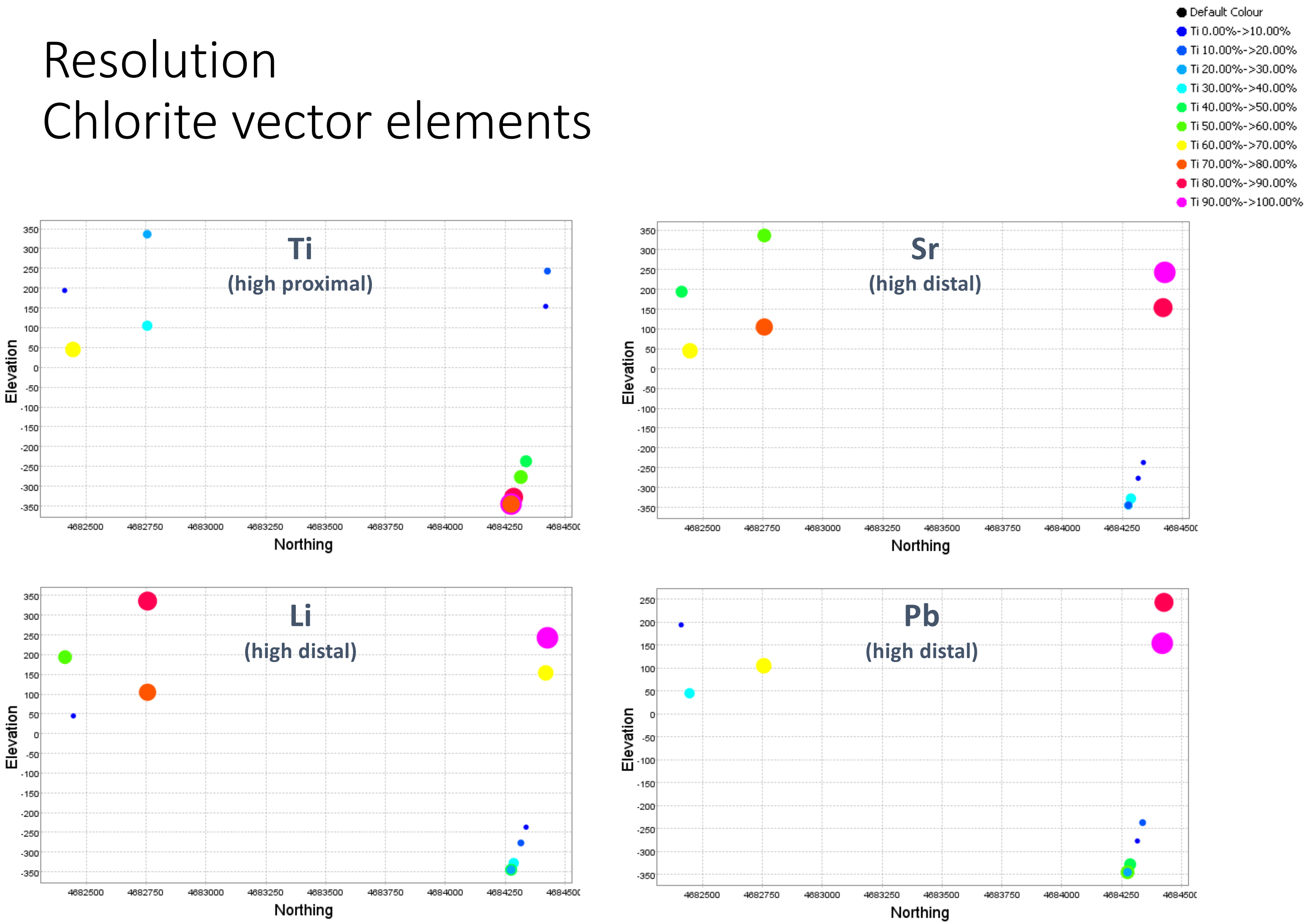
Excluding tonalite-hosted samples at <325 m

Calculating distance to porphyry centres using the Batu Hijau Ti/Sr proximitor

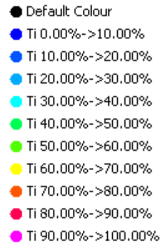


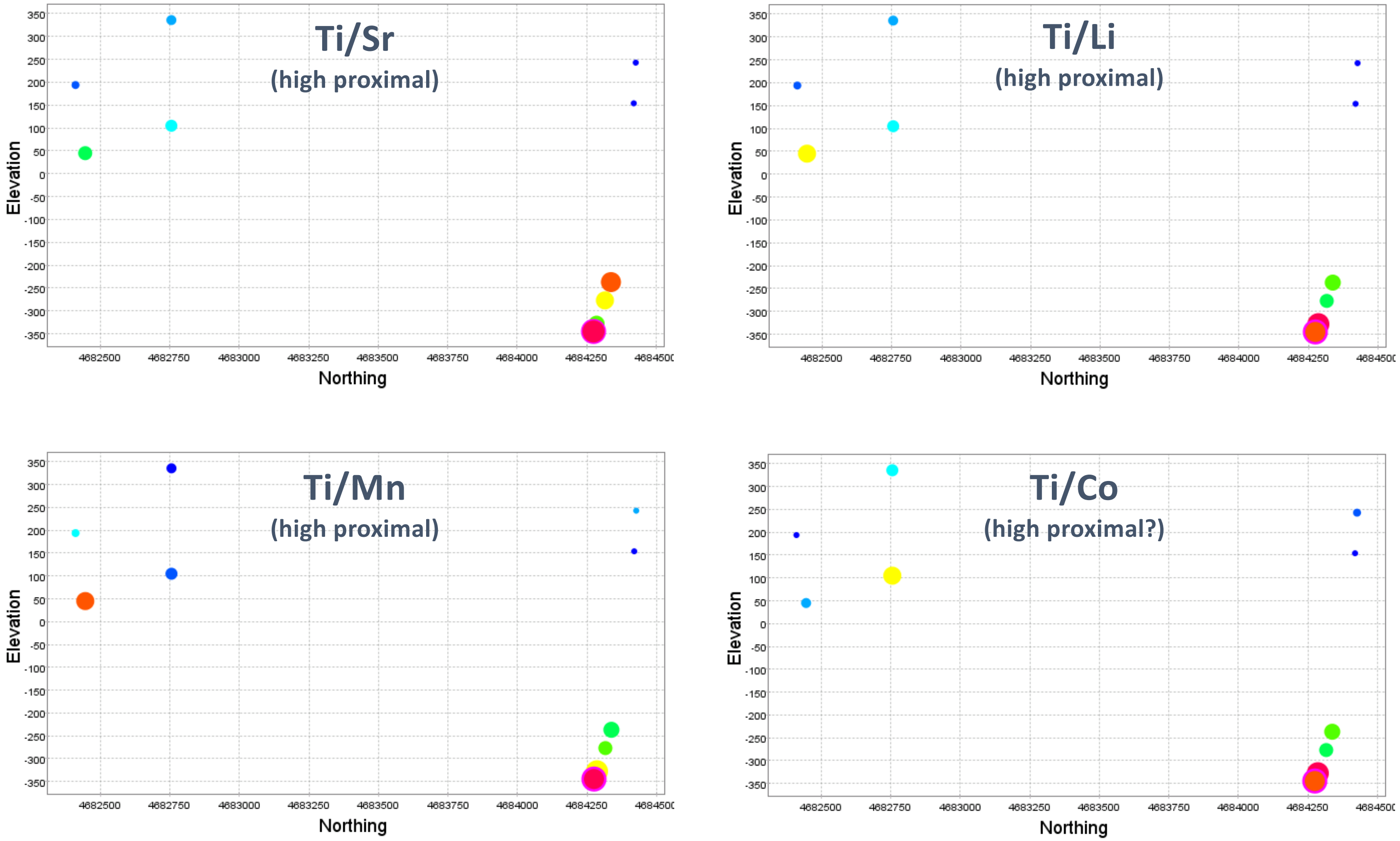
Wilkinson et al. (2015)

