NSW GOVERNMENT | Planning & Environment

Neutralising Cobar type: an evolving skarn model for the Hera-Nymagee orebodies

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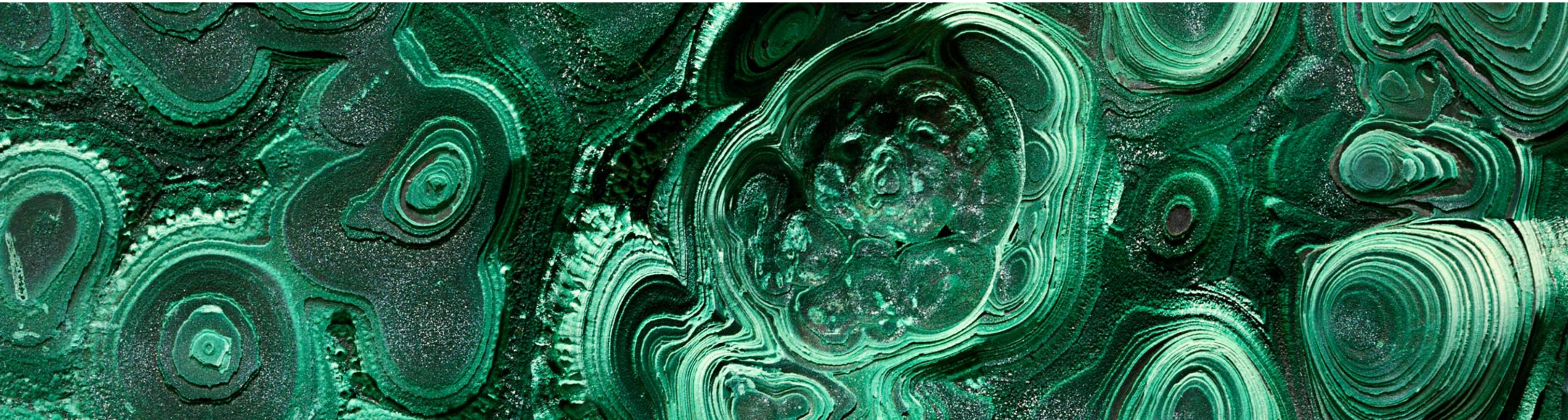
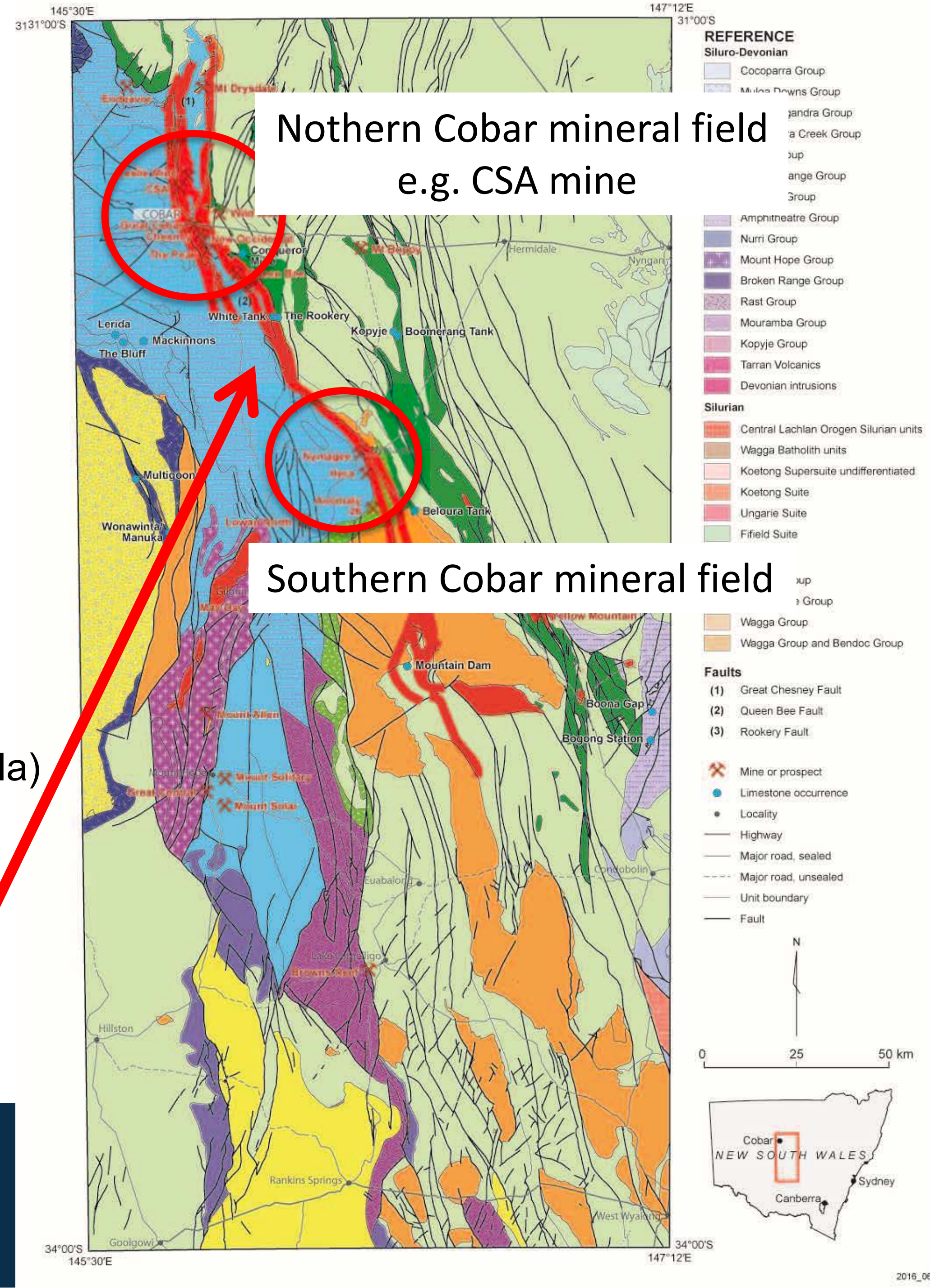


Cobar Basin in a slide

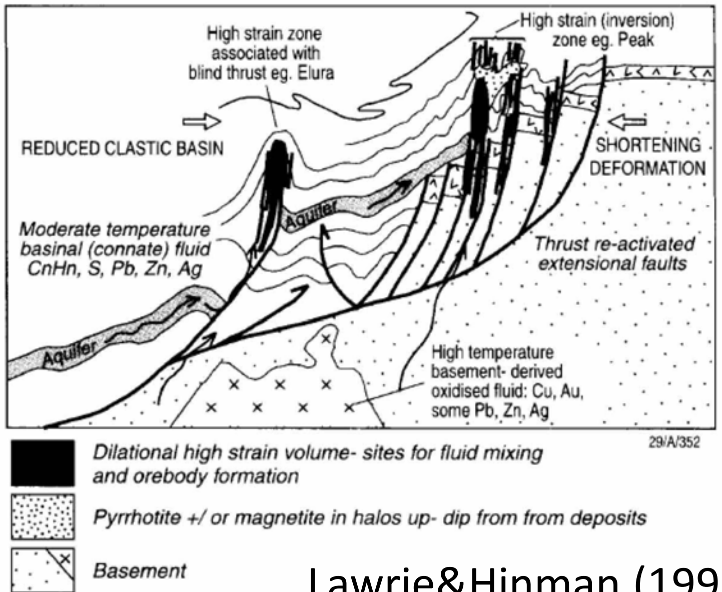
- Ordovician basement
- Intruded by Silurian granite
  - Exhumed prior to…
- Siluro-Devonian Basin
  - Deepwater sedimentary basin
  - Volcanogenic troughs
  - Western shelf
  - Eastern shelf
    - Shelf/volcanic belt
  - Early Devonian intrusions (420-415 Ma)
- Overlain by middle-late Devonian
- **Major fault systems active in**
  - **Basement**
  - **Basin opening**
  - **Inversion**

Cobar-type mineralisation



What is a Cobar-type?

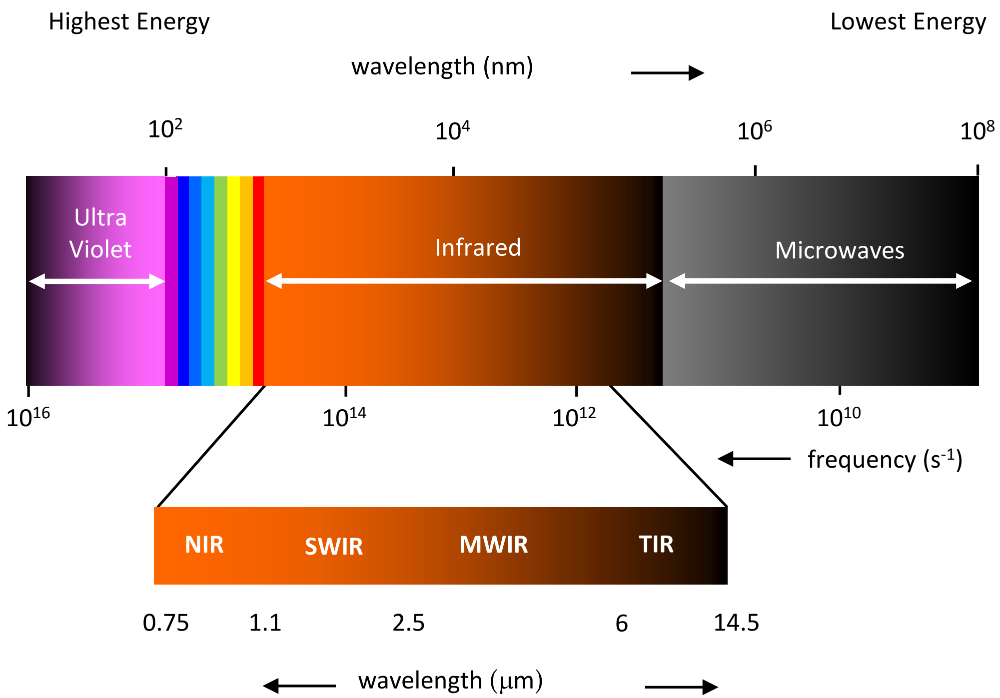
- Described in the NE
  - CSA, Peak, Great Cobar, Chesney
- Geometry e.g. CSA
  - Multiple pipe like lenses
  - Short strike length
  - Large vertical extent
- Deposit-scale
  - Metal zoning/variability
    - Within and between deposits
  - Massive sulfide and vein-hosted
    - Multiple overprinting veins sets
  - Broadly stratabound, but cross-cut bedding at **deposit-scale**
- Genesis
  - Syn-deformation - developed during basin inversion c. 380 Ma
  - Mixing of basin Pb-Zn and basement Cu-Au-rich fluids
  - Remain enigmatic. Variously attributed in the past
    - VMS, epithermal, subhalative-exhalative…



Lawrie&Hinman (1998)

If structural/metamorphic model then…
Need to understand metamorphism in the basin

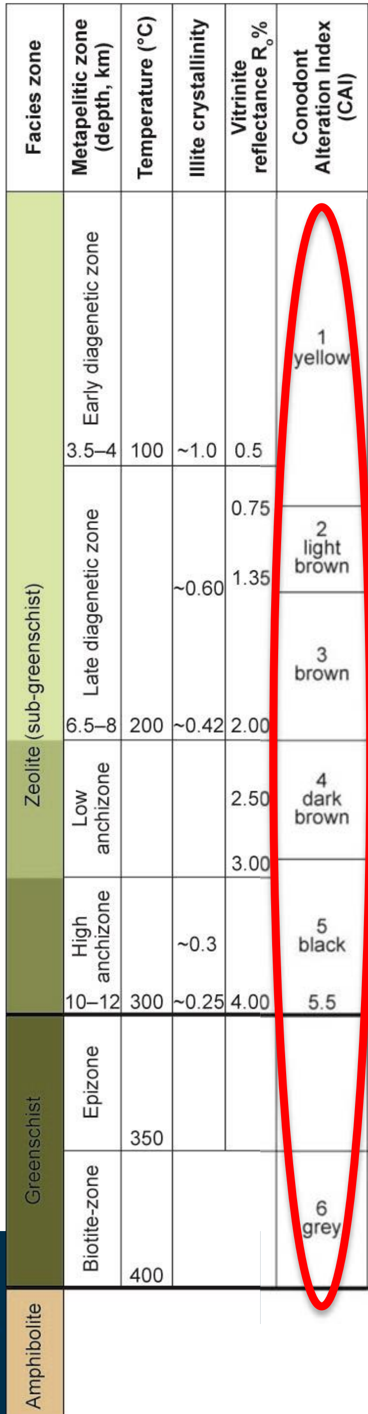
GSNSW HyLogger



Digging up heat in the Cobar Basin

How a washed up metamorphic petrologist ended up in Cobar

Burial metamorphism



Diagenetic: 0-200°C
Anchizone: 200-300°C
Epizone: 300-350°C
Biotite zone: 350-400°C
Amphibolite facies/pyroxene hornfels >400°C

Number of methods to determine burial metamorphic grade in very low grade pelitic rocks.

- Illite crystallinity (Kübler index)
- Vitrinite reflectance
- **CAI (Conodont Alteration Index)**

Mapping heat in the Cobar Basin

R. Mawson, J.A. Talent,
D. Mathieson and A.J. Simpson

- **CAI**
- Unaltered conodonts exhibit a pale yellow colour and a smooth surface with silky brightness (CAI 1). Exposure to increasing temperatures results in carbonization of conodont matter that produces a progressive colour sequence of light to dark brown (CAI 1.5–4) to black (CAI 5), then grey (CAI 6) and white (CAI 7).

