Metaexhalites, seafloor alteration and retrograde processes from metamorphosed deposits, Aileron Province

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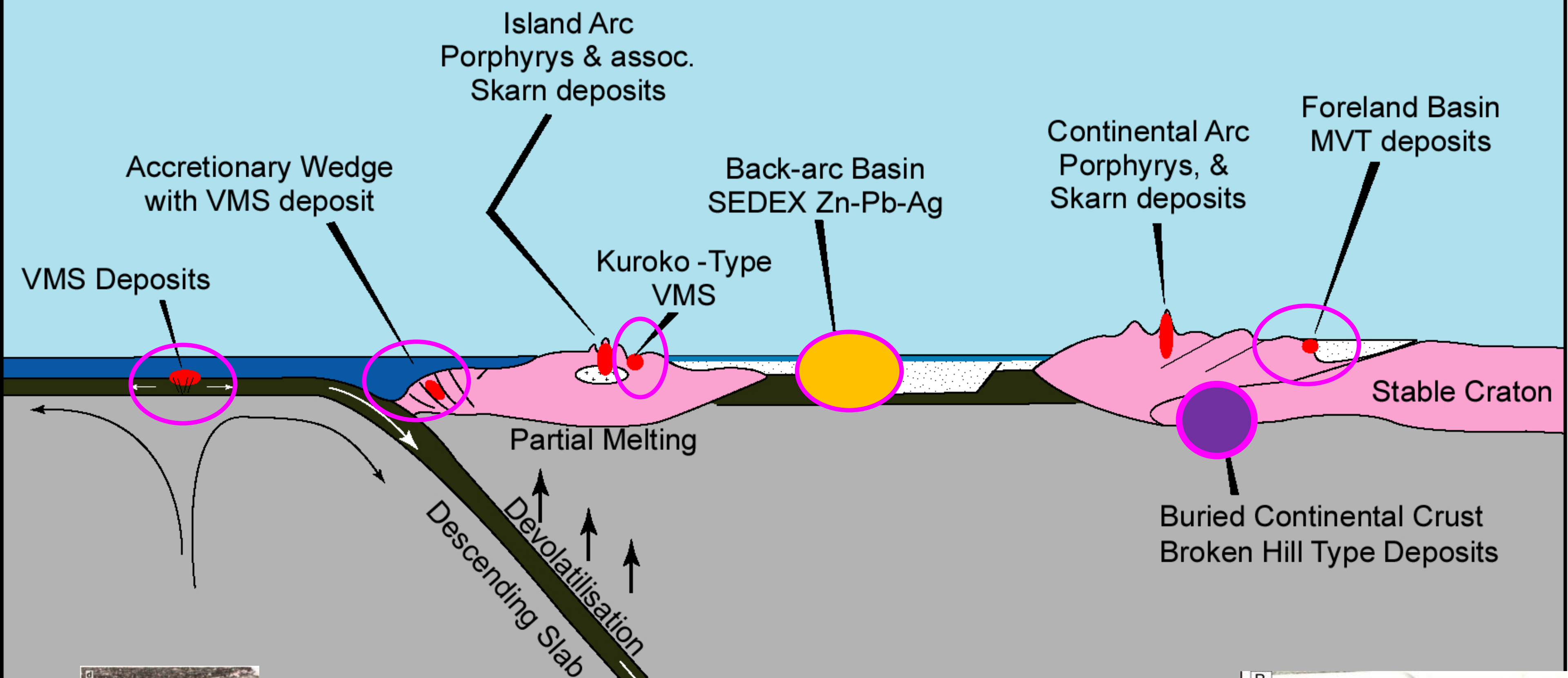
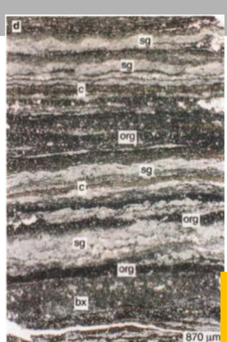
Also thanks to:

Bob Trumbull (GFZ Potsdam), Roland Maas, Graham Hutchinson (Melb Uni) Kelvin Hussey (NTGS), Natalie Kositcin, David Huston, Jon Claoué-Long (GA), KGL Resources and Rox Resources

Basin-hosted massive sulfide deposits

Range of tectonic settings, most older deposits get deformed as basins close and are buried