Resolution
Chlorite vector elements



Resolution
Chlorite vector element ratios

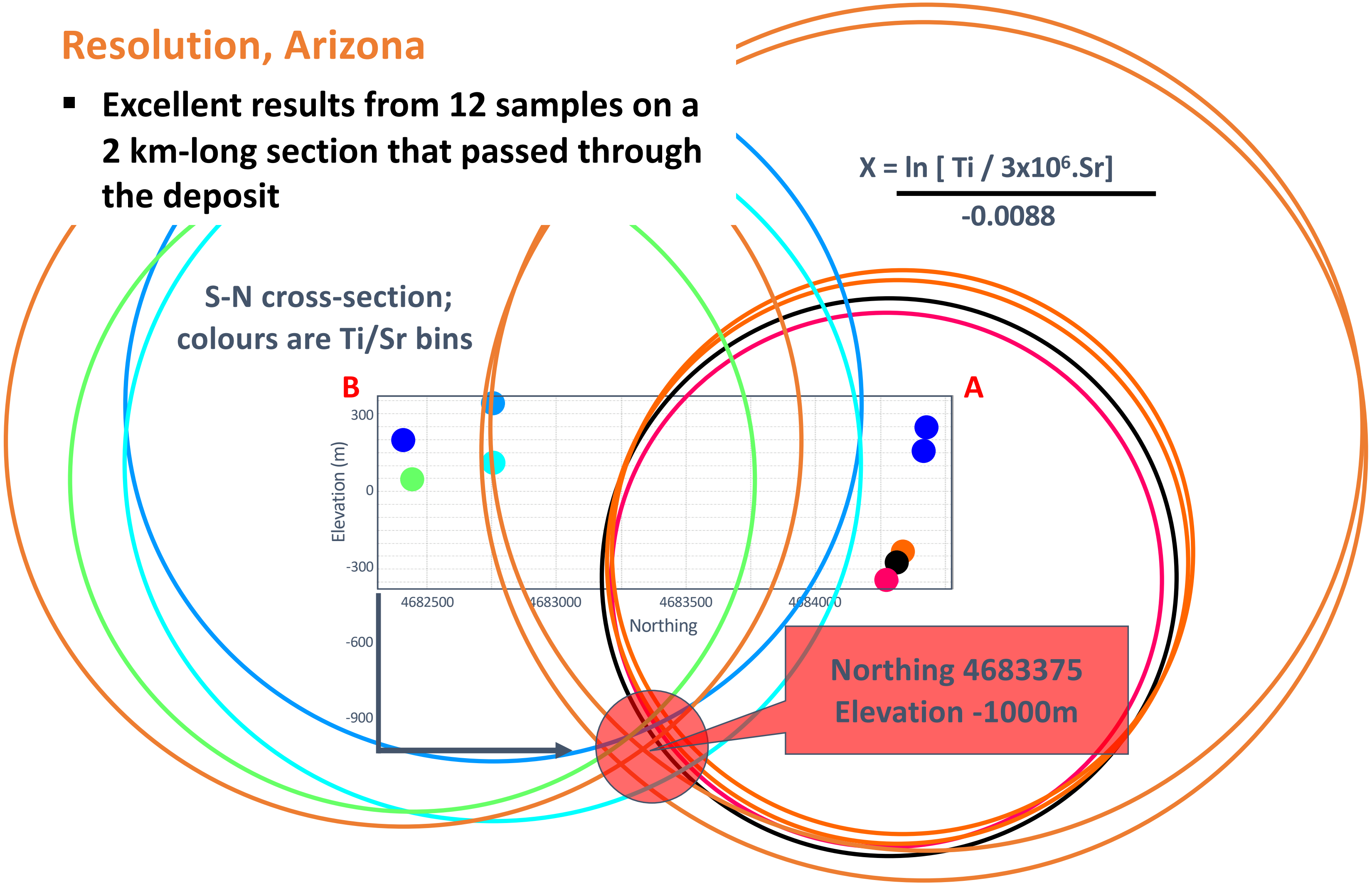




Green Rock Tools – Chlorite proximitor

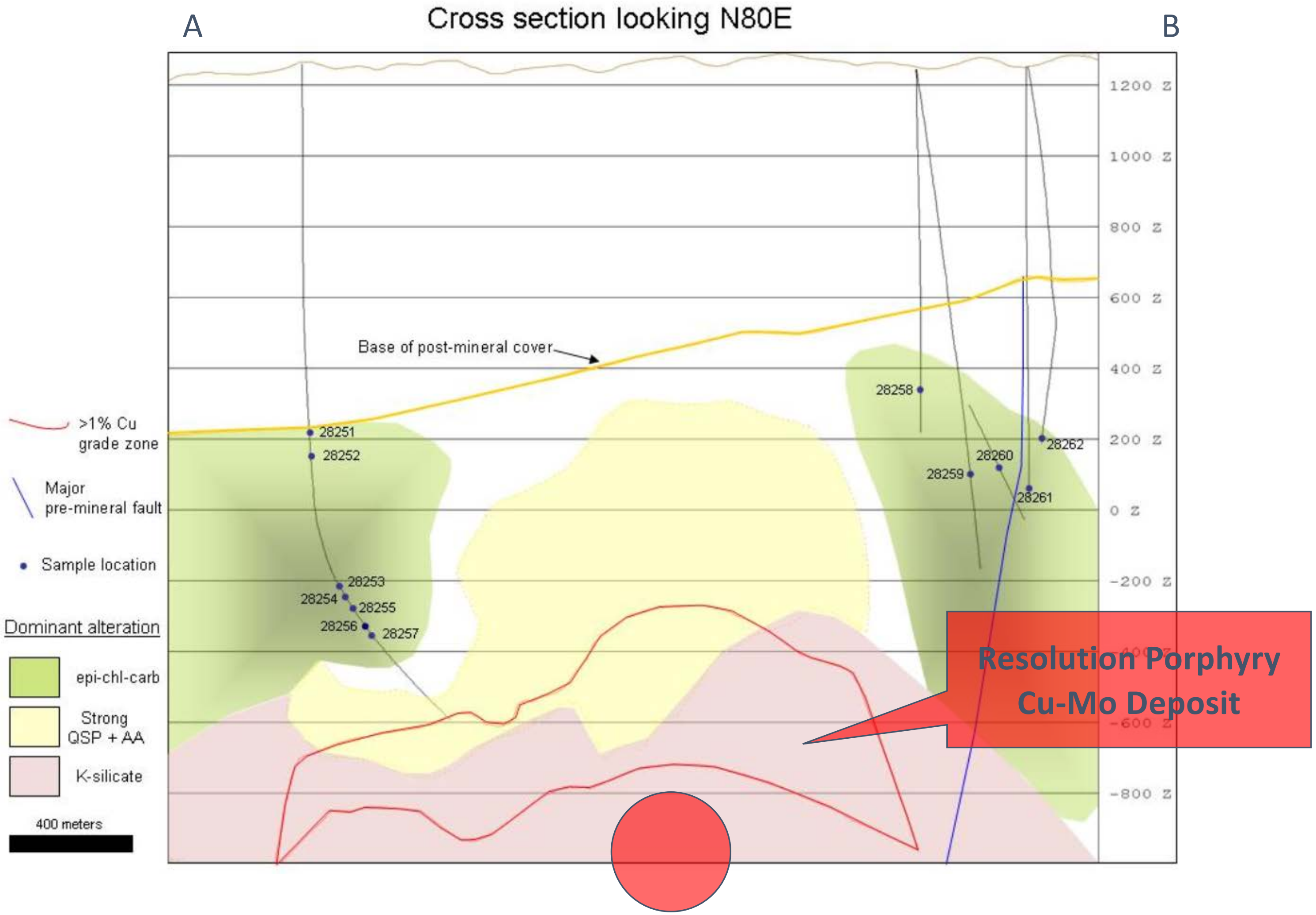
Resolution, Arizona

- **Excellent results from 12 samples on a 2 km-long section that passed through the deposit**



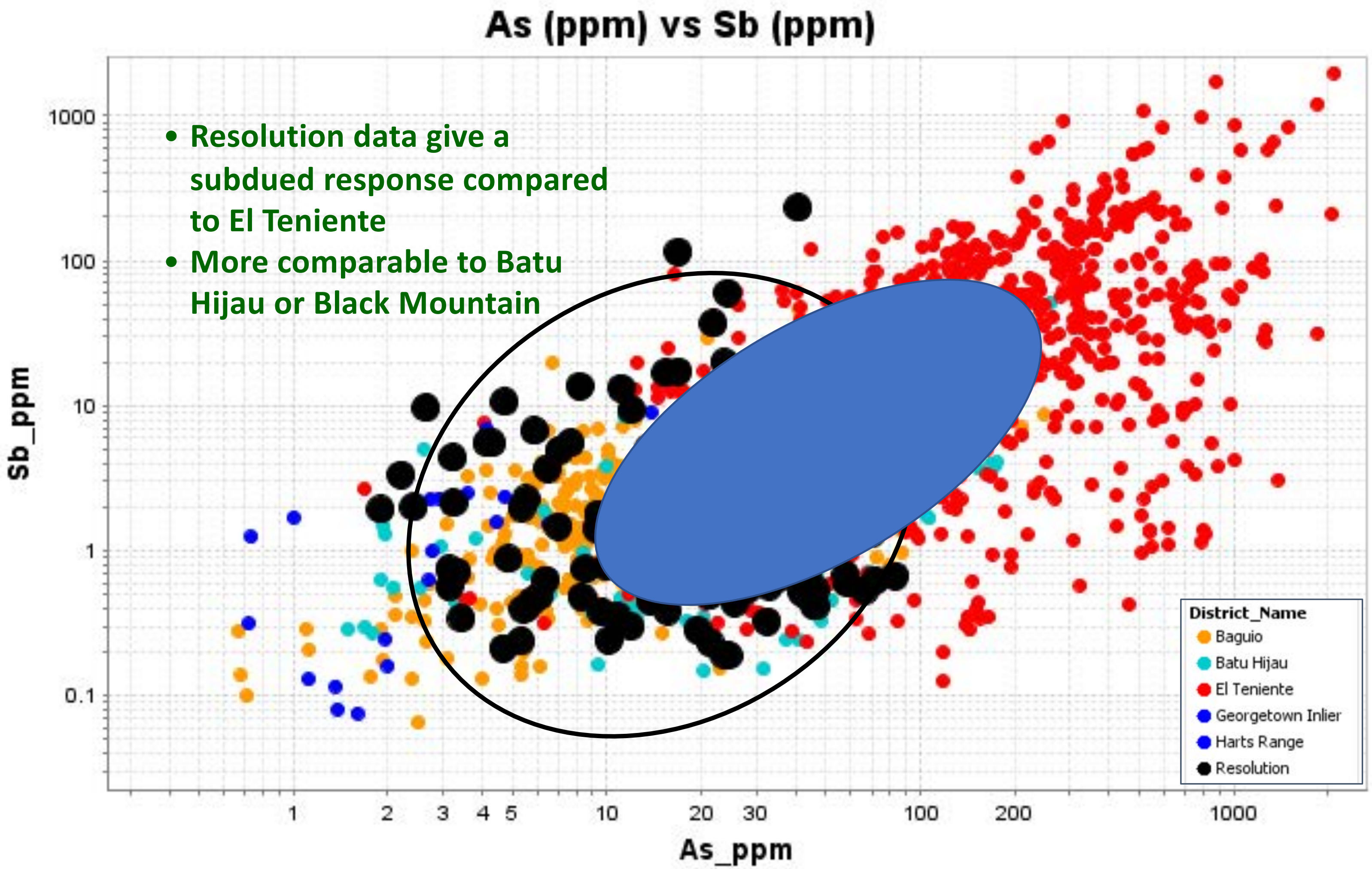
Distances calculated using Batu Hijau Ti/Sr proximitor (Wilkinson et al., 2015)