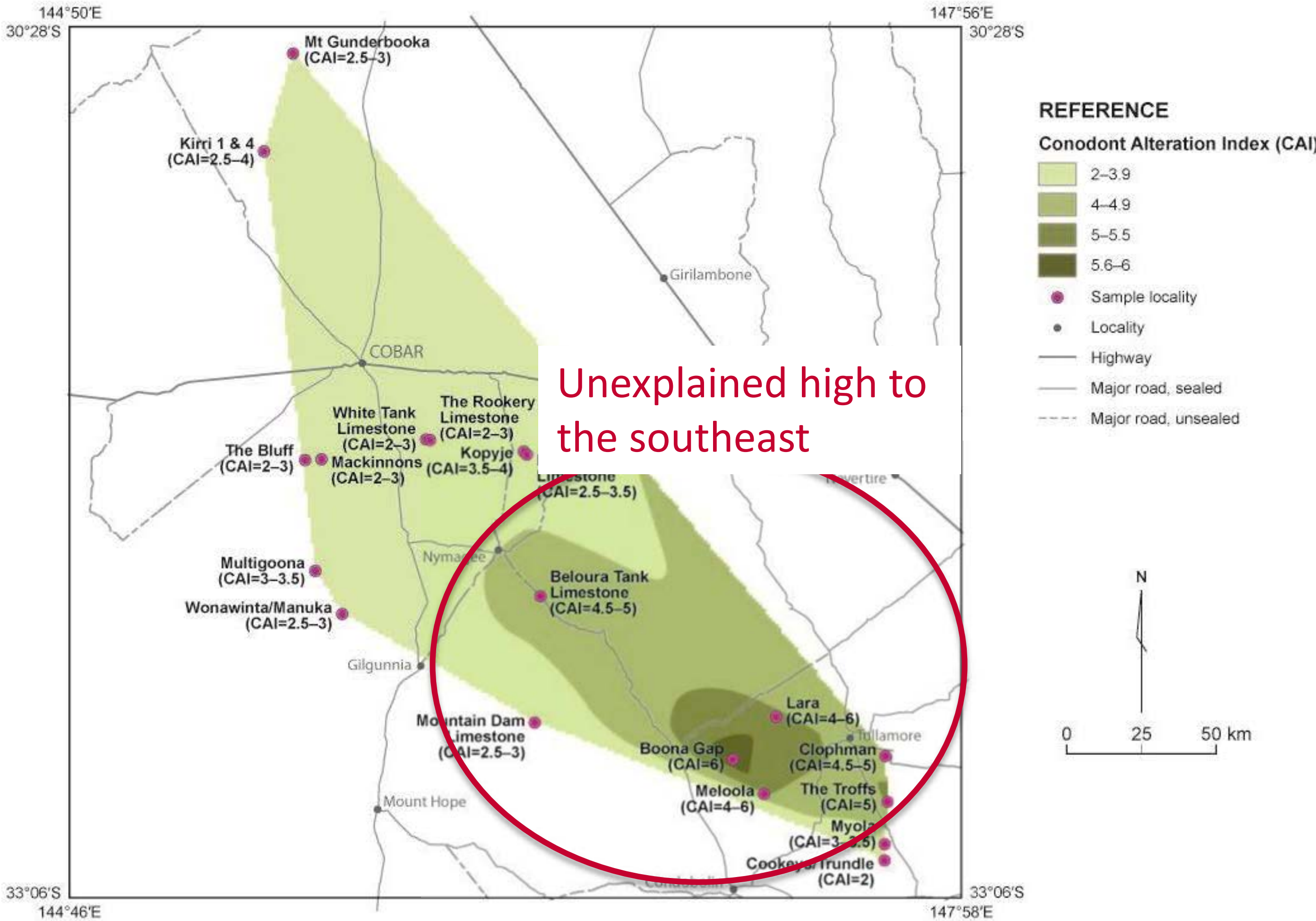
1) Virgin Hills (0-100^{o}C)

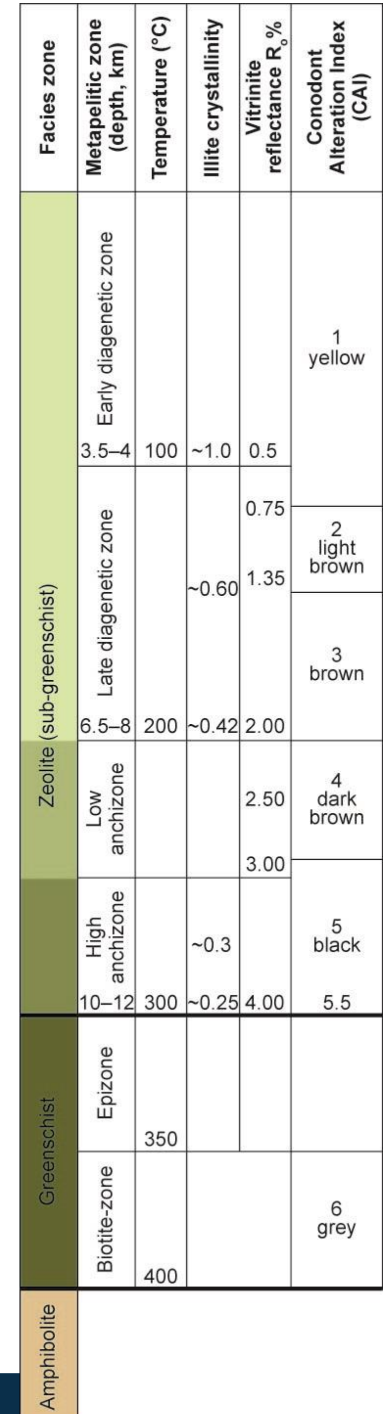
2) The Rookery (100-150^{o}C)

3) Manuka (150-200^{o}C)

5) Beloura Tank (250-300^{o}C)

Mapping heat in the Cobar Basin





Mapping heat in the Cobar Basin

Distal to mineralisation

- Illite crystallinity (Δ°2θCu-Kα) values
  - Kyne (2014) – CSA mine (0.24–0.27)
  - Brill (1988) – Endeavor mine (0.24–0.27)
- Fluid inclusions
  - Seccombe (1990) – Endeavor mine (170-225°C)
  - Giles (1993) – Manuka mine (~150°C)
- Chlorite thermometry
  - Bush (1980) – Mineral Hill mine (~150°C)
- Vitrinite reflectance
  - Robertson and Taylor (1987) – CSA mine (3.3–3.4)

Proximal to mineralisation

- Illite crystallinity (Δ°2θCu-Kα) values
  - Brill (1988) - CSA mine (0.25-0.21), Chesney mine (0.26-0.18)

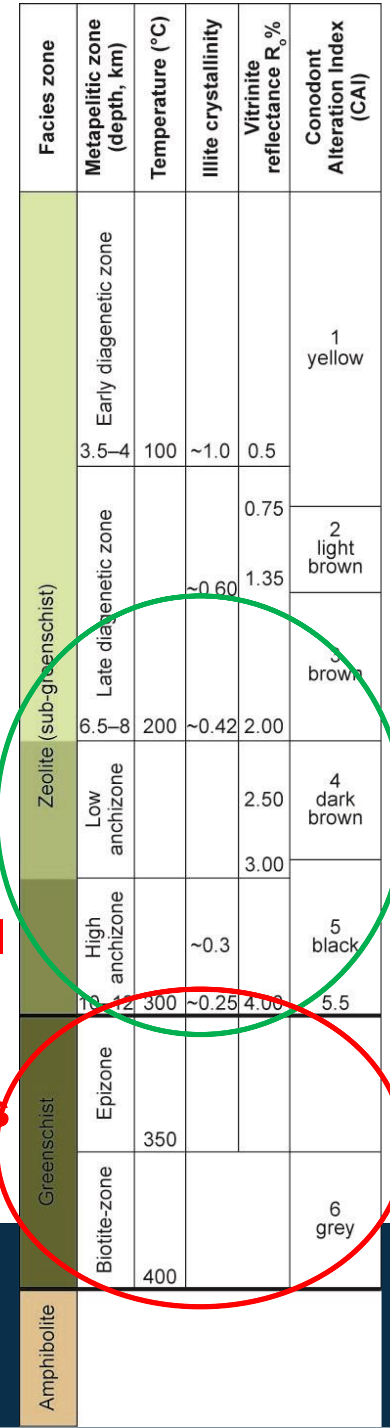
  Queen Bee mine (0.21-0.19), The Peak mine (0.29-0.21)
- Fluid inclusions
  - Giles & Marshall (2004) – CSA mine (350–380°C)
  - Sun & Secombe (2000) – Endeavor mine (286-374°C)
  - Forster & Secombe (2000) – Mackinnons mine (270-340°C)
- Chlorite thermometry
  - Page (2011) – Hera mine (270-365°C), Nymagee (292-394°C)
  - Bush (1980) – Mineral Hill mine (~300°C)

Temperatures of 150-250°C distal to mineralisation

Localised nature of heat

Temperatures of 300-380°C proximal to mineralisation.

Within 100's of meters

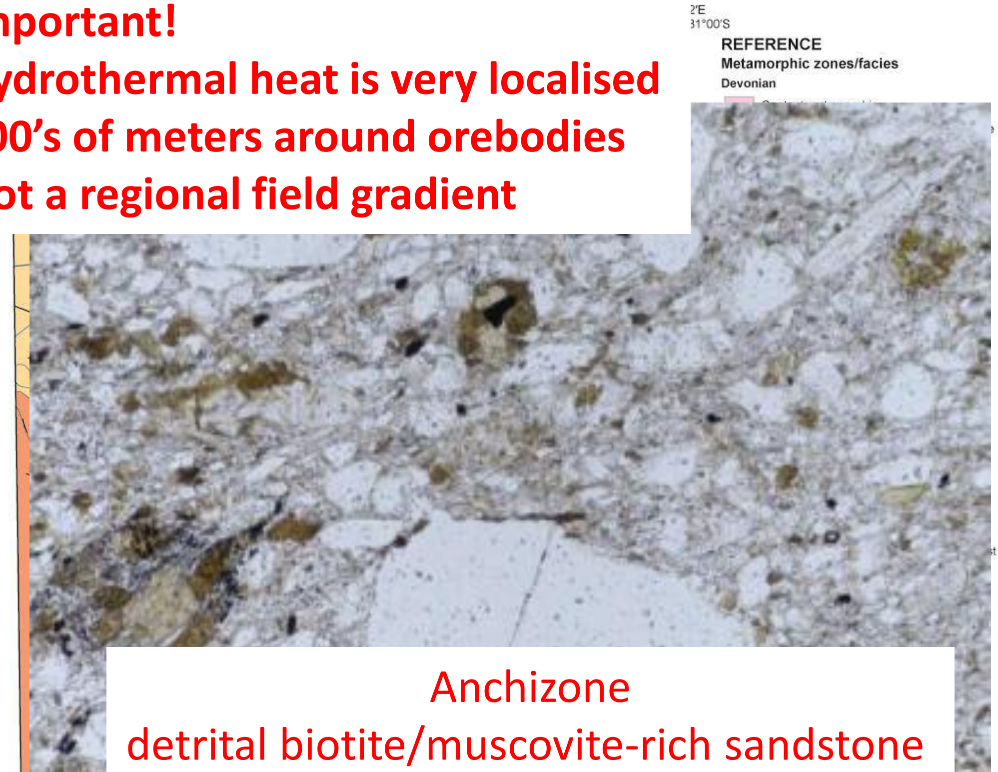


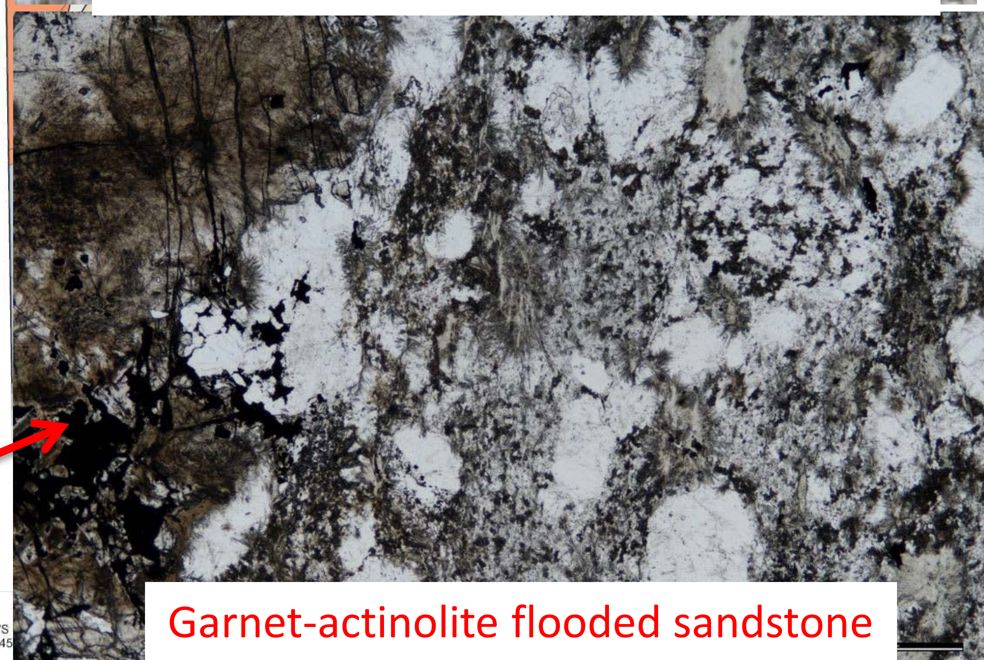
Department of Industry

Mapping heat

- Basement
  - Lower greenschist east of Gilmore
  - Sub-greenschist west of Gilmore
- Western Shelf
  - Diagenetic zone
- Deep water basin
  - Sedimentary – anchizone
  - Contact metamorphism
- Eastern shelf
  - Anchizone-middle greenschist
- Hydrothermal metamorphism
  - Close to major faults
  - Northeast – greenschist (biotite)
  - South – pyroxene hornfels facies

Important!
Hydrothermal heat is very localised
100's of meters around orebodies
Not a regional field gradient



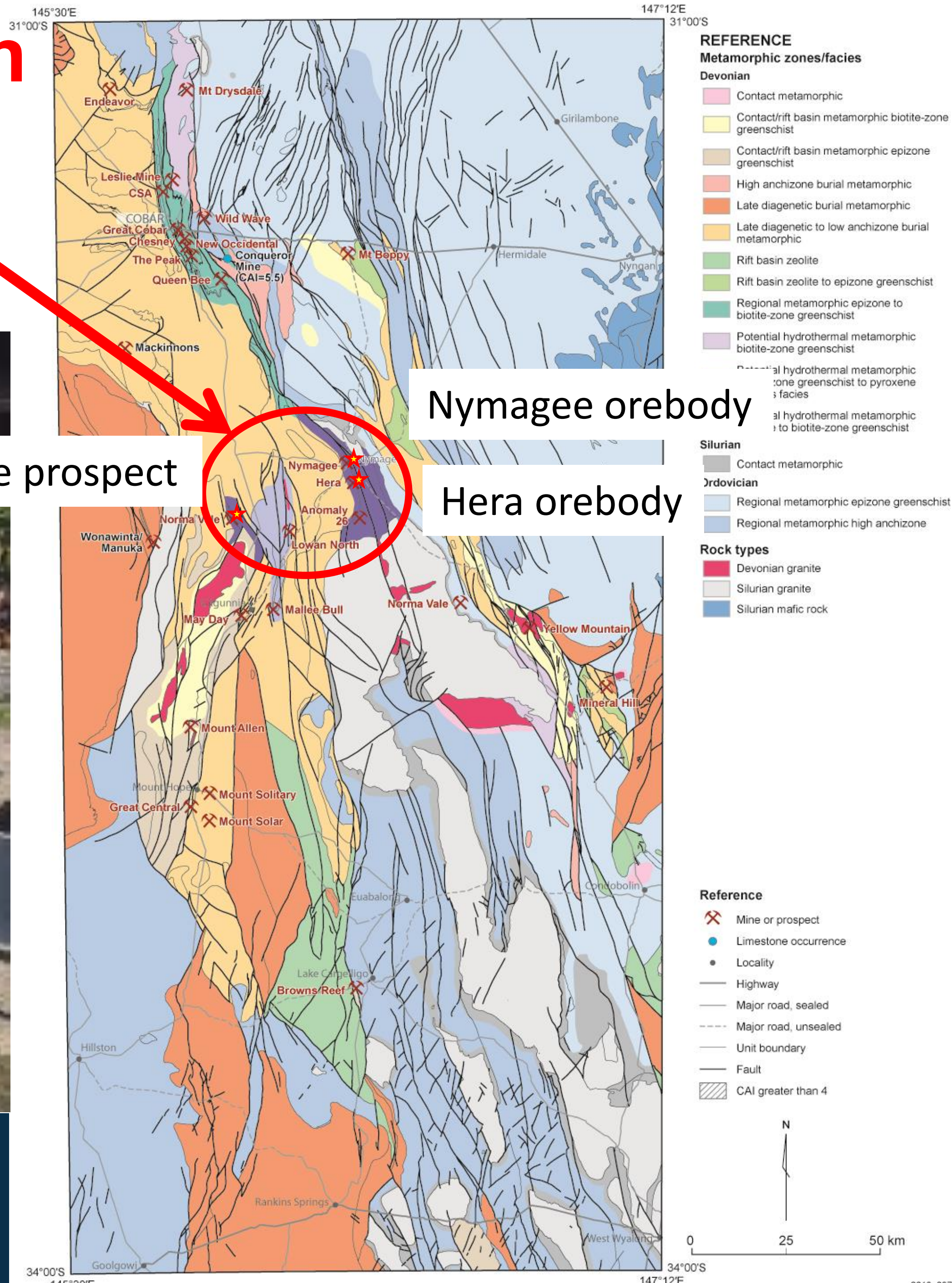


Tour mineralisation in Hydrothermal 'Hot Zone'