Resolution – technique validation



Epidote fertility: Porphyry deposits and Ernest Henry

- Resolution data give a subdued response compared to El Teniente
- More comparable to Batu Hijau or Black Mountain



NW Queensland mineral geochemistry vectoring project – research team

CODES team

David Cooke

Shaun Barker

Jeff Steadman

*Jonathan Cloutier**

Rob Scott

Peter McGoldrick

**Begins 1 Feb 2019*

GSQ

Vladimir Lisitsin

UQ (WHBRC)

Rick Valenta

CSIRO

Jim Austin

John Walshe (camera shy!)

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Work completed to date

- **Lady Loretta pilot study**
  - Small set of proximal and distal pyritic samples from Peter McGoldrick's collection
  - LA-ICPMS spot analyses and processing completed by Wei Hong (PhD; post-doc)
  - Comparison of these data to HYC proximal and distal pyrites (Mukherjee and Large, 2017)
- **Deposit fingerprinting – magnetite and pyrite from various IOCG systems**
  - Identifying the trace element 'fingerprint' of SWAN-style mineralization
    - Pyrite (many)
    - Magnetite (many)
    - Epidote data (Ernest Henry only)
    - Chlorite data (Ernest Henry only)

Wei Hong

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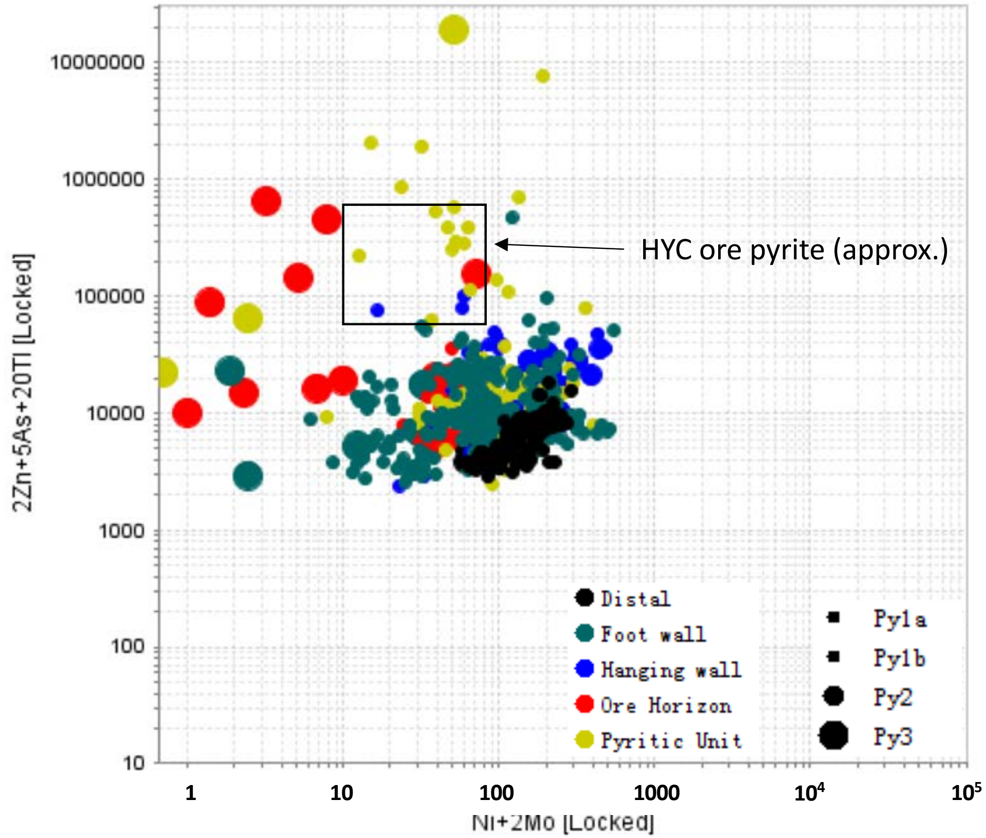
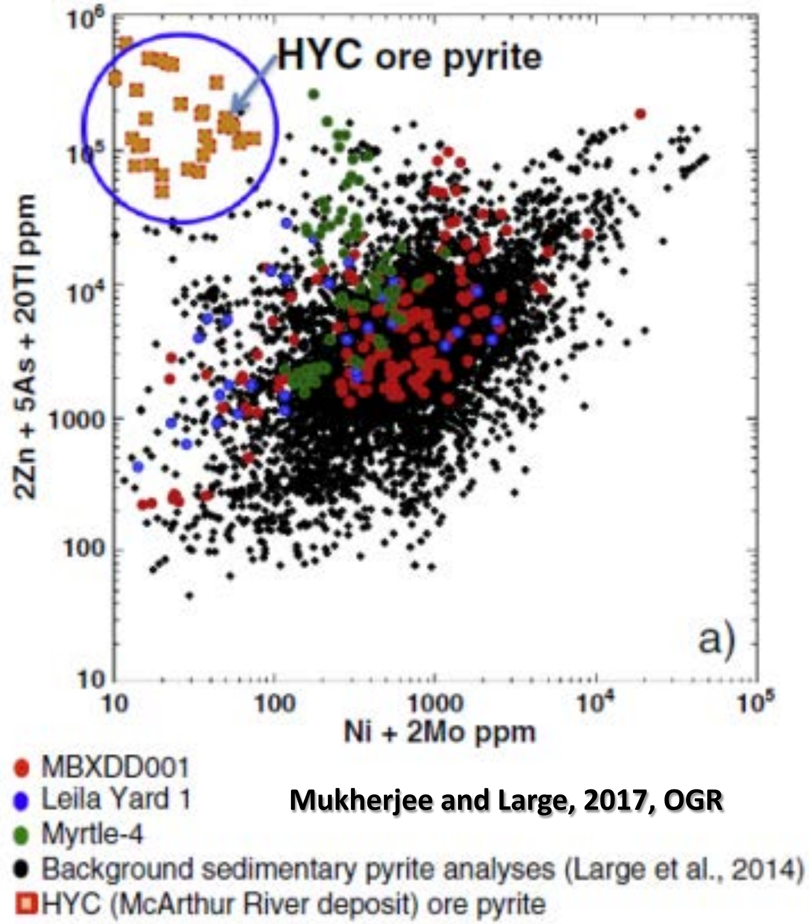
Lady Loretta pyrite data: comparison to HYC





Mukherjee and Large, 2017, OGR

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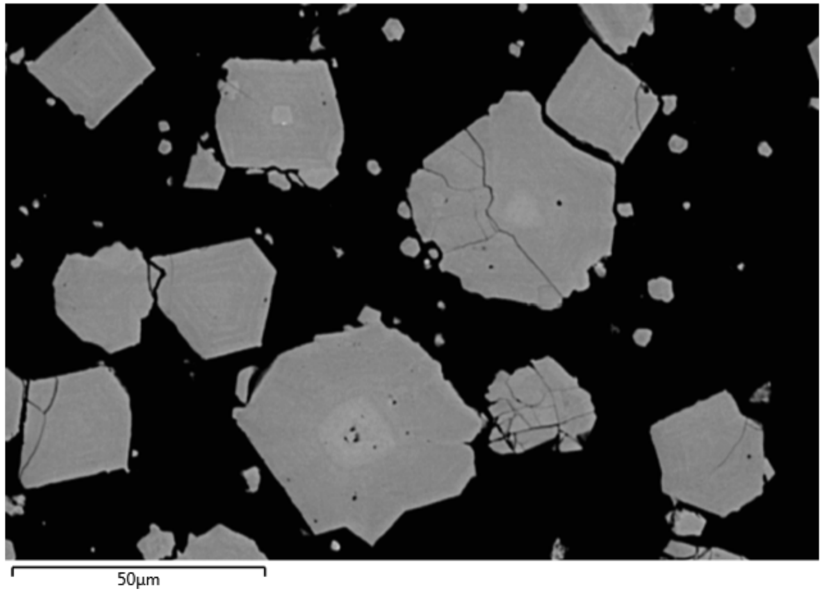
Lady Loretta pyrite study: conclusions

- LA-ICP-MS trace element analyses of pyrite-bearing samples from within and around the Lady Loretta SEDEX Zn-Pb deposit reveal **consistent enrichment/depletion trends in certain key elements, which are correlated with distance from the ore zone**
  - E.g., Zn increases toward the ore zone; Ni and Mo decrease toward the ore zone
- This pattern is comparable to that defined for McArthur River (HYC) by Mukherjee and Large (2017)
- Pyrite textures and paragenesis at Lady Loretta are similar to other SEDEX-style systems of various ages around the world (e.g., Black Butte, USA = ~1470 Ma)



Complex zonation in fine-grained pyrite, Lady Loretta (sample Q13)

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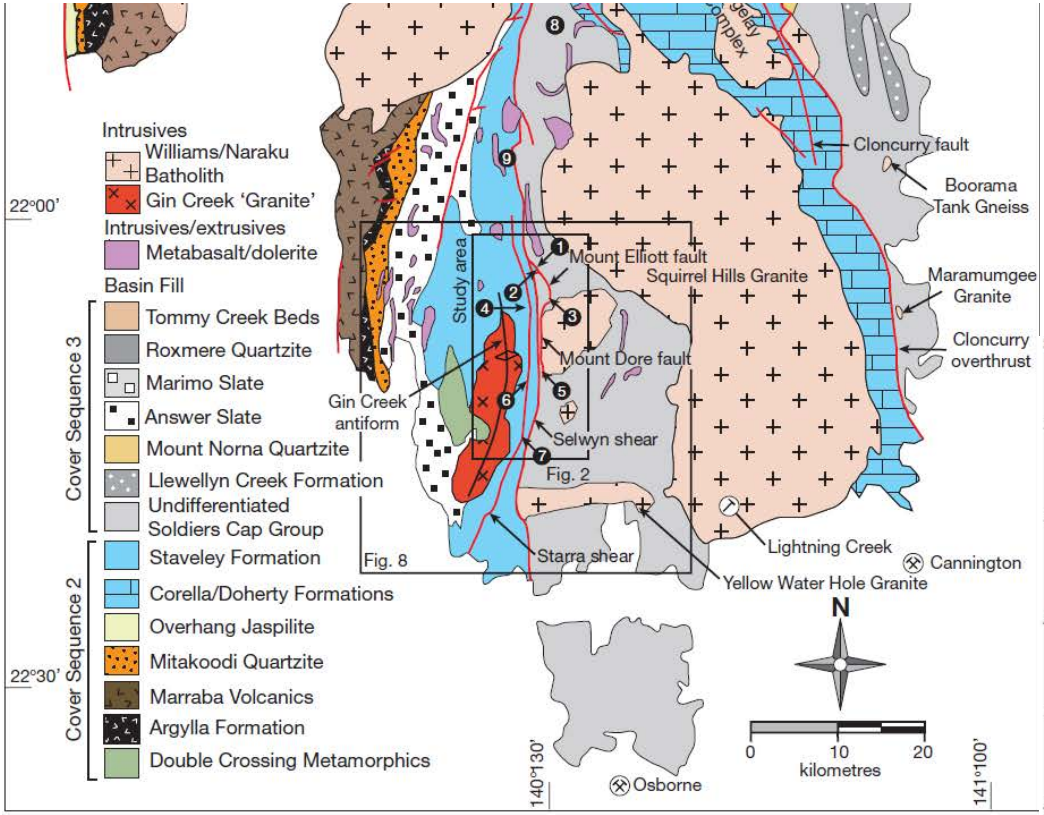
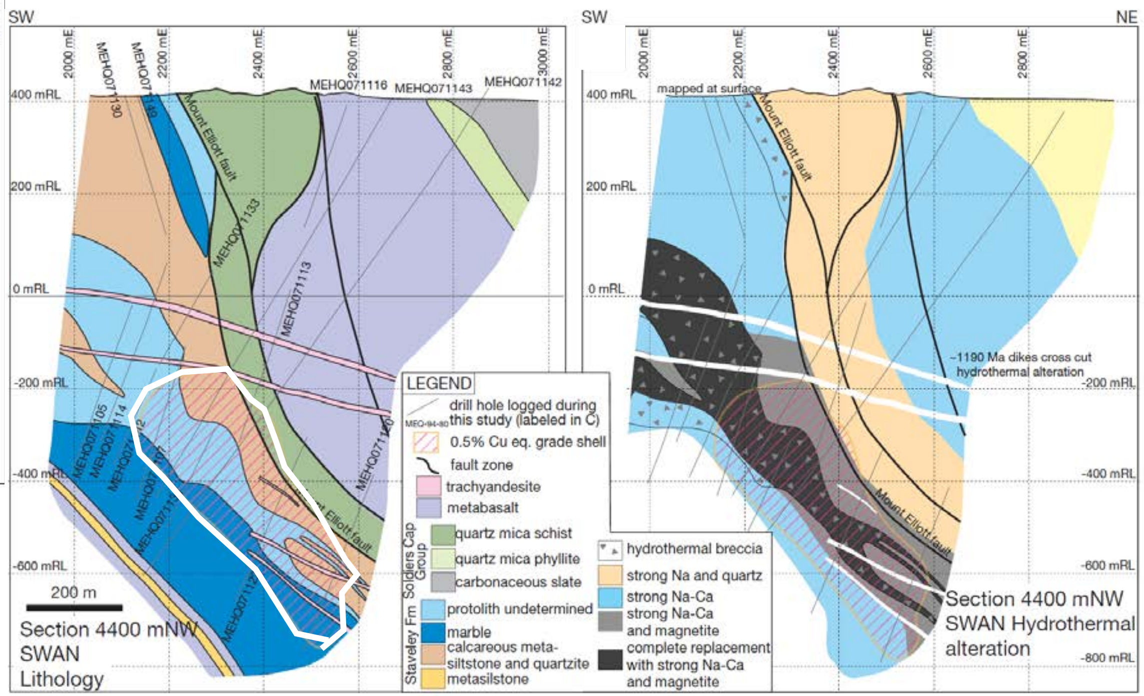
Deposit Fingerprinting: Southwest Anomaly (SWAN)

- ***Breccia-hosted IOCG-style Cu-Au-REE mineralization***
  - ***Extension of Mt. Elliot***
- ***CSIRO dataset: 43 samples from a single drill hole***
- ***Focus on sulfides and oxides first***
- ***Silicates, carbonates, and phosphates to follow***





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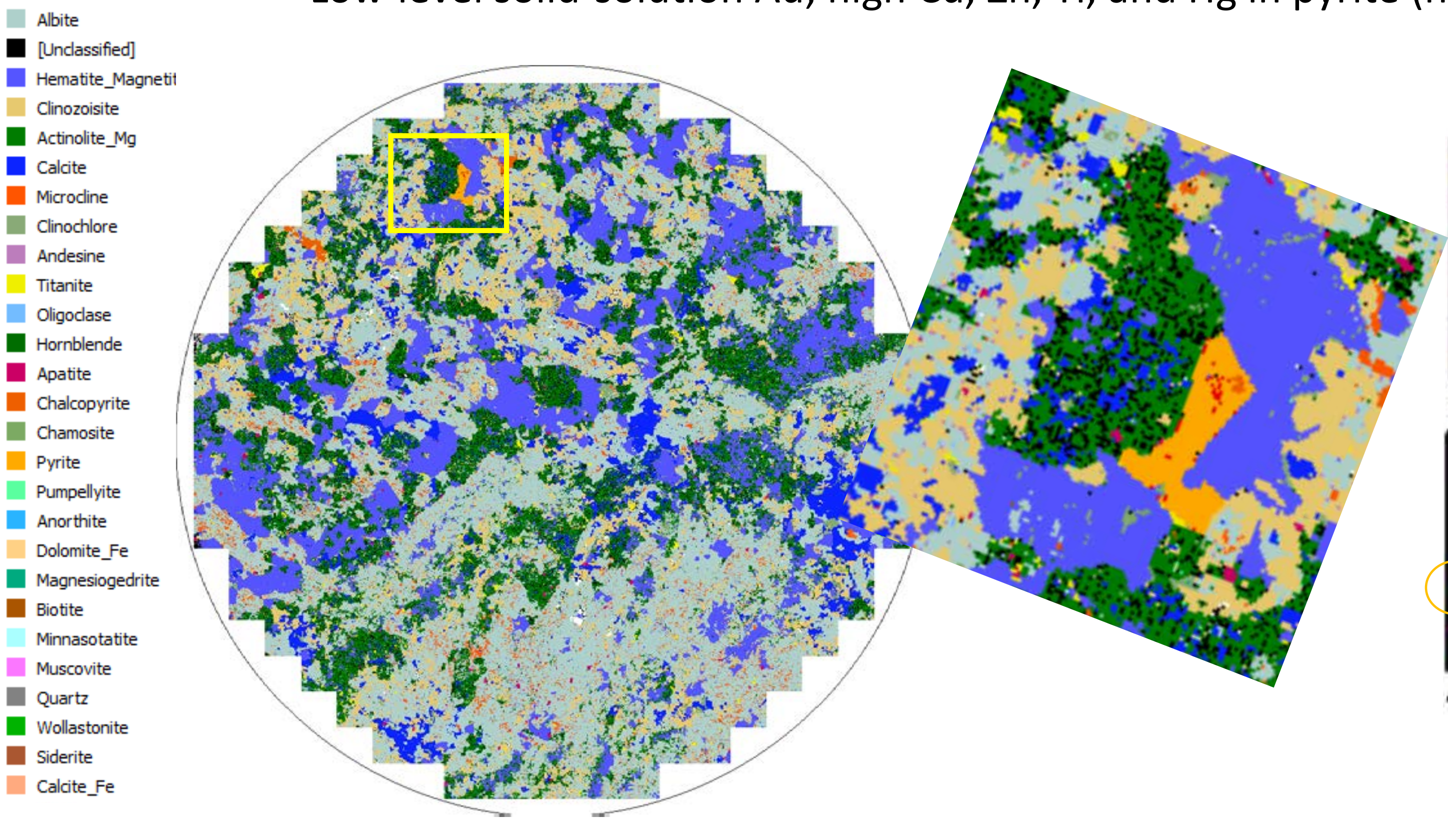
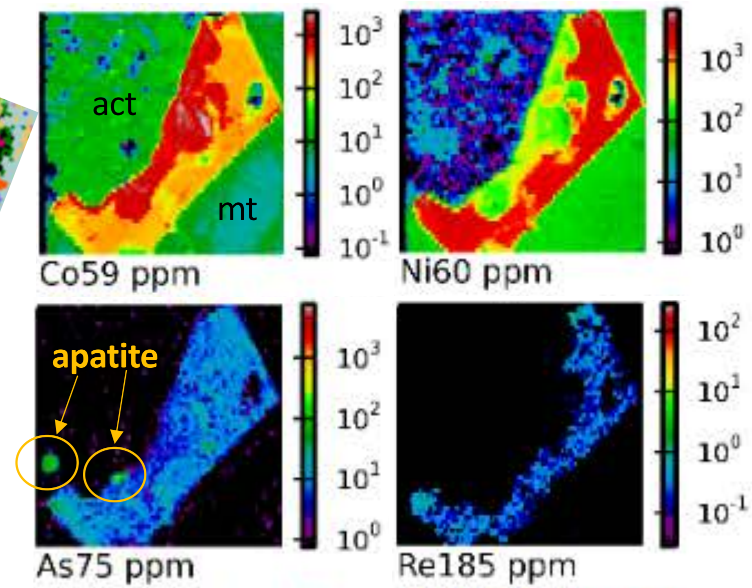
Duncan et al., 2014