Norma Vale prospect

Nymagee orebody

Hera orebody



Hera orebody

- Au-Ag-Zn-Pb
  - Steeply west-dipping
  - Short strike length
  - Sulfide vein/breccia zones
  - Similar to other Cobar type deposits

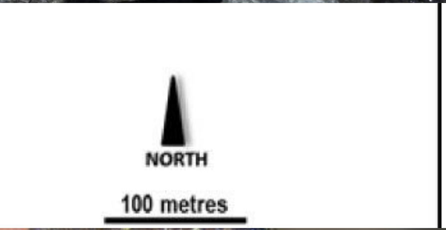
- Mineralisation hosted within intensely silicified siliciclastic turbidite

- Gold associated with sulfide zones, but not always within the sulfides

Intensely silicified turbidite

Sulfide breccia

Sulfide breccia



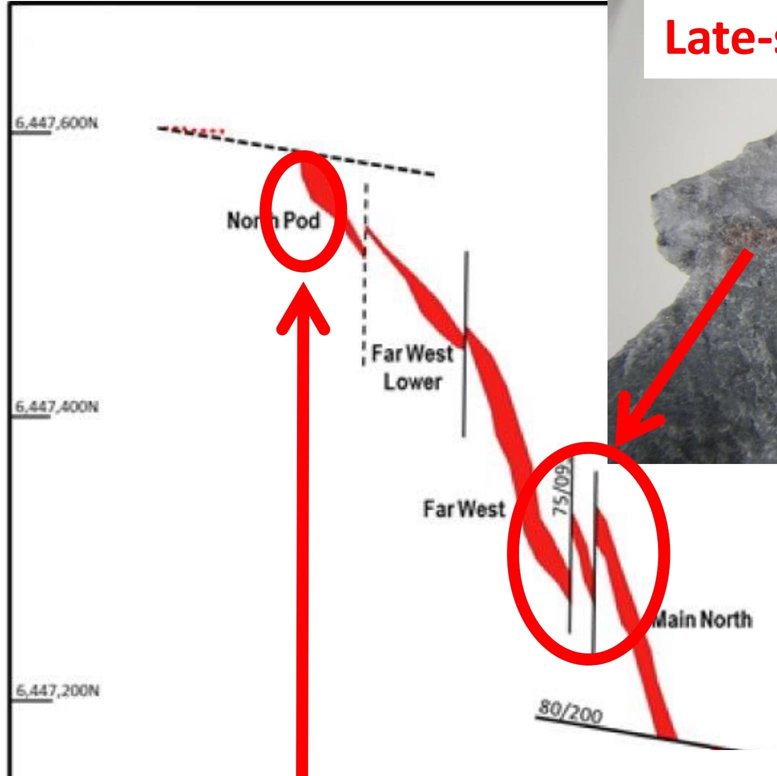
Gold in foliation

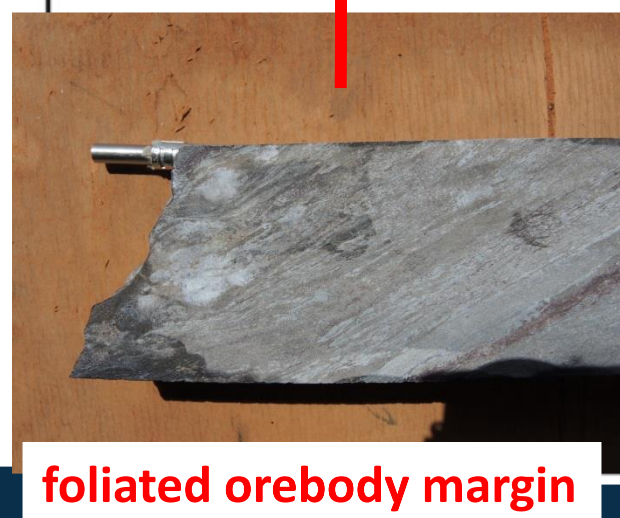
Gold and sphalerite

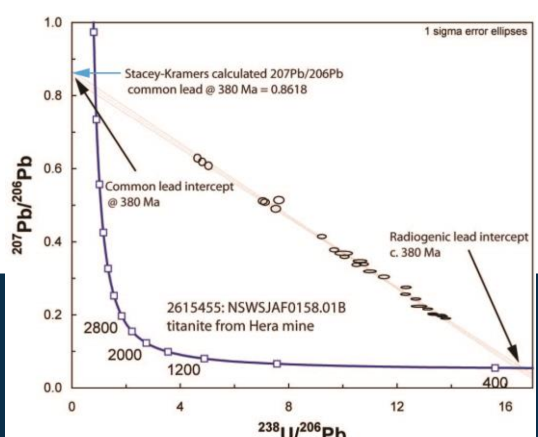
High-T minerals have been described

Hera Orebody

- Orebody interpreted as a single ?horizon
- Orebody enveloped by steeply west-dipping foliation
- Late (post-foliation) steeply east dipping thrust repartition
  - Titanite 380 Ma

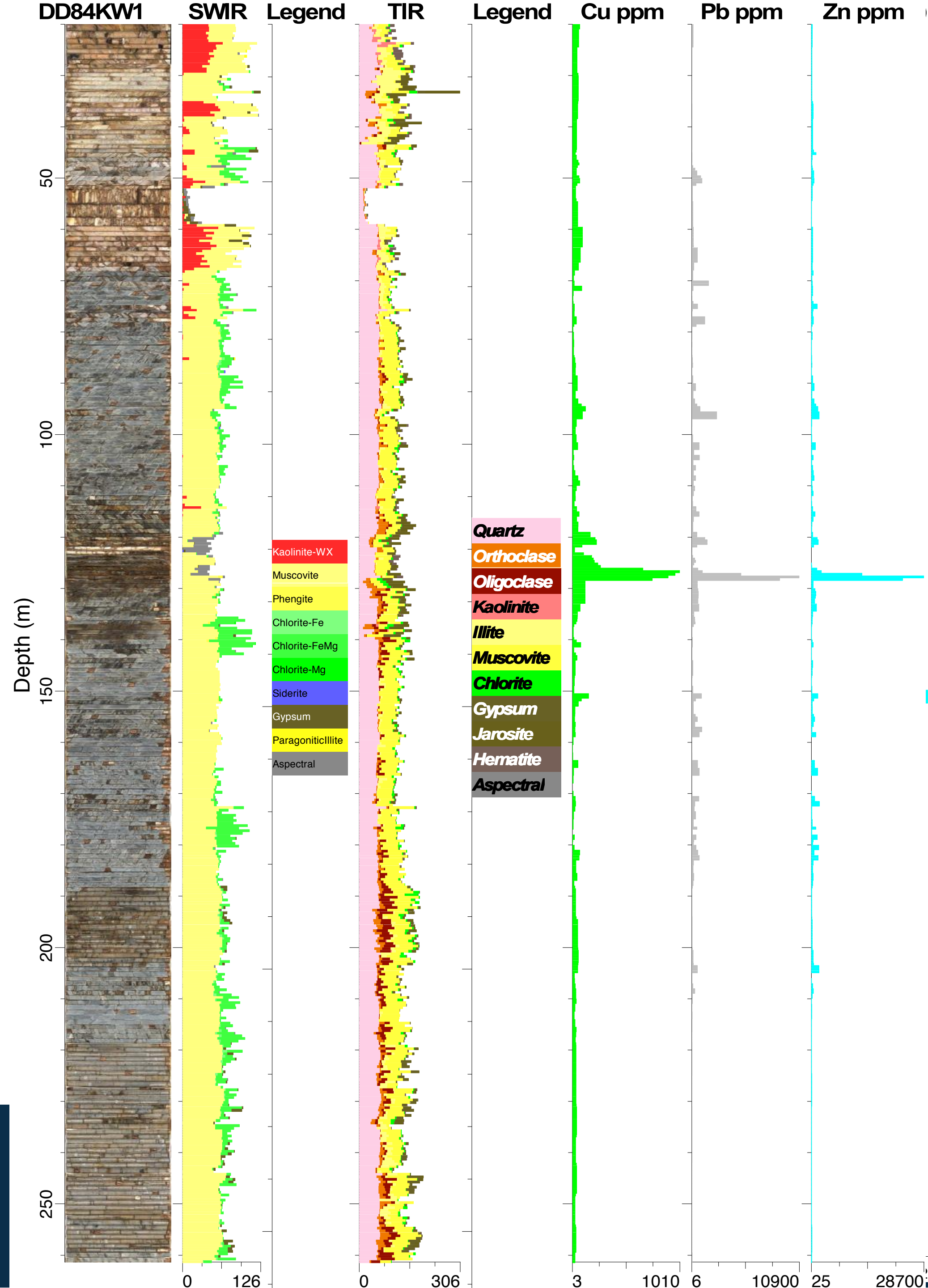






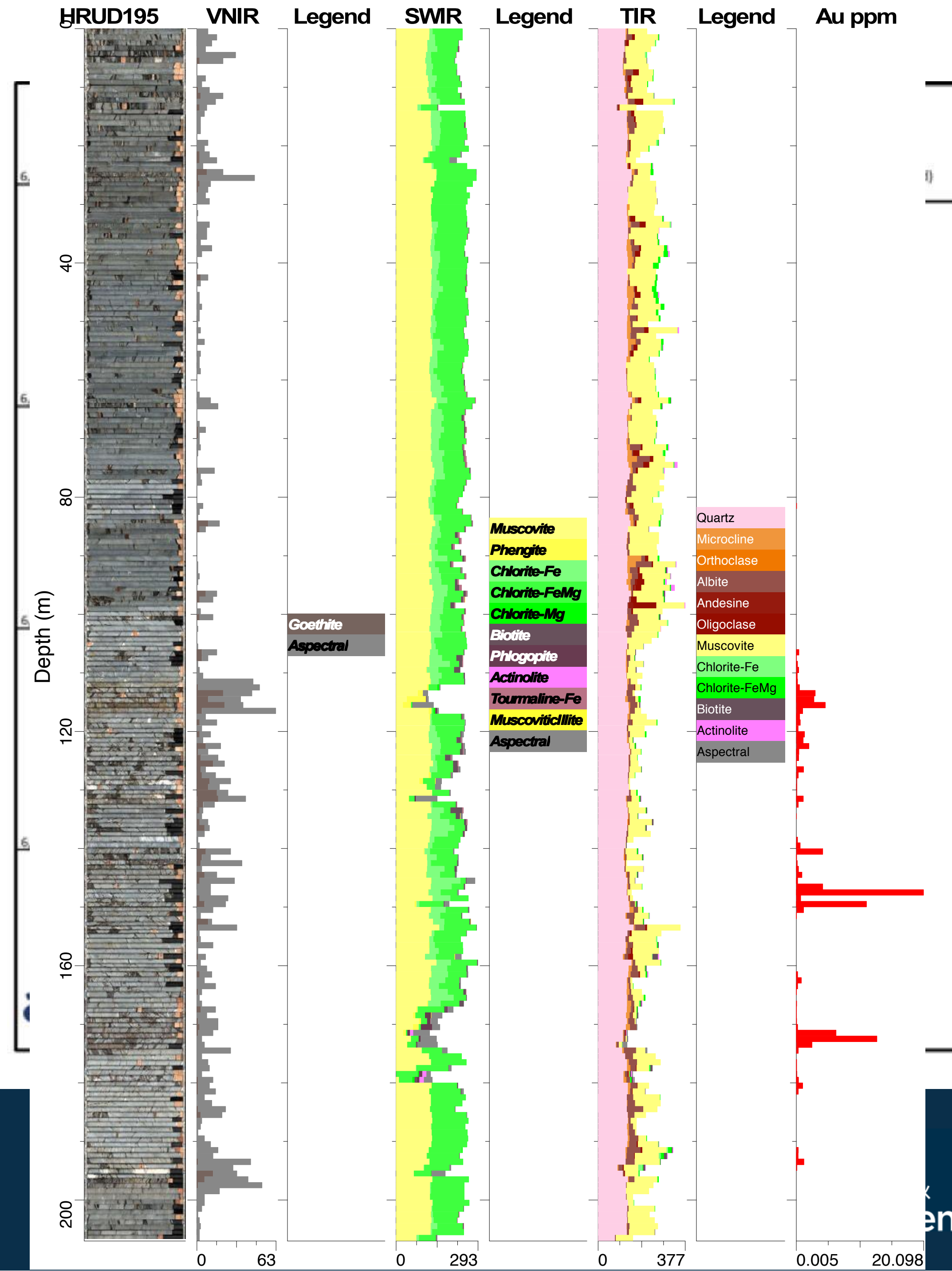
Hera orebody

- Nymagee Hylogger study.. Downes et al (2016)
- Drill holes from south of the main orebody
- Chlorite–phengitic muscovite dominant alteration.
- Chlorite becomes Mg-rich
- Sniff of K-feldspar
- Hylogger failed to pick up biotite
- But no signs of anything abnormal



Hera Orebody

- A drill hole through Main North and the top of Far West
- K-feldspar-biotite-actinolite
- Strongly overprinted by chlorite-albite.
- Suggestion of high-T potassic, calc-potassic alteration



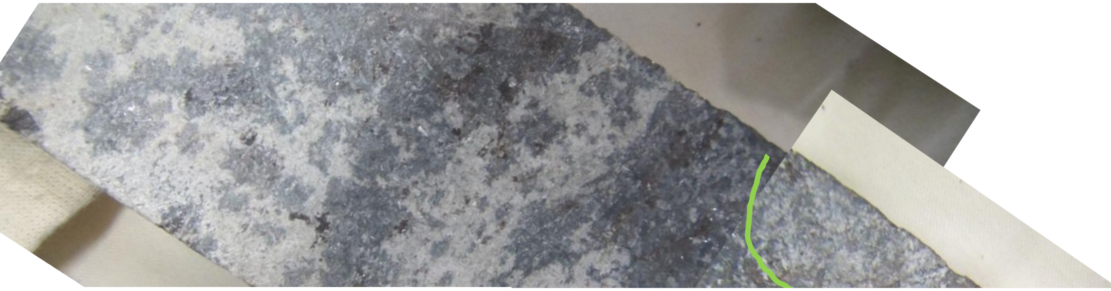
Hera Orebody - Digging deeper

Hera Orebody

- Into the skarn
  - Far West/North Pod
- Remnant high-T skarn and carbonate clasts
  - South to north zonation
  - Garnet-rich
  - Pyroxene-rich
  - Anorthite-scapolite
    (remnant carbonate)
- Siliciclastic-hosted skarn alteration and veins
  - South to north zonation
    - Garnet (±scheelite)
    - Biotite (±scheelite)