Results – pyrite imaging

- SWAN pyrite is enriched in Co, Ni, As; minor Re (e.g., **SWN036 [641.6m]**)
  - Exceptions: SWN023 (383m) and SWN053 (389.5m)
    - Low-level solid-solution Au; high Cu, Zn, Tl, and Hg in pyrite (next slide)





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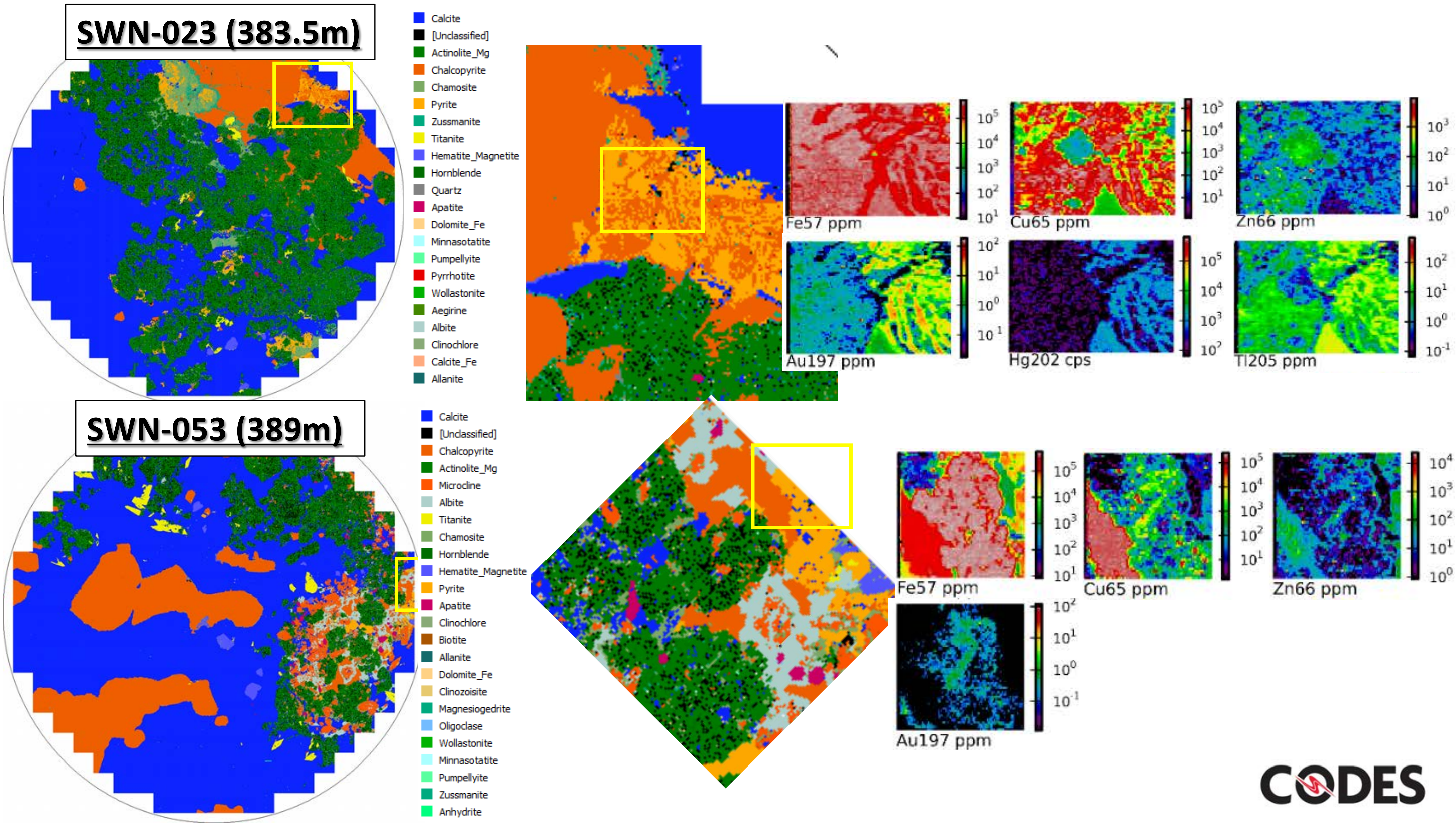
SWN-023 (383.5m)
Calcite
[Unclassified]
Actinolite_Mg
Chalcopyrite
Chamosite
Pyrite
Zussmanite
Titanite
Hematite_Magnetite
Hornblende
Quartz
Apatite
Dolomite_Fe
Minnasotatite
Pumpellyite
Pyrrhotite
Wollastonite
Aegirine
Albite
Clinochlore
Calcite_Fe
Allanite
Fe57 ppm
Cu65 ppm
Zn66 ppm
Au197 ppm
Hg202 cps
Tl205 ppm
SWN-053 (389m)
Calcite
[Unclassified]
Chalcopyrite
Actinolite_Mg
Microcline
Albite
Titanite
Chamosite
Hornblende
Hematite_Magnetite
Pyrite
Apatite
Clinochlore
Biotite
Allanite
Dolomite_Fe
Clinozoisite
Magnesiogedrite
Oligoclase
Wollastonite
Minnasotatite
Pumpellyite
Zussmanite
Anhydrite
Fe57 ppm
Cu65 ppm
Zn66 ppm
Au197 ppm

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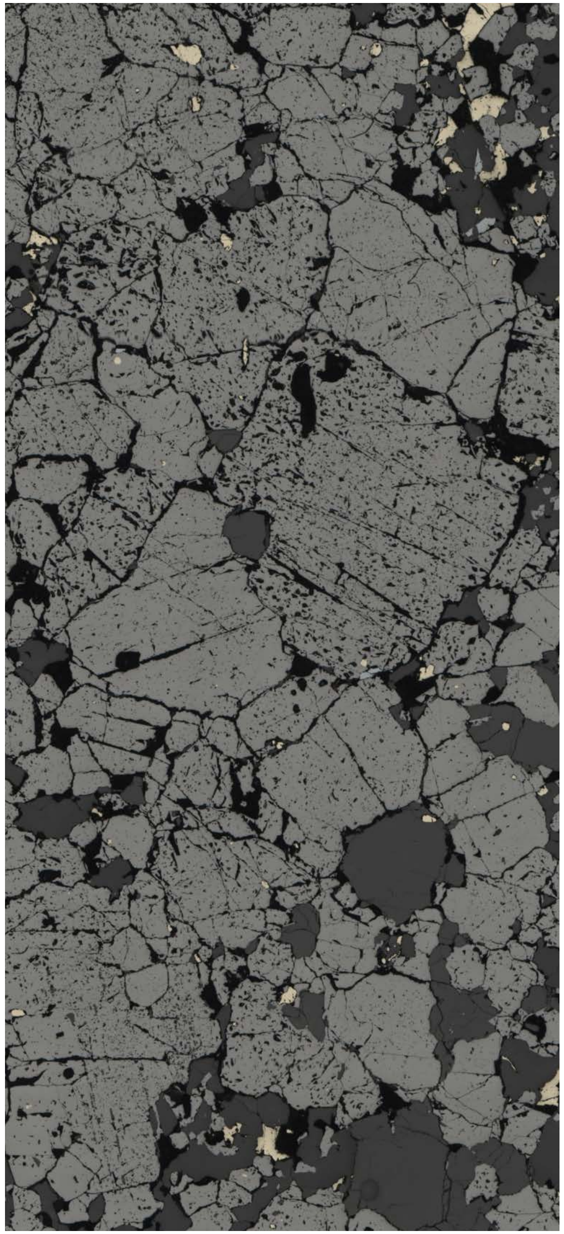
Results – magnetite imaging