Hera Orebody

Hydrous retrogression & mineralisation



Complete tremolite replacement

Su

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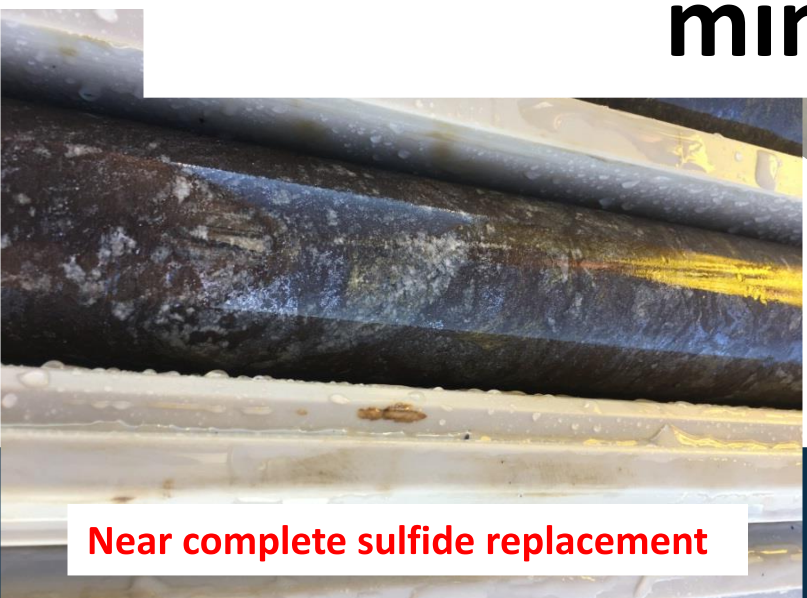
Compl

Rare to find high-T skarn due to pervasive retrogression and mineralisation



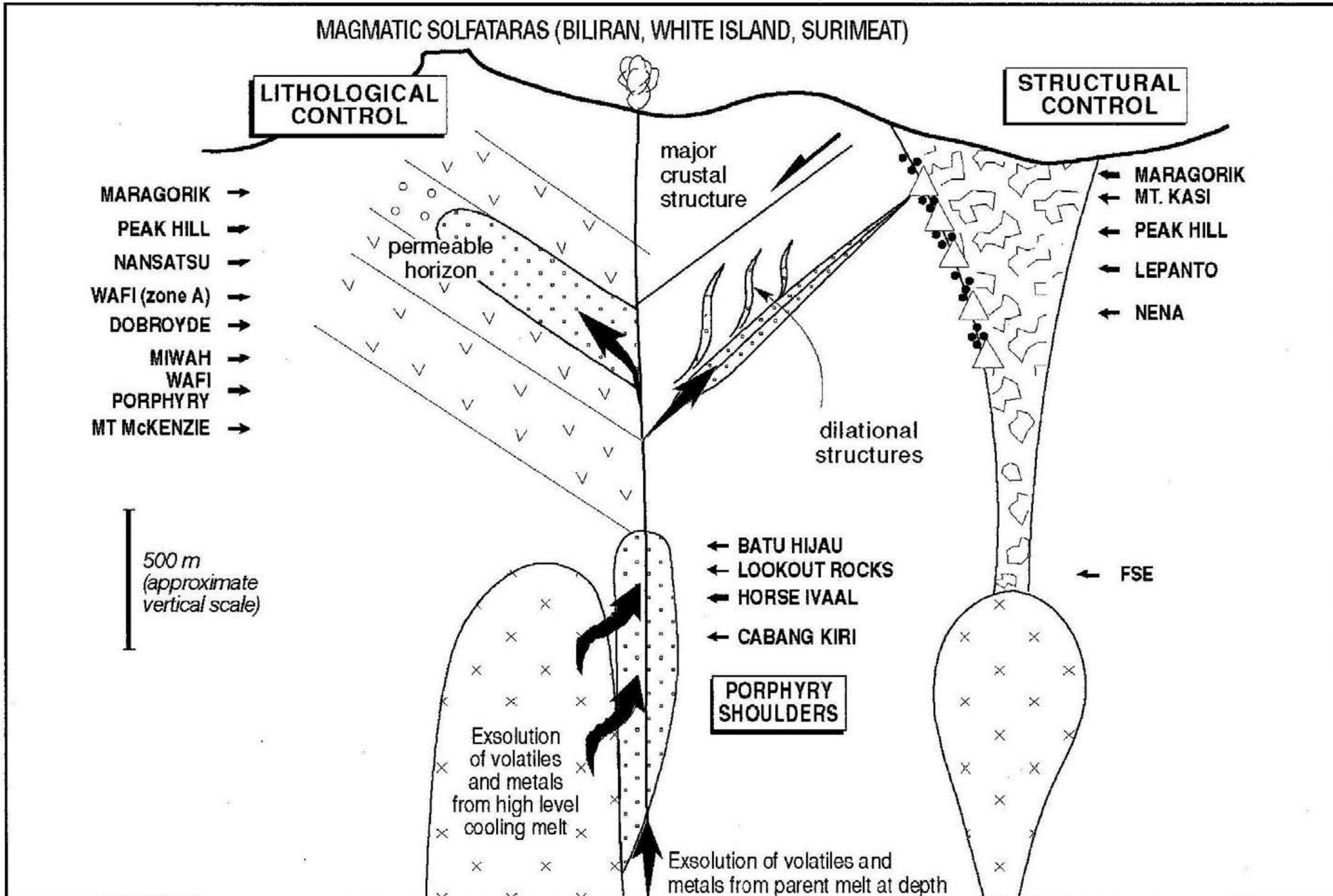
Near complete sulfide replacement

Garnet-pyroxene skarn

Sulfide-tremolite hydrous rind

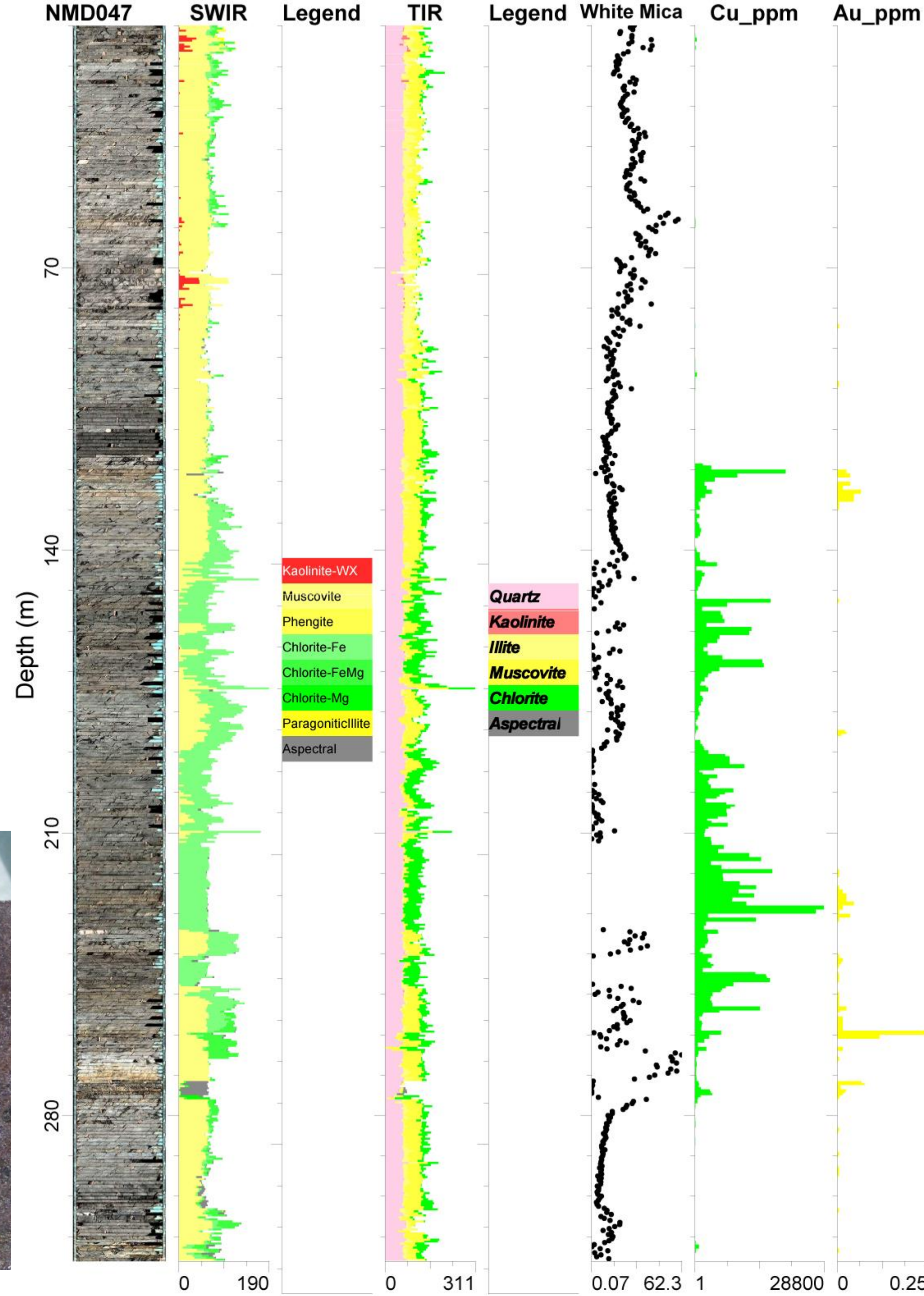
Textural preservation

Corbett and Leach



Nymagee Orebody

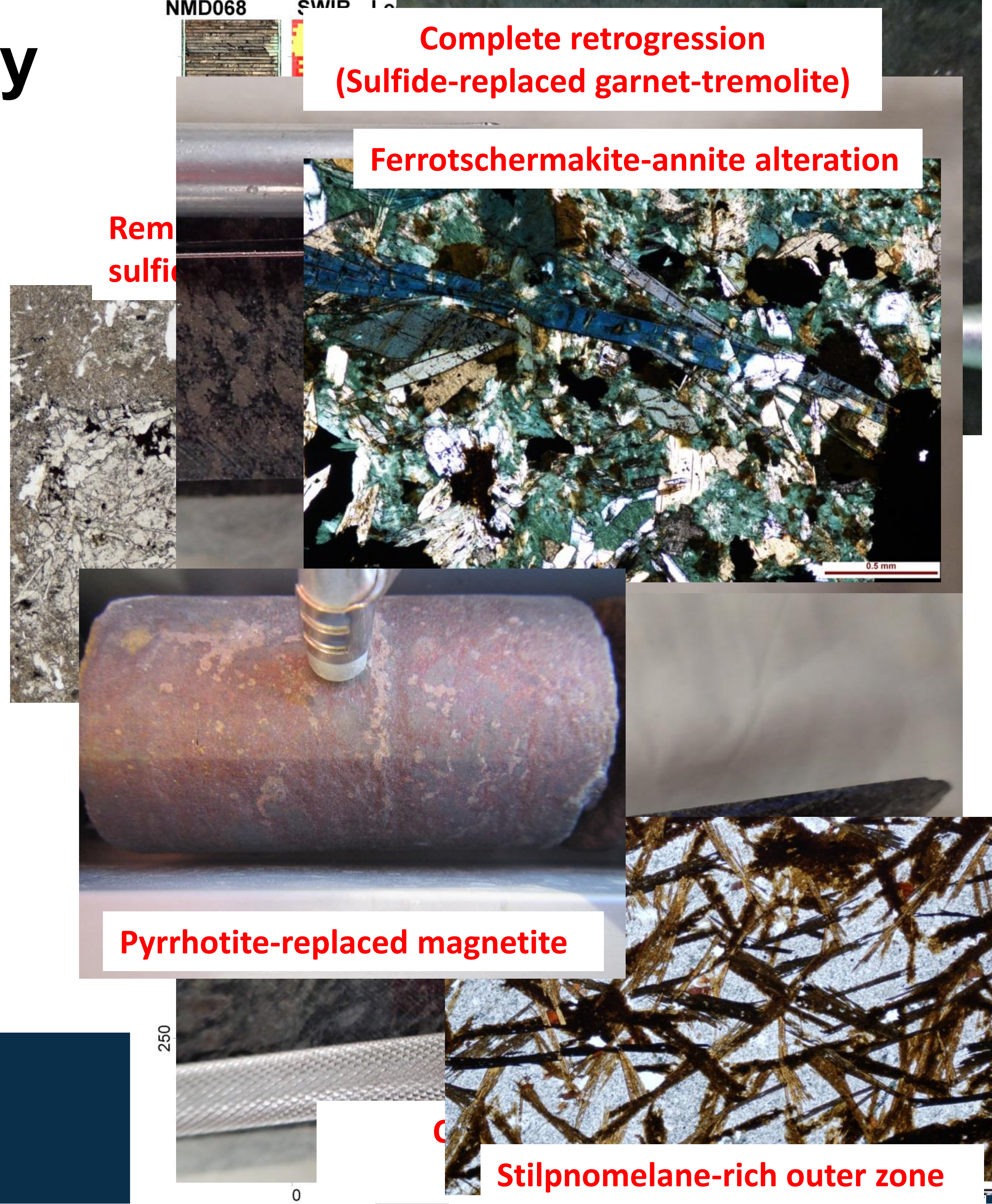
- Cu-Zn-Pb-Ag mineralisation in steeply west-dipping sulfide vein/breccia zones similar to other Cobar-type deposits
- Foliation envelopes orebody
  - Preliminary evidence of same bulky white quartz cross veins terminating ore lenses
- Metals zoned between lenses
  - Western zone is Zn-Pb-rich
  - Eastern zone is Cu-rich
- Initial magnetite-rich mineralisation overprinted by sulfides
- Muscovite-illite-chlorite-rich alteration



Nymagee Orebody - Digging deeper

Nymagee Orebody

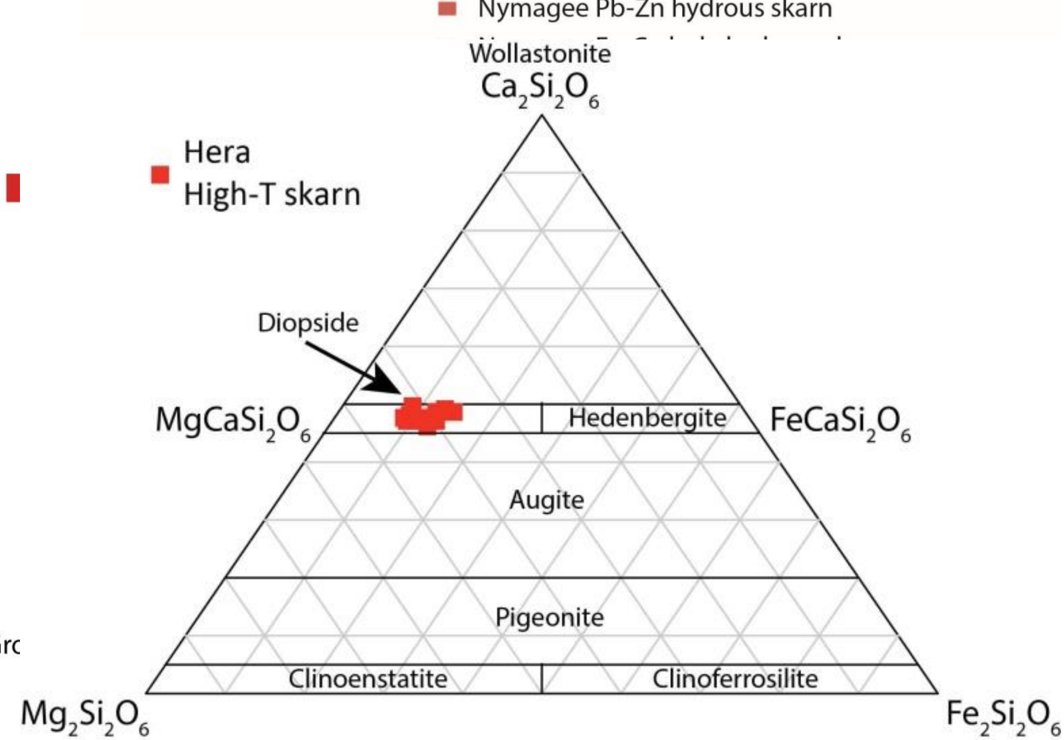
- Garnet-anorthite-zoisite-tremolite skarn
  - Coincident with mineralisation
- Pervasive retrograde evolution
  - Initial tremolite-sulfide
  - Pervasive chlorite-talc-muscovite-sulfide
    - Particularly Cu lodes
- Ferrotschermakite-annite-magnetite-rich skarn
  - Fe-pelite-hosted



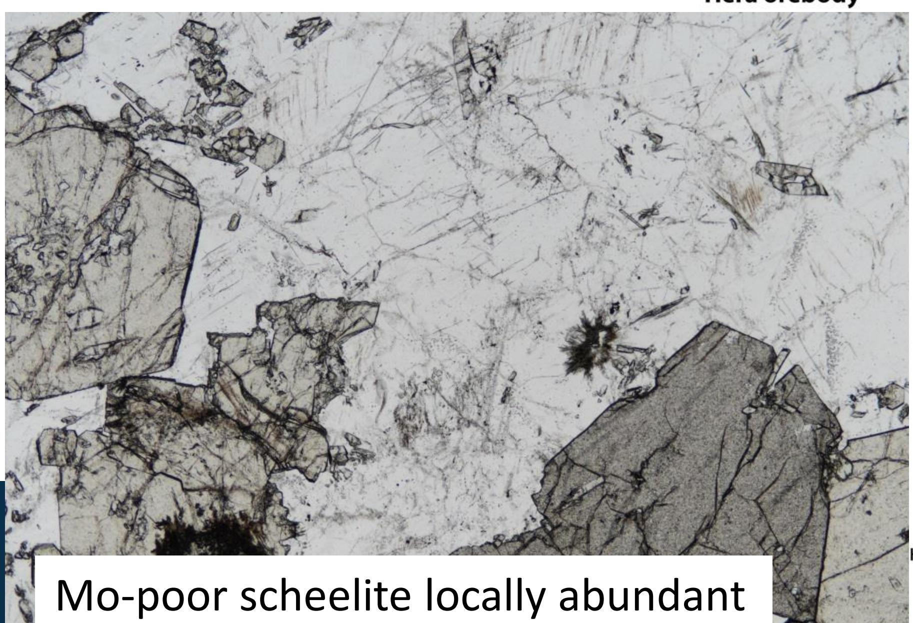
Hera-Nymagee Orebodies

Silicate mineral chemistry

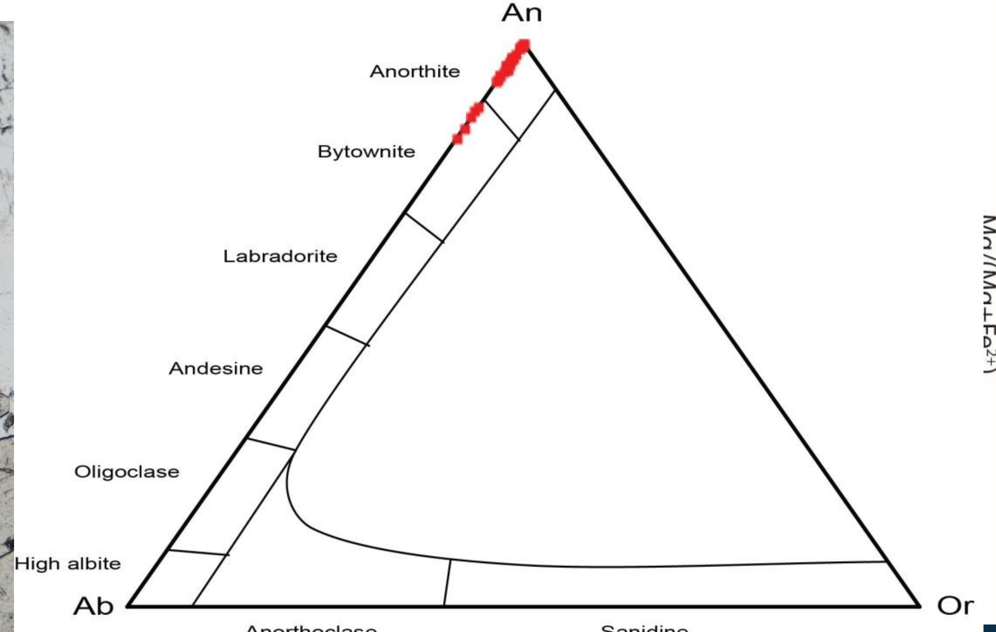
- Garnet = sub-calcic
  - Siliciclastic = spessartine
  - Carbonate = grossular
- Initial carbonate → zoisite-rich



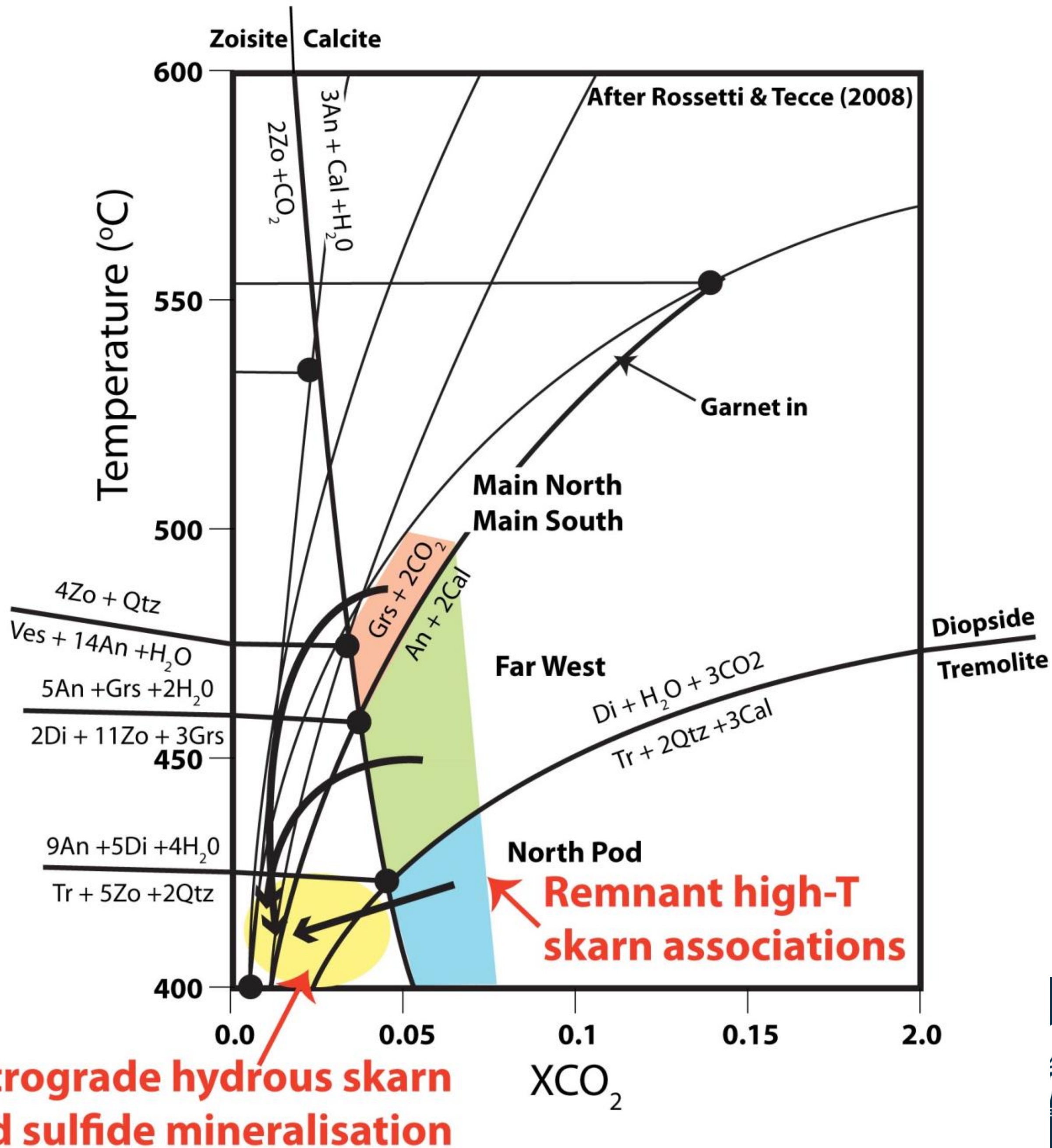
Hera orebody



Mo-poor scheelite locally abundant



Schematic T-XCO_2 at 1.5 Kbar
CaO-MgO-Al2O3-SiO2-H2O-CO2



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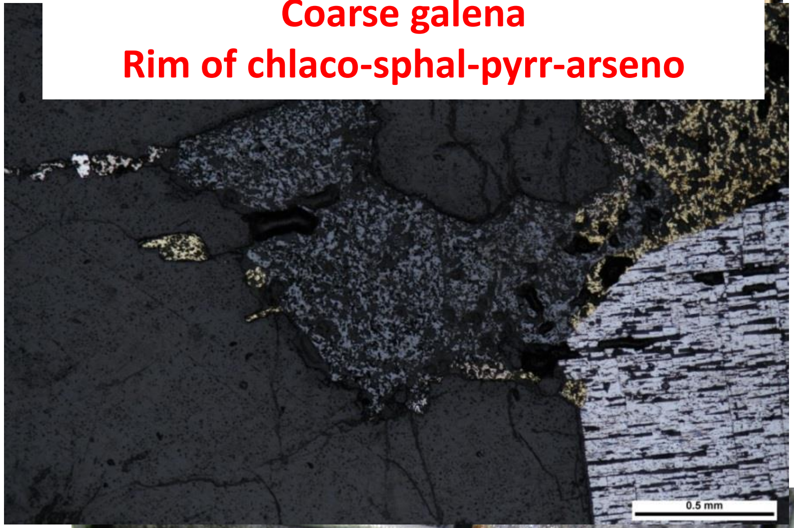
~~The black arts~~ Isotopes

- **Pb²⁰this over Pb²⁰that Hera and Nymagee:**
  - Crustal lead isotopic signature with a lead model age of (Downes et al 2016)
    - ~420 Ma and 420-428 Ma respectively
    - I think latest is 400 odd Ma?, but seems to be a lot of recent change?
  - **Consistent with age of basin deposition and igneous activity, Maybe younger?**

- **S Hera and Nymagee**
  - $\delta^{34}S$ (‰) multiple sulfides range of 3-10
    - Downes (2016)
    - paragenetically unconstrained
  - Sulfides constrained from single lens hydrous skarn only Hera orebody
    - $\delta^{34}S$ (‰) ranges from 3-5

Low numbers consistent with magmatic S input, possibly mixed with formational

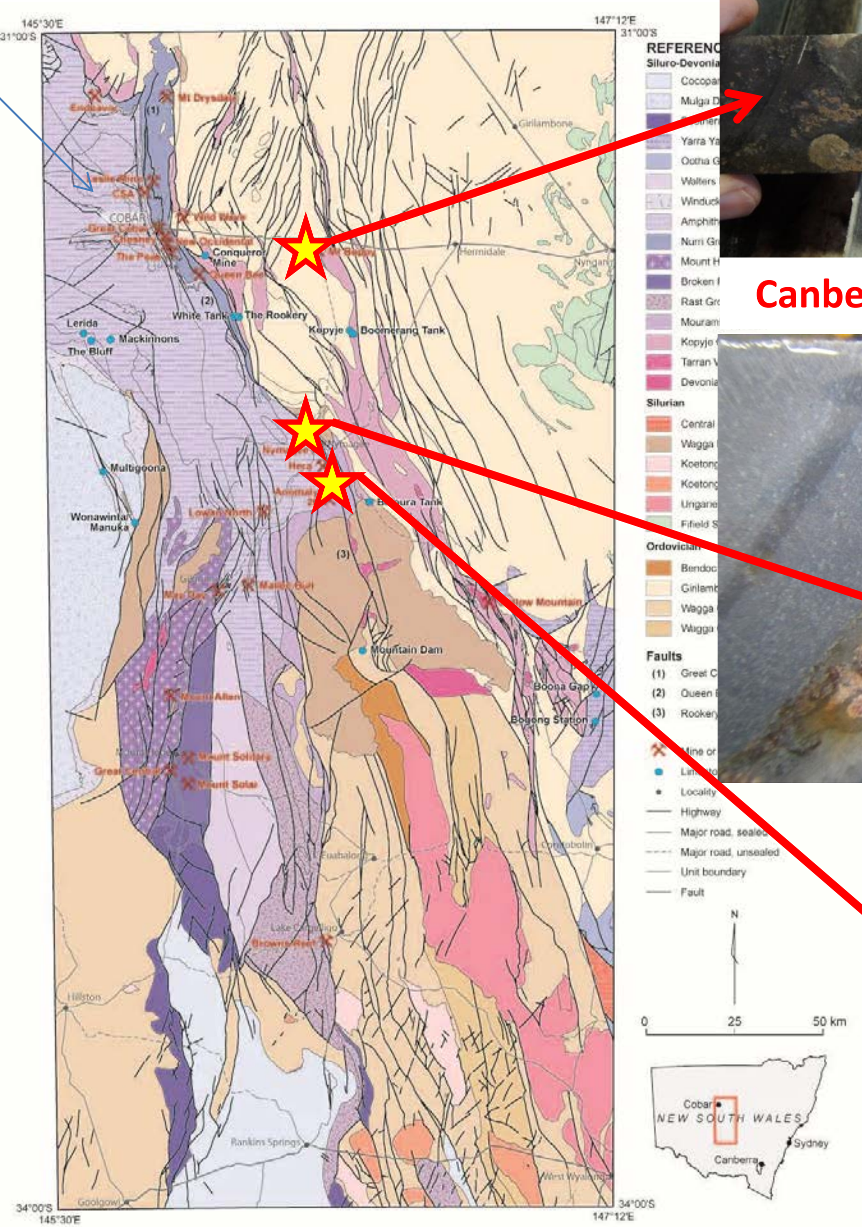
Coarse galena
Rim of chlaco-sphal-pyrr-arseno



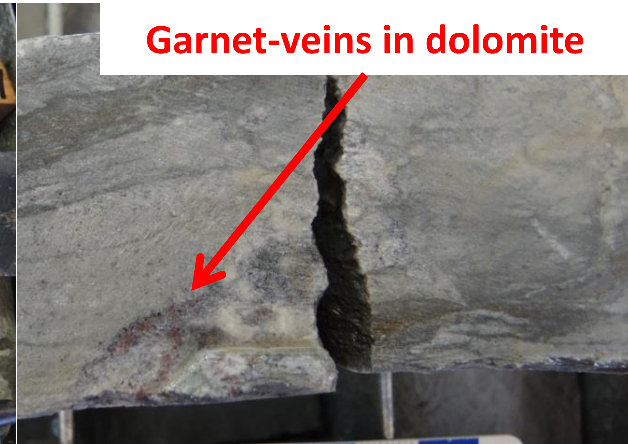
Late massive galena
(post foliation)

Hydrous skarn galena

One off?