- Magnetite geochemistry is fairly constant throughout the hole
  - Enrichments in Al, Ti, V, Mn, Co, Ni, and Ga (± Zn, Mg, Pb, Sn)
  - **Almost no zonation in these elements**
- **However, chromium (Cr) is zoned in almost all samples**
  - Best example: SWN056 (804.4m)
  - See next slide



Mt-ap ore, Osborne Cu-Au deposit

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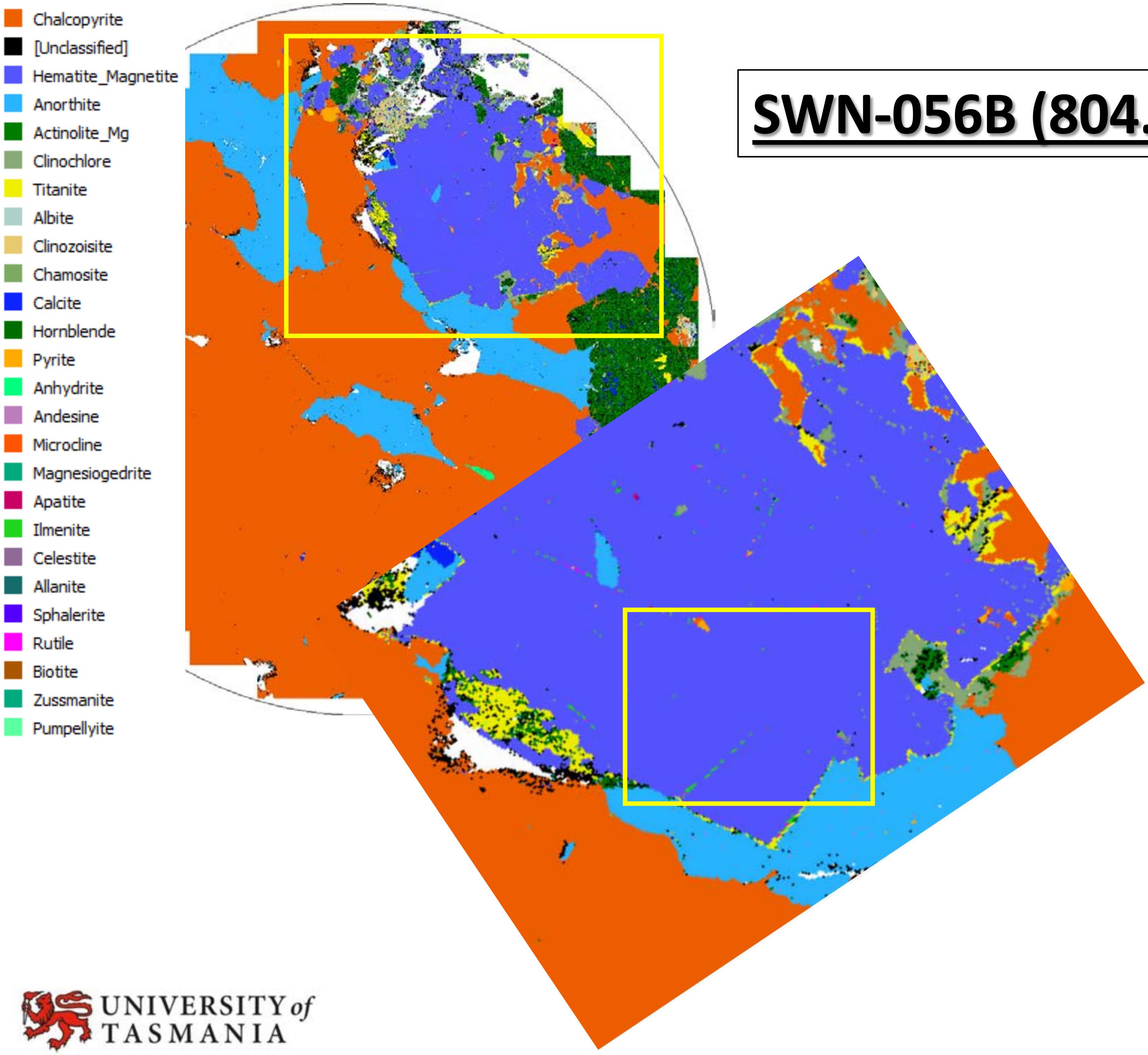
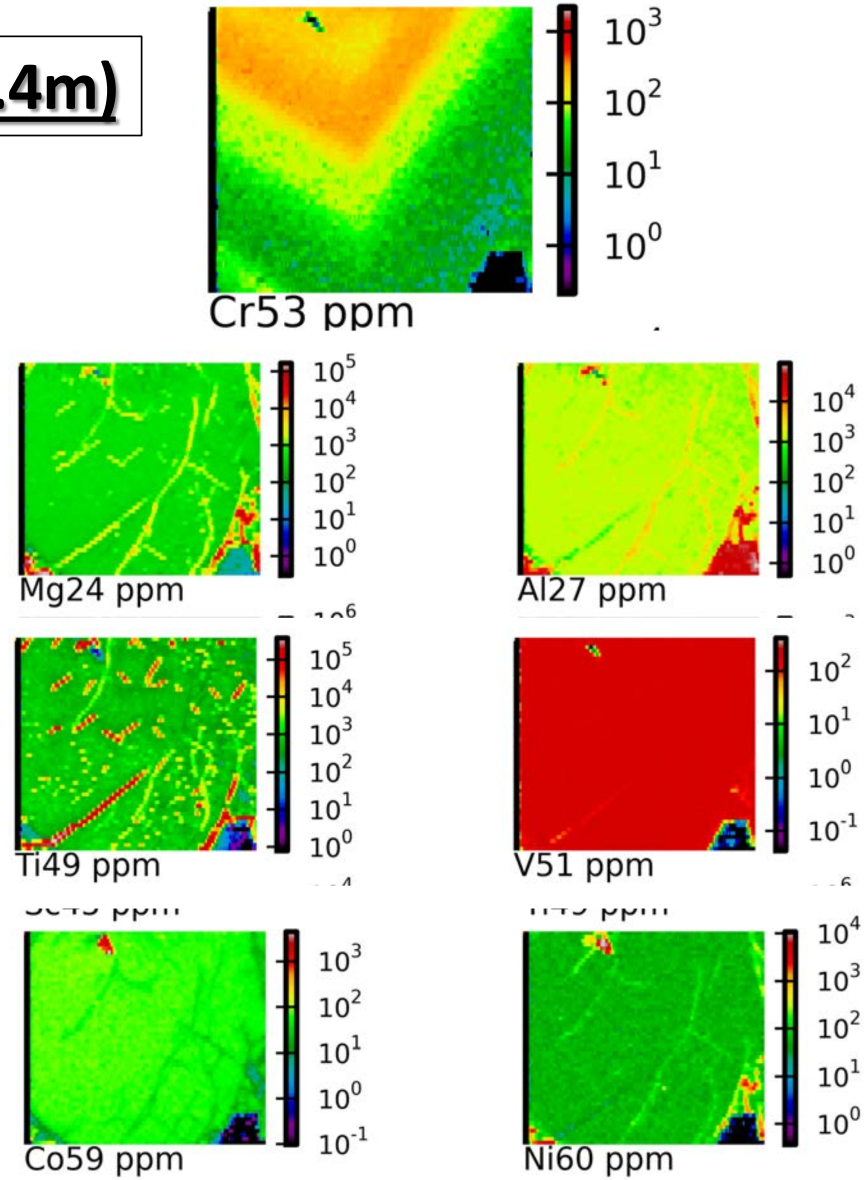


SWN-056B (804.4m)