Canbelego magnetite skarn


Garnet-veins in dolomite


Happy Jacks, garnet-rich vein/zone


Hebe quartz-garnet-scheelite veins

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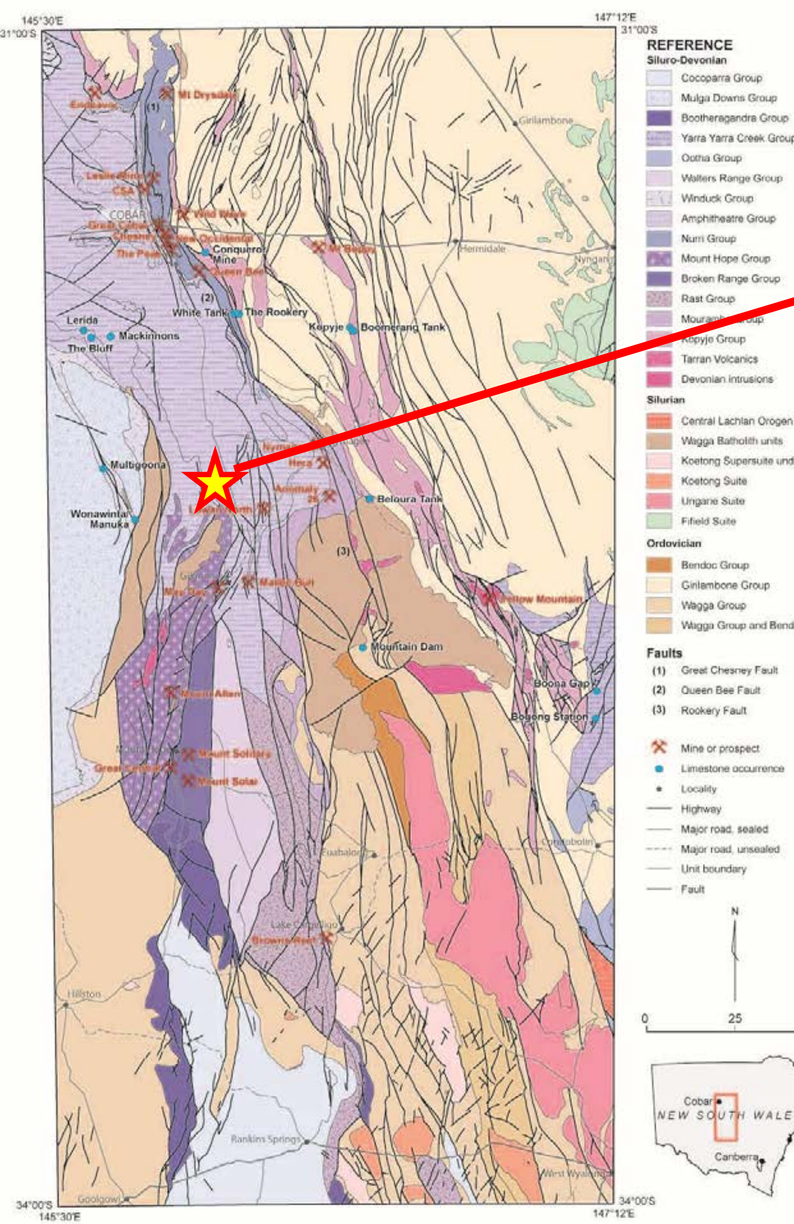
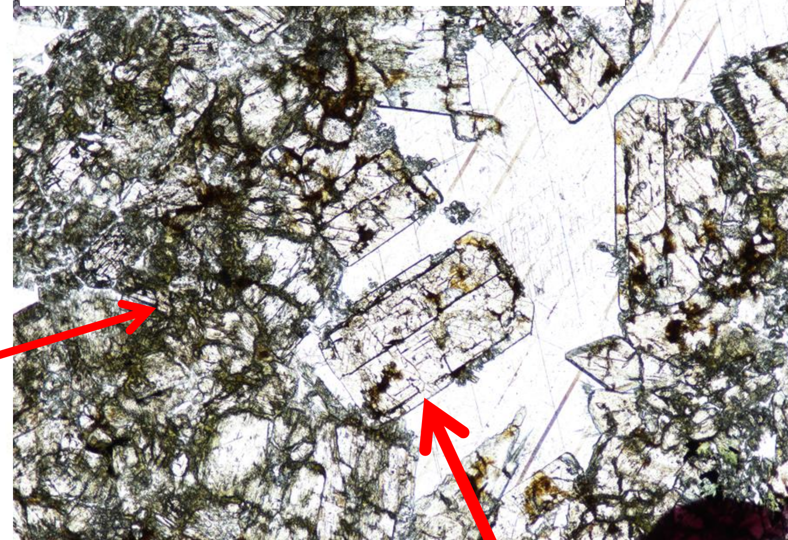
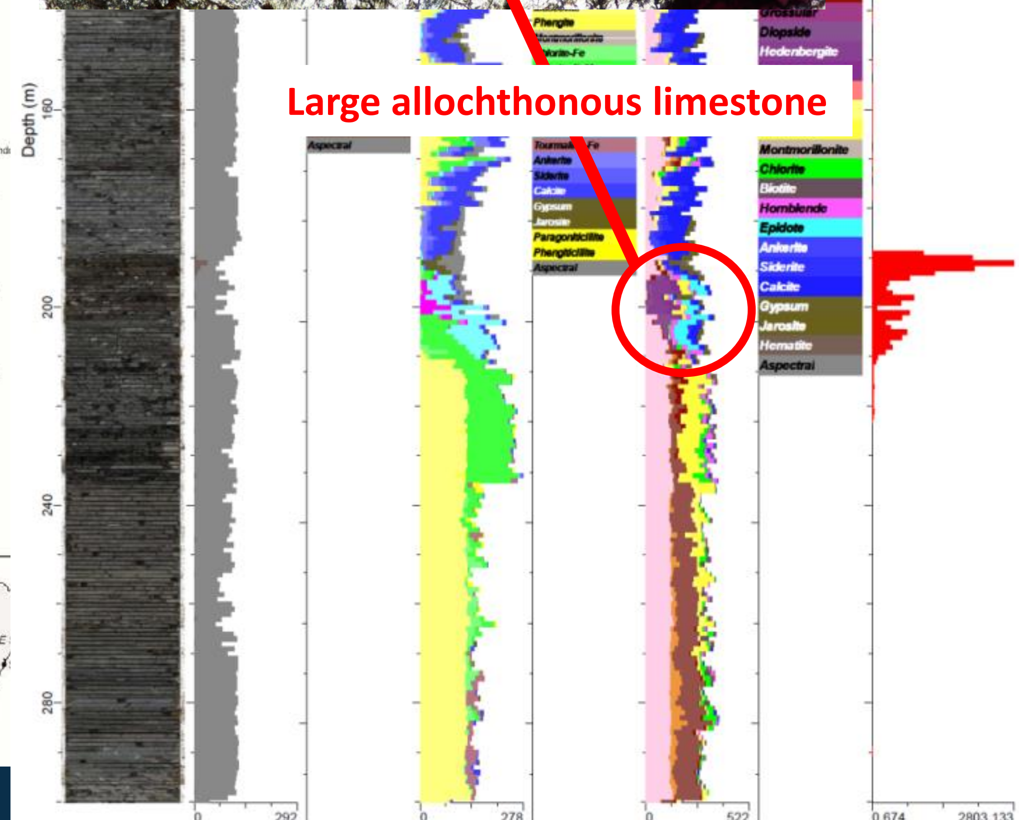
Norma Vale







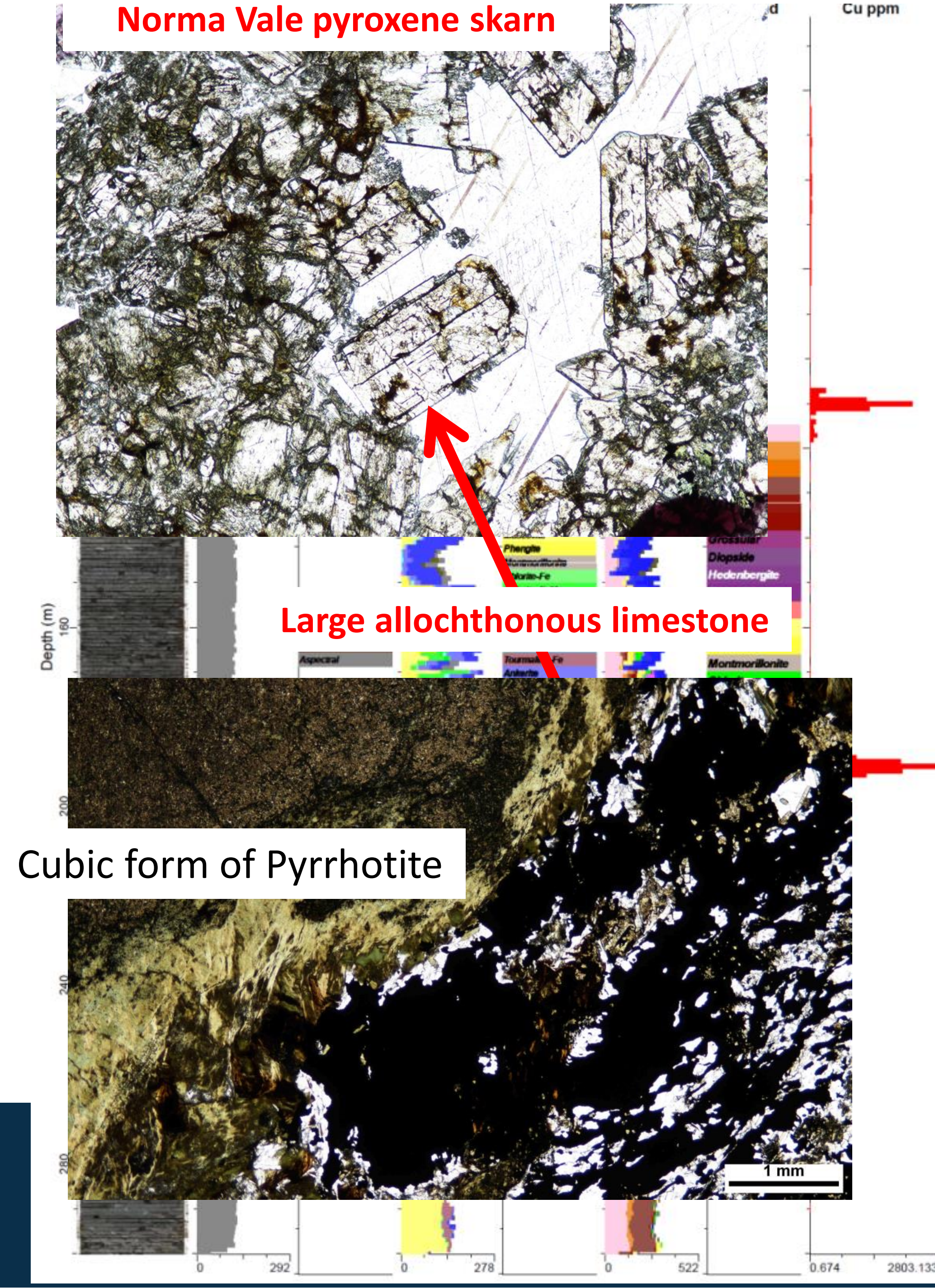
Norma Vale pyroxene skarn

Large allochthonous limestone

Norma Vale

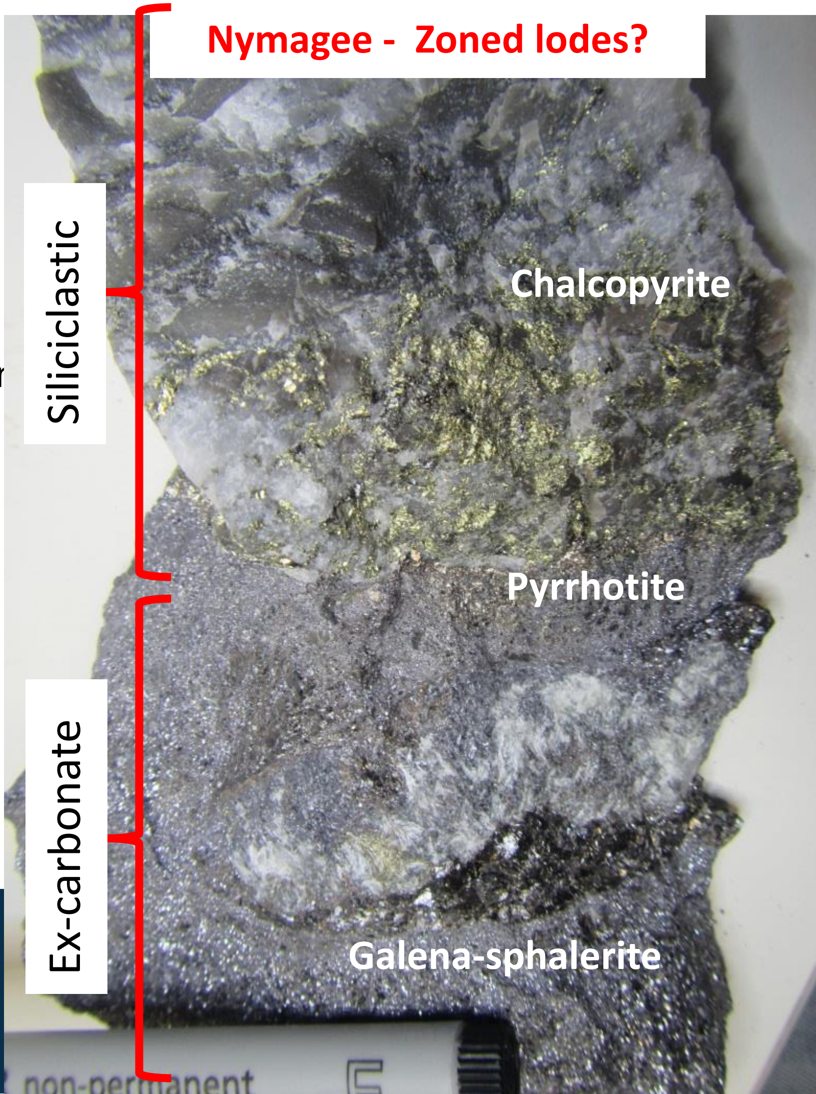
Silicate mineral chemistry

- Garnet = sub-calcic
  - Siliciclastic = spessartine
  - Carbonate = grossular
- Carbonate-rich skarn
- Pyroxene = Hedenbergite
- Sulfides phase
  - Fe-rich stilpnomelane
  - Fe-rich epidote
  - Amphibole = actinolite

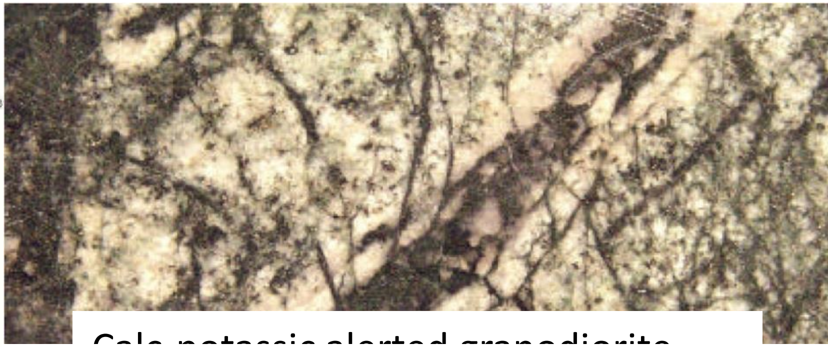


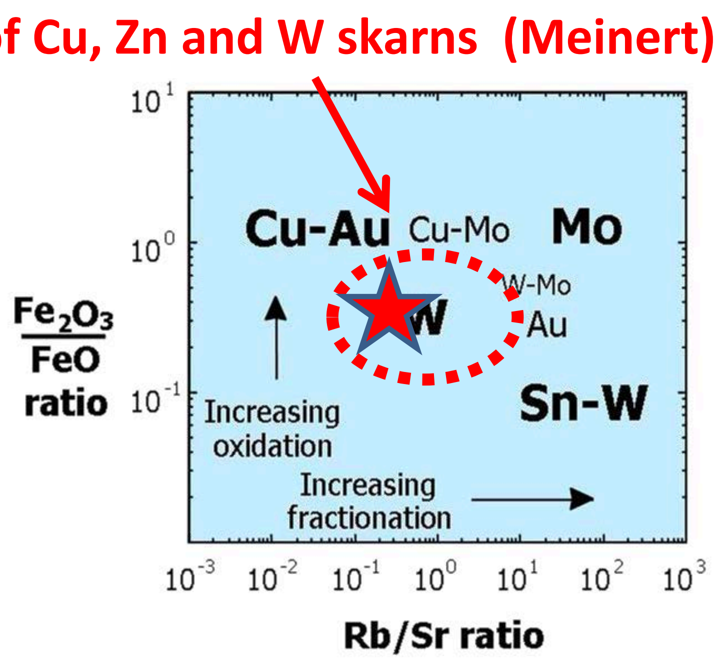
What is a southern Cobar-type?

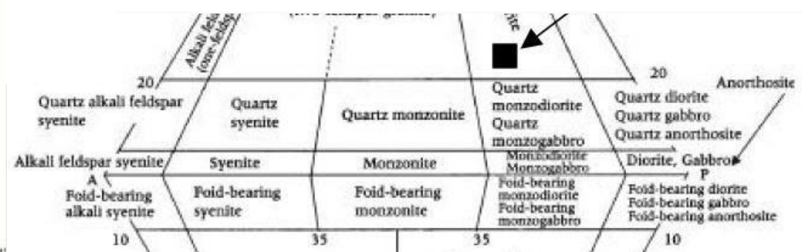
- **Secret herbs and spices**
  - **Never deeply buried**
    - Anchizone basin (250°C) with very local zones of thermal perturbation up to ?500°C
  - **Carbonate-bearing stratigraphy**
    - Allochthonous horizon
  - No direct link to intrusive rocks
    - But, high heat flow, skarn development and…
  - **Hera** Zn(W)-Au skarn
    - Consistent with strongly reduced, low CO_2 Zn-skarn
      - Low-Mo scheelite, sub-calcic garnet
      - Zoisite-anorthite-rich skarn
      - Mn-enriched calc-silicate mineralogy
  - **Nymagee** Fe-Cu and Pb-Zn-(Cu) skarn
    - Early Fe-Oxide evolving to pyrrhotite-chalcopyrite
      - Usual ferrotschermakite hydrous skarn
    - Zn-Pb lodes consistent with low CO_2 Zn-Skarn
      - Zoisite-anorthite-rich
      - Mn-enriched calc-silicate mineralogy

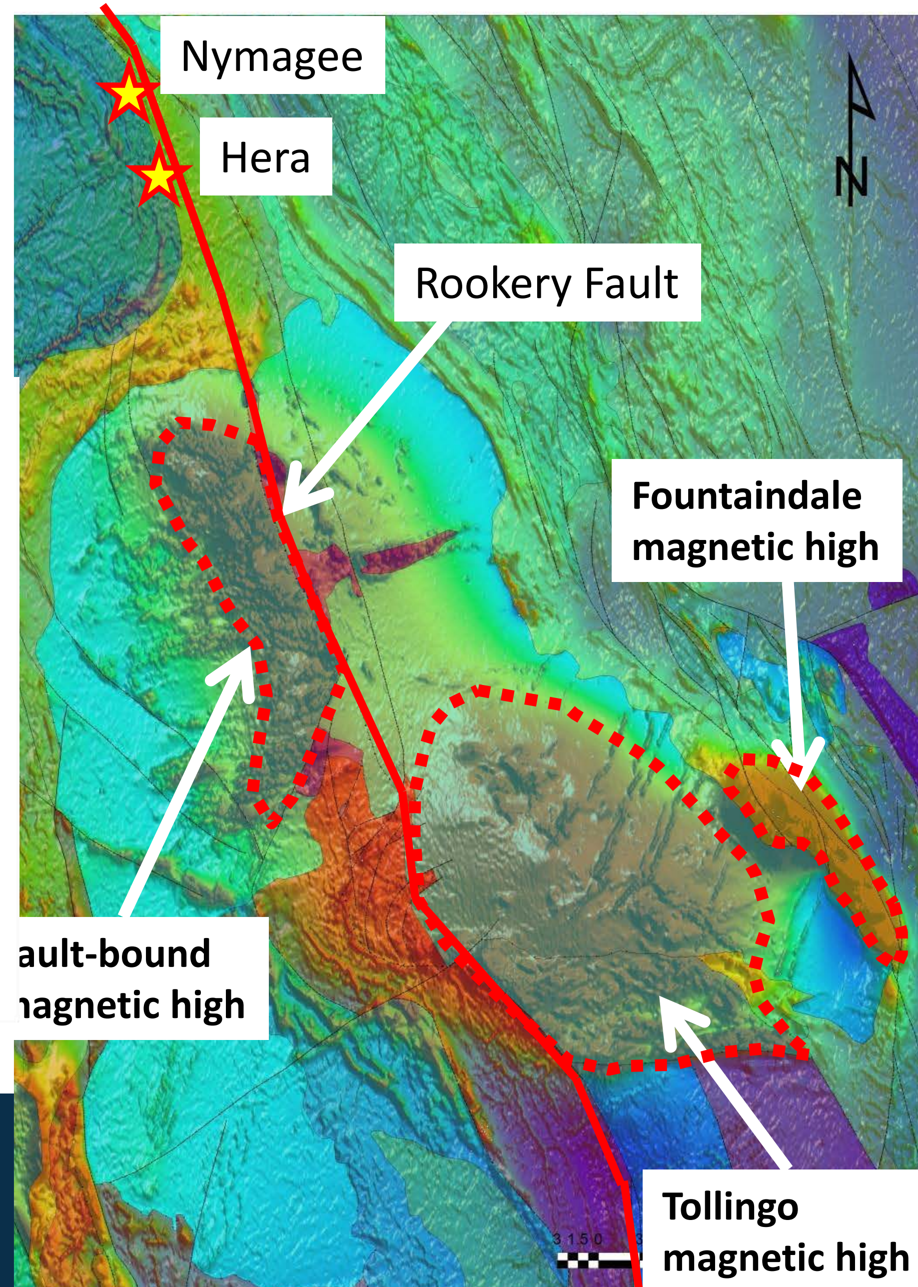


c. 420 Ma I-type magmatism - a link?