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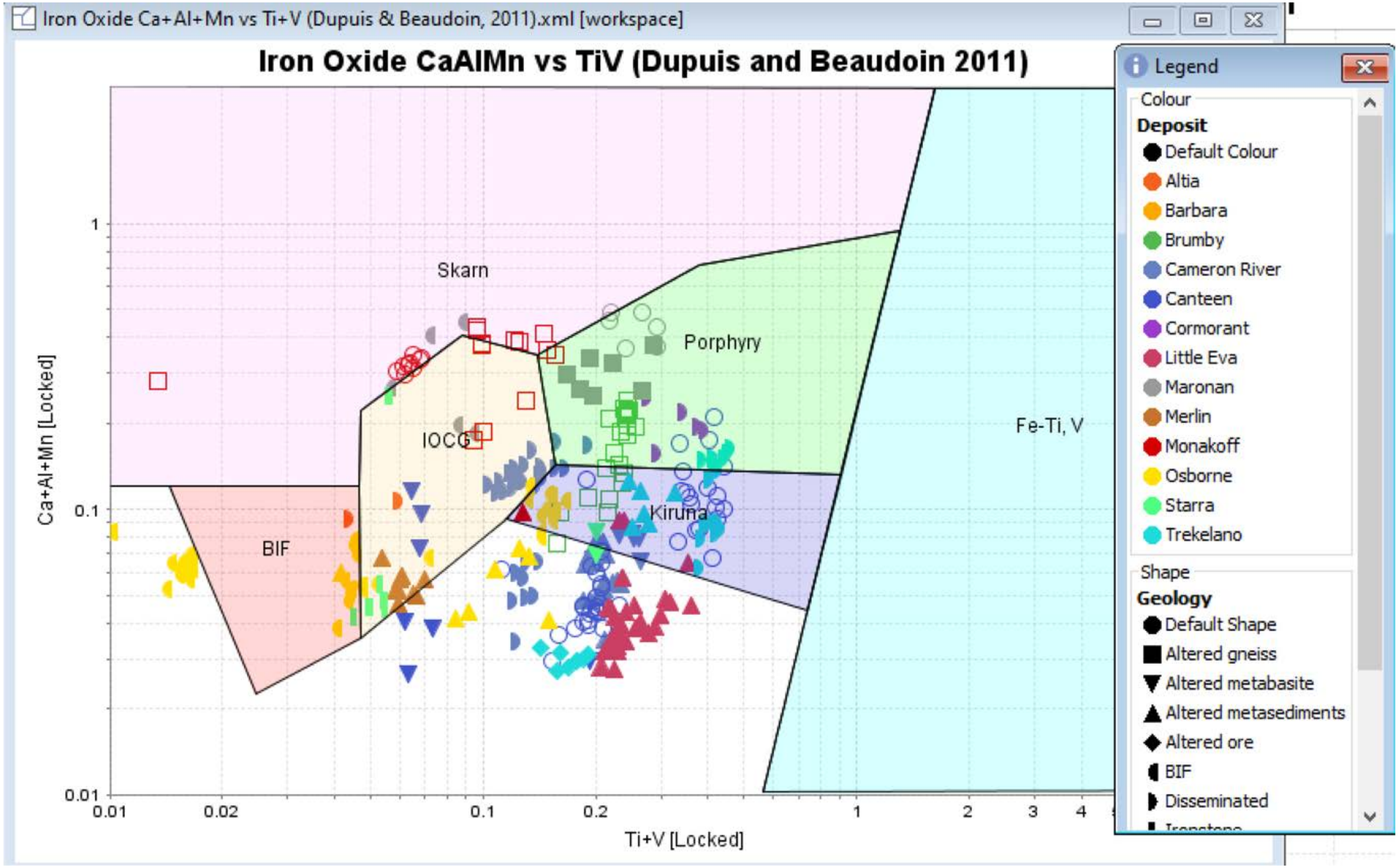
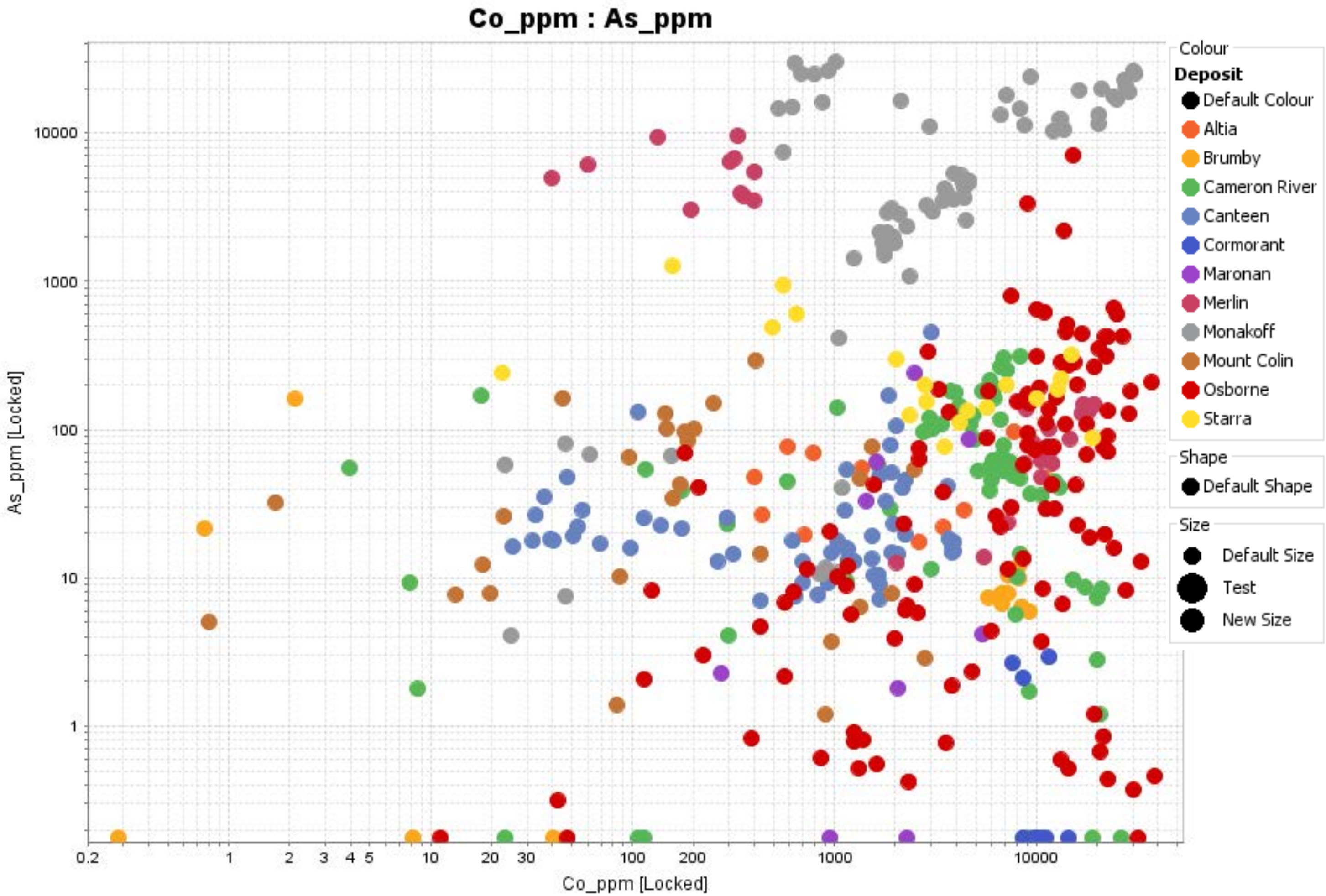
Magnetite IOCG “Fingerprinting” initial results

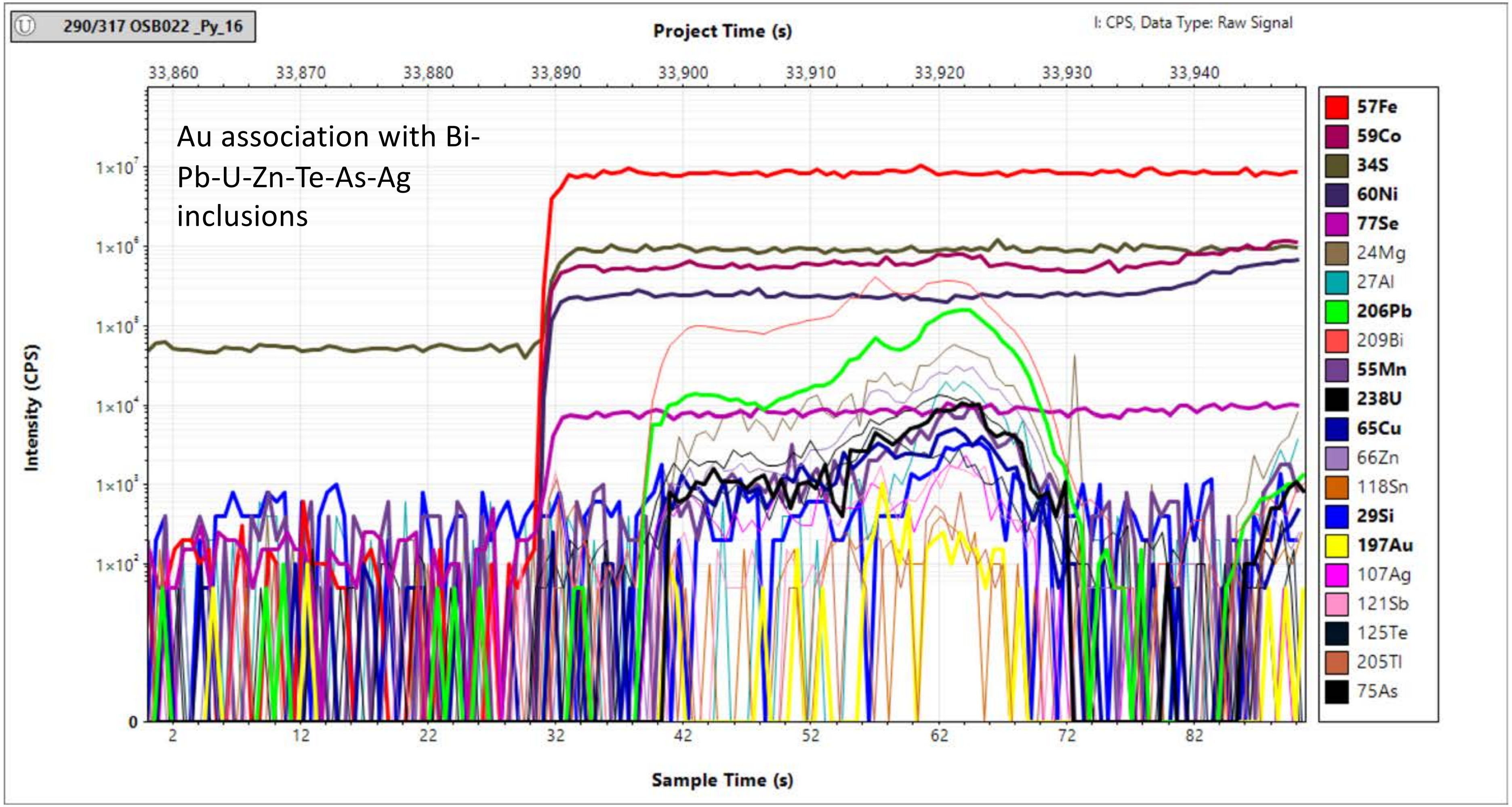


Pyrite IOCG "fingerprinting" summary



- Spectacular variations in pyrite chemistry – in initial stages of assessing what data means
- Potential for Co resource in pyrite from IOCG deposits (1-3 wt% Co in pyrite at Osborne, Monakoff, Cameron River)

Osborne – OSB022 – gold inclusions in pyrite

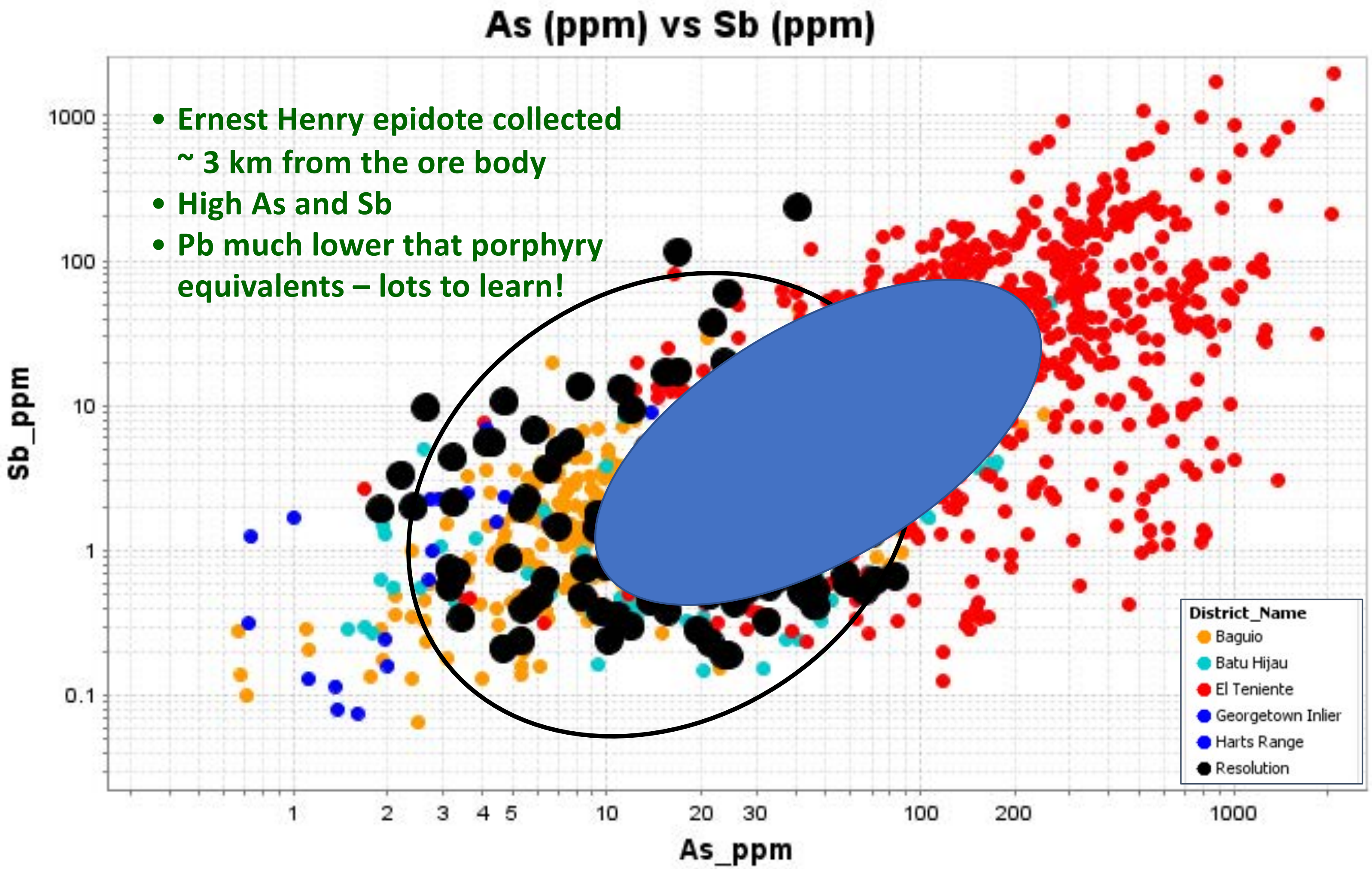


Ernest Henry Cu-Au deposit

- Representative drill holes
  - two through orebody
  - two within the inner halo
  - one deep drill hole (1.7km)

  - three drill holes from FC4WS target

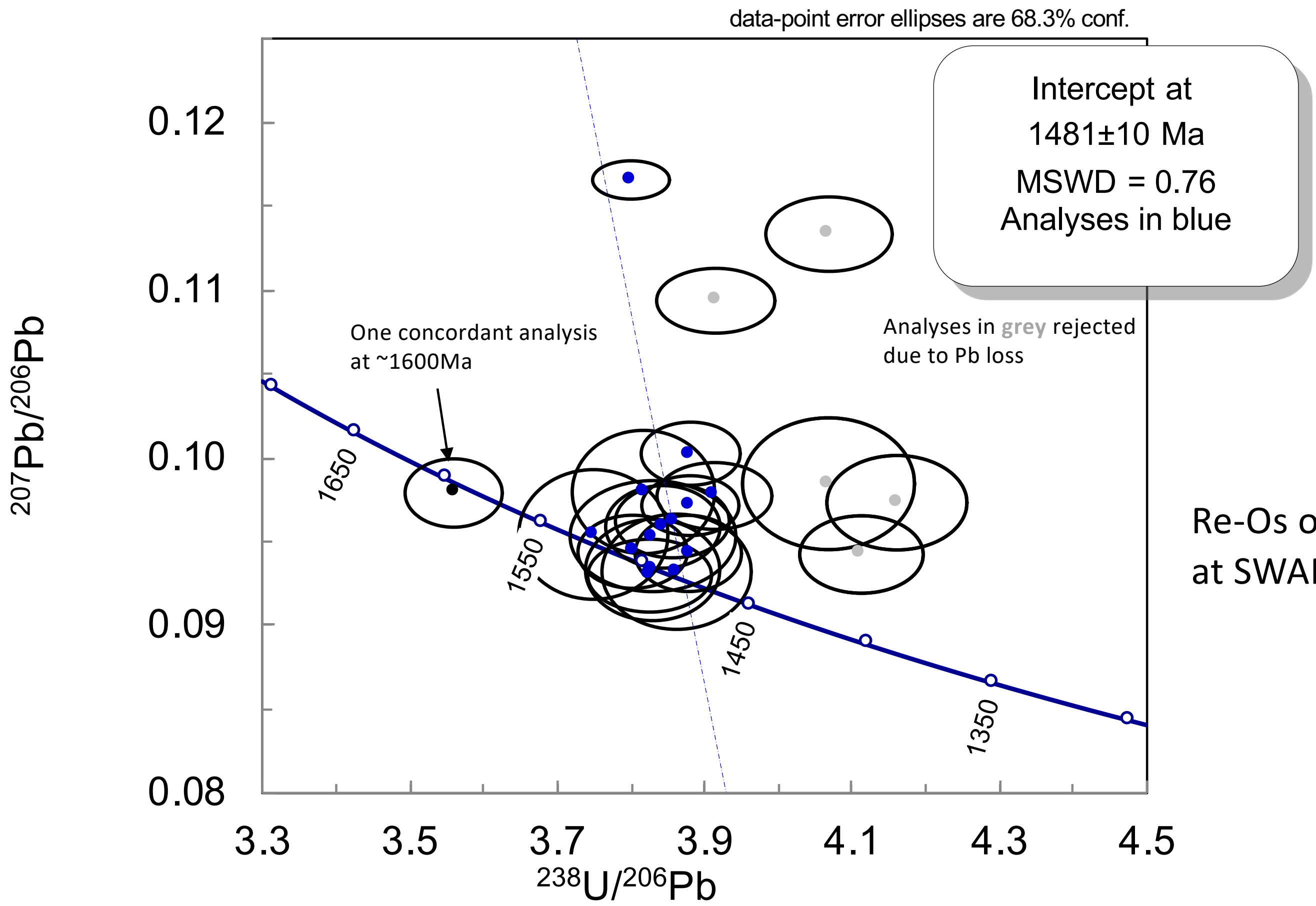
Epidote fertility: IOCG epidote – first results from Ernest Henry



What next?

- Additional mineral fingerprinting – chlorite, epidote, apatite, others…
- IOCG vectoring case study site – Starra (legacy samples)?
- Sediment Pb-Zn-Ag case study site needed
- Field work (winter 2019)

Allanite U-Pb age dating – SWAN



Re-Os on molybdenite
at SWAN ~1515 Ma