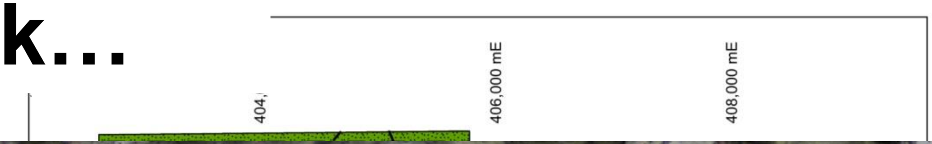


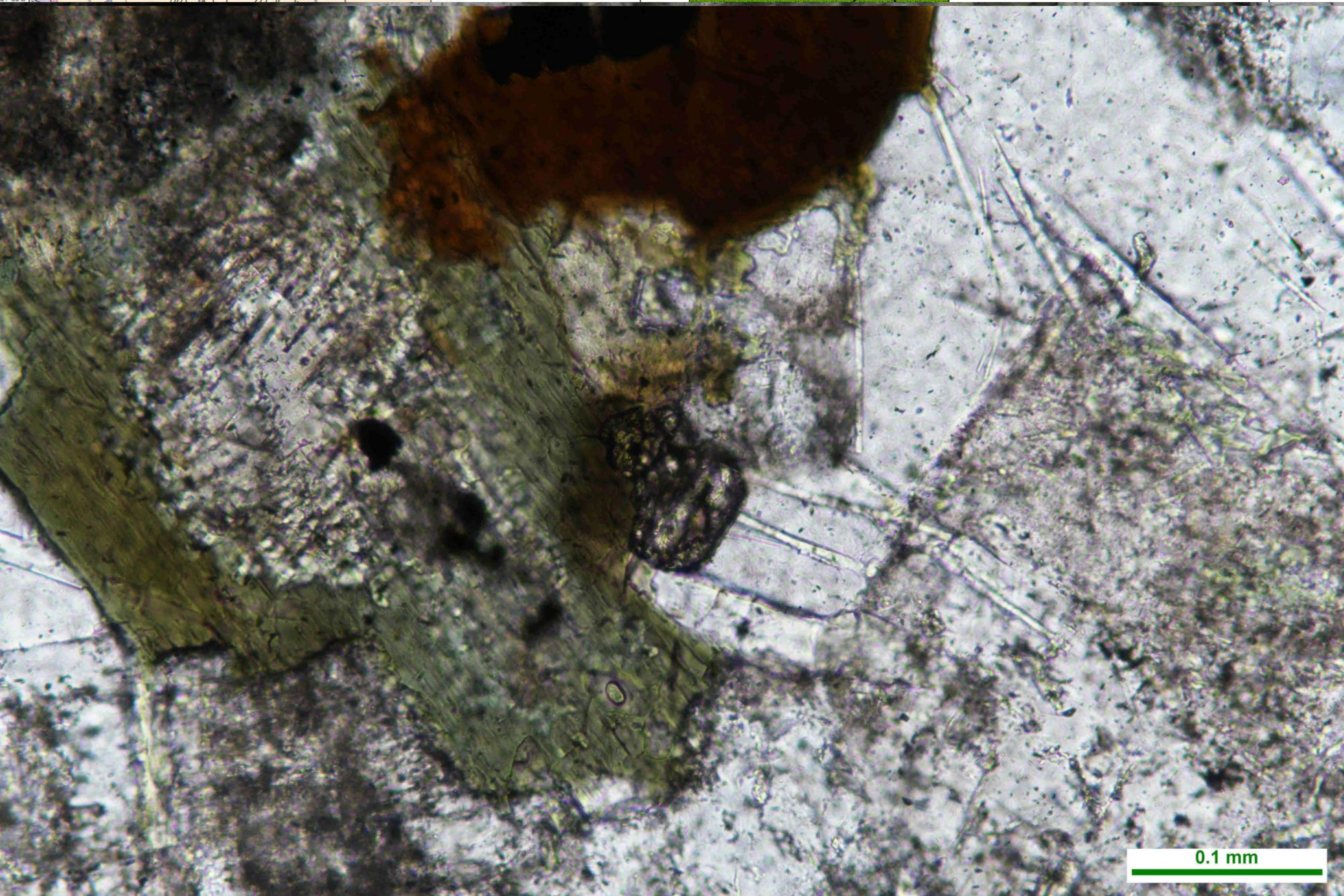




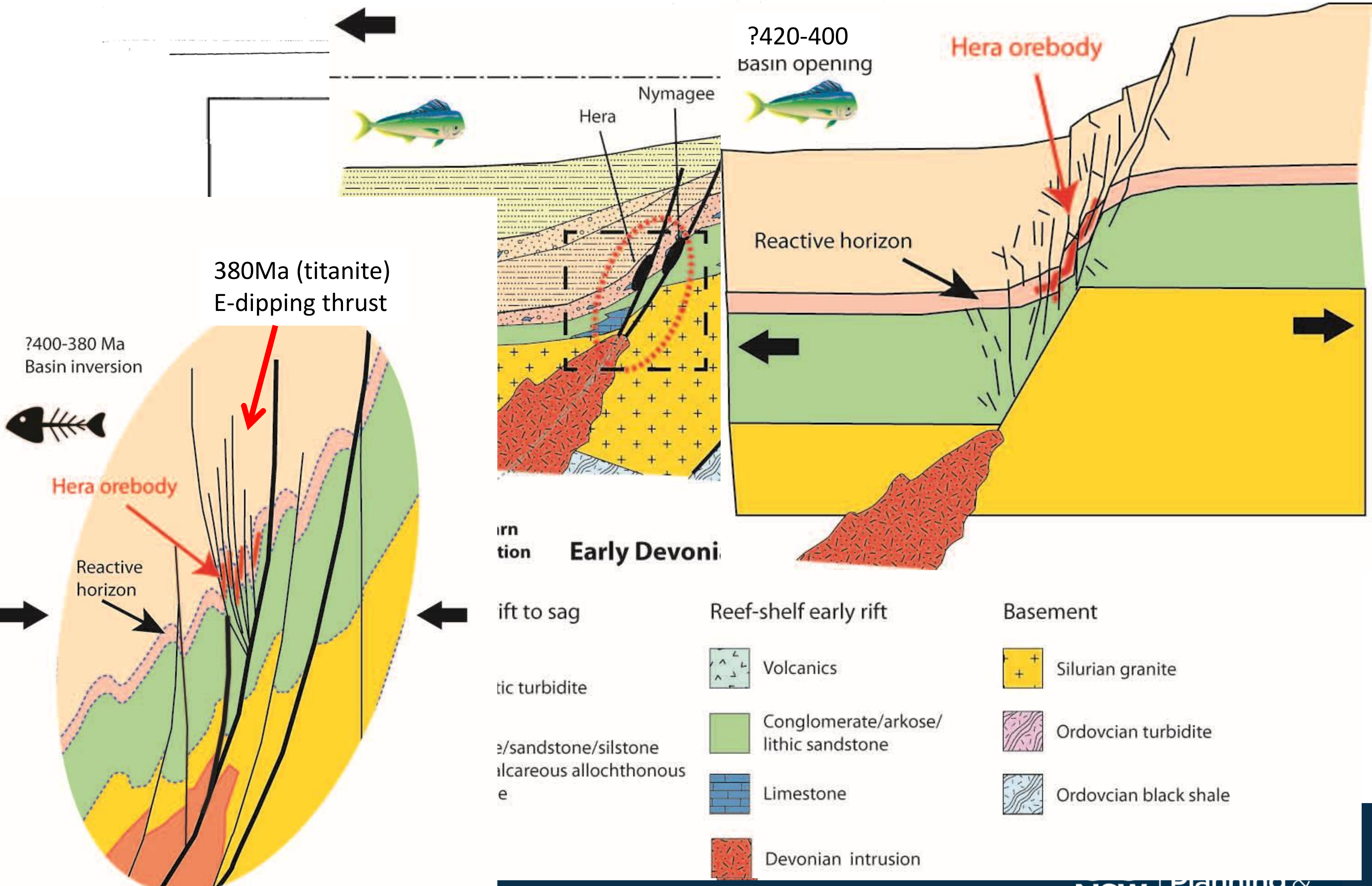


Norma Vale, mafic link…





• **Southern skarn formation**



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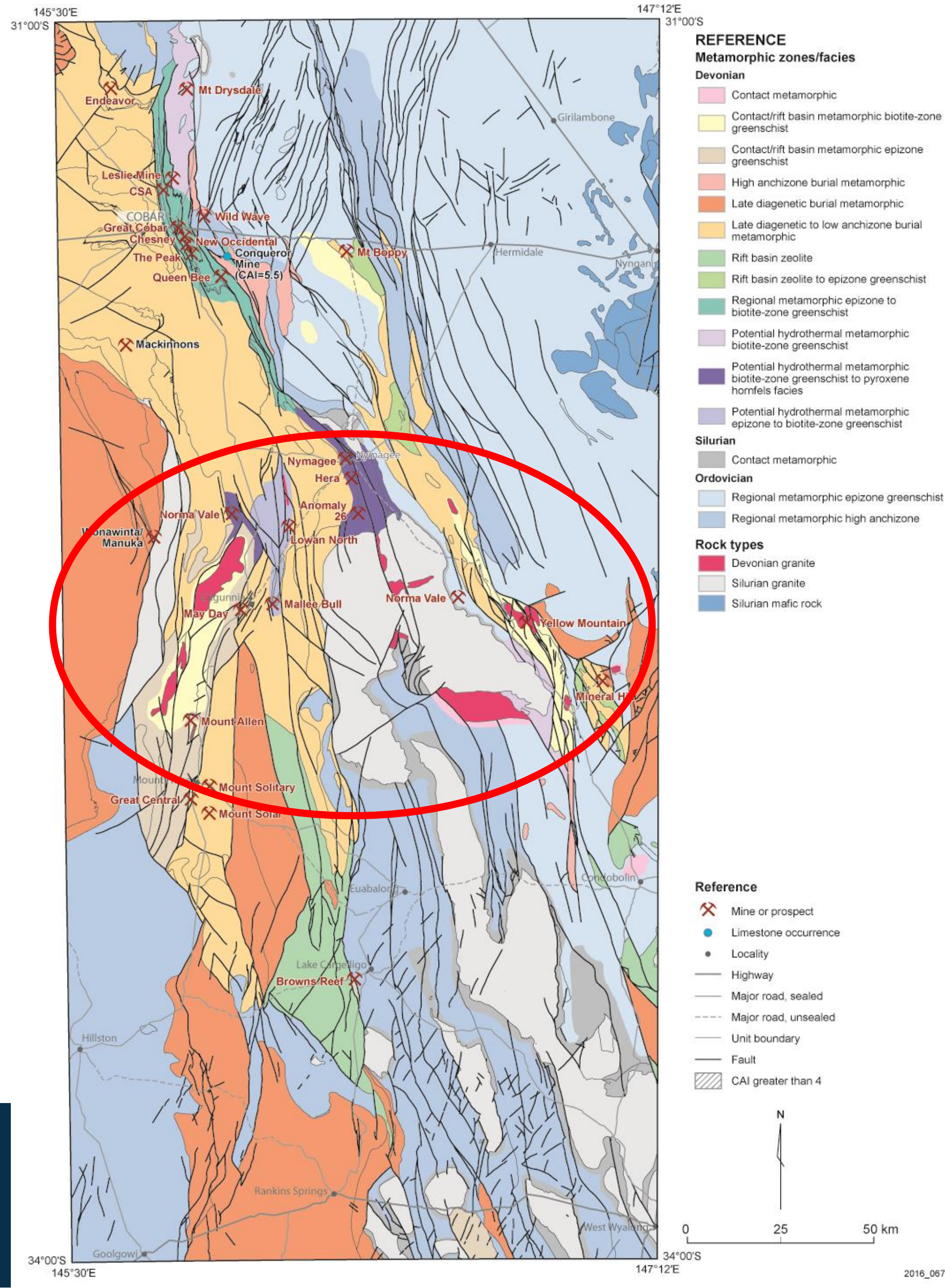
Cobar described in terms of east to west

But…. South to north

Higher Intrusion level in the south. Intrusion proximal mineralisation



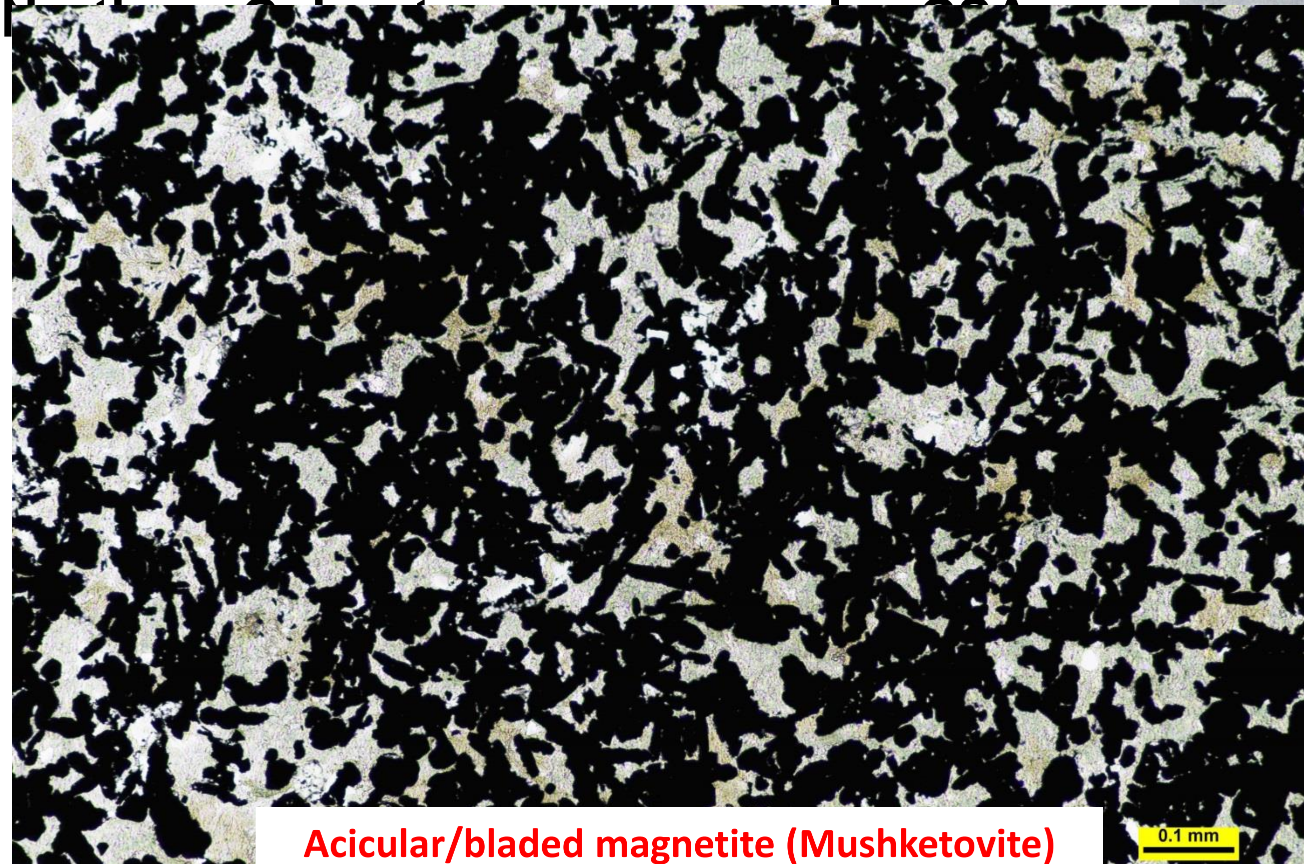
Northern sister deposits

Twins?

Sister deposits, twins?

lcareous sandstone (shelly)

chalcopyrite replaced magnetite



Acicular/bladed magnetite (Mushketovite)

Conclusions

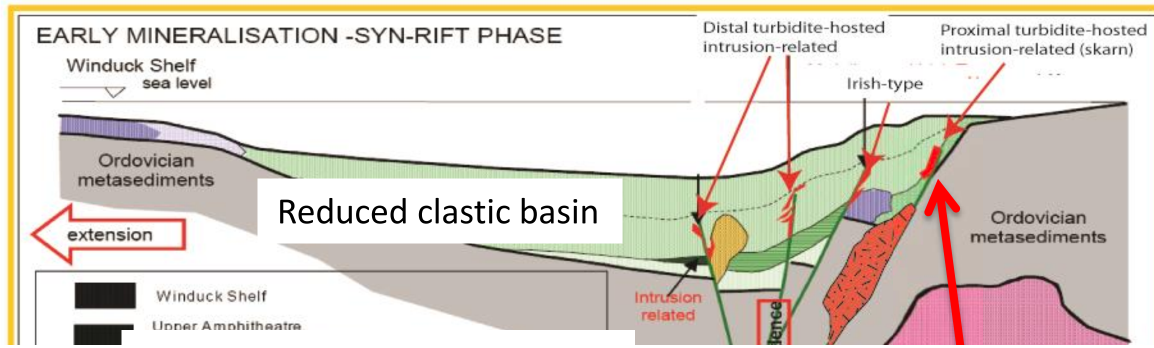
Importance of…

- Syn-rift faults
- **Reactive horizons (carbonate)**
  - Proximal = skarn
  - Distal = Lower-T lithological controlt?
- Devonian intrusions?
  - High thermal contrast
  - Fluid/metals
- Inversion, remobilisation or continued mineralisation?

Implications…

- Potential for metal trapping at several stratigraphic levels in the basin
- Skarn? in drowned, early-rift carbonate sequences
- Look through deformation and Cobar-type could be anywhere in the basin…

David (2005)

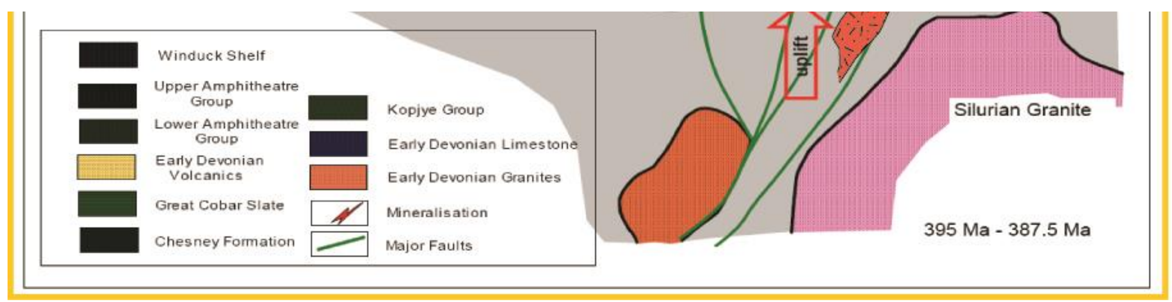


But… age of intrusive rocks?

Is intrusion diachronous?

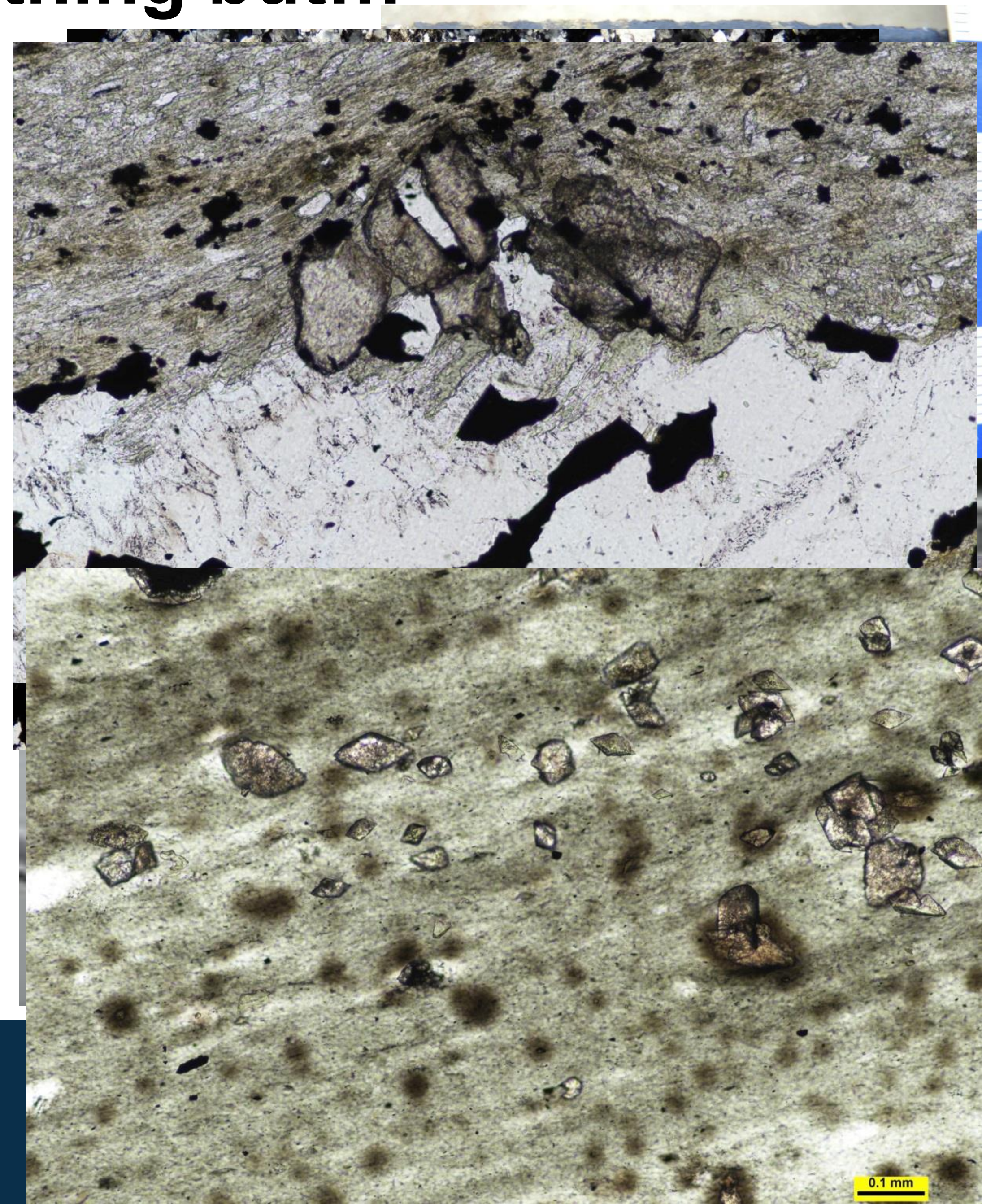
Are there younger intrusive rocks?

Age of mafic intrusive rocks?



What’s next? Everything but…

- Northern Deposits
  - Great Cobar
    - H-O isotopes on early oxide phase
    - Titanite dating
  - Perseverance
    - H-O isotopes on early potassic alteration
    - Titanite dating
  - CSA
    - H-O isotopes on early oxide phase
    - Systematic S-isotope studies
    - Titanite dating
  - Nymagee-Hera
    - Scheelite REE-studies
    - Apatite dating
    - Titanite dating
    - VR-C-isotopes
    - Whole rock O
  - Norma Vale
    - 3x SHRIMP dates on I-type intrusives



Thanks

aurelia METALS Ltd.

newgold

CSA Mine

GLENCORE

CBH Resources Limited

NSW GOVERNMENT Planning & Environment