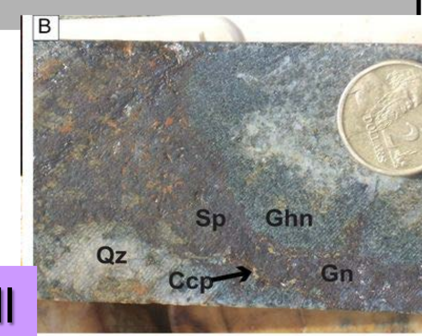




increasing
metamorphism, deformation, alteration

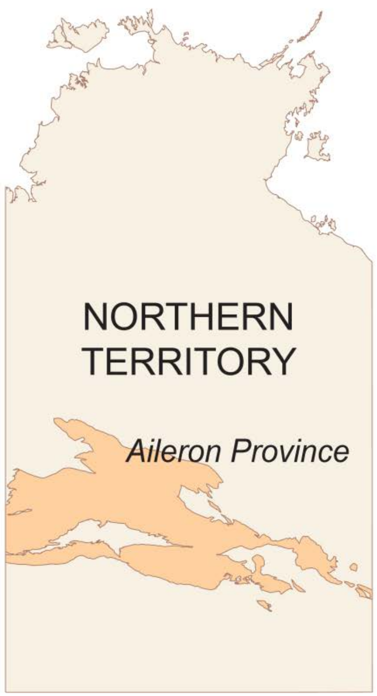
HYC

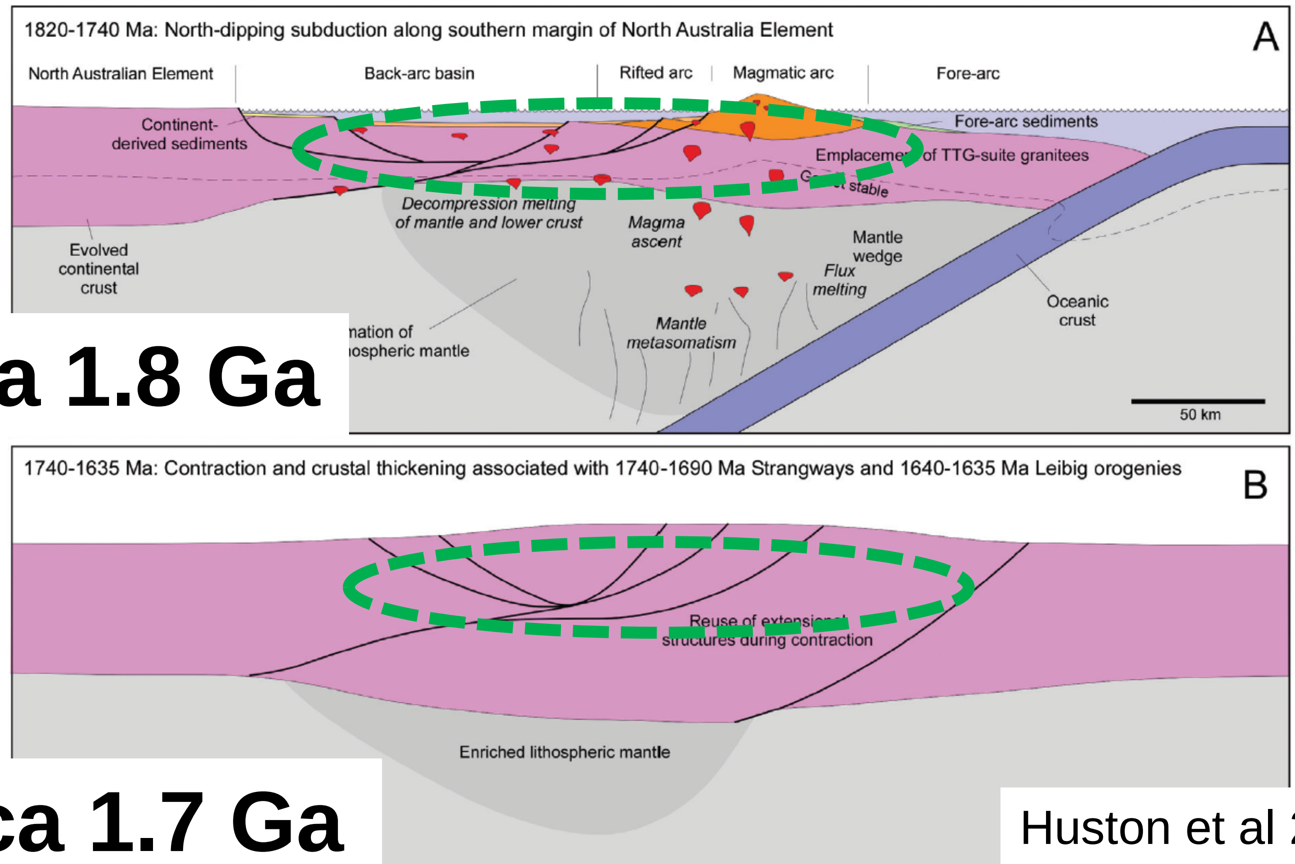
Broken Hill



Palaeoproterozoic Aileron Province

- ca 1.80-1.79 Ga Cu-Ag-Pb-Zn mineralisation
- forming in contiguous belt of basin successions
- located on southern margin of the tectonically active NAC
- metamorphosed : upper amphibolite to granulite facies





ca 1.8 Ga

ca 1.7 Ga

Huston et al 2017

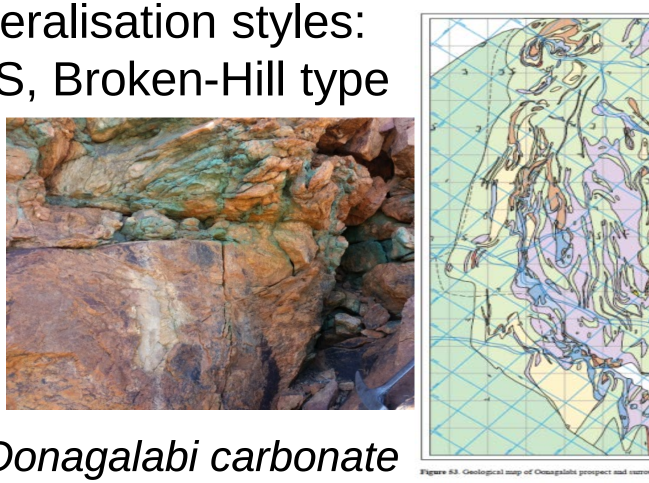
AUSTRALIA'S NORTHERN TERRITORY

AGES2017

Metamorphosed, deformed, altered deposits & host rocks

Range of syngenetic/diagenetic mineralisation styles: many unconfirmed; eg VAMS, VHMS, Broken-Hill type carbonate-replacement

Green Parrot and Reward, Jervois mineral field (BHT)



Oonagalabi carbonate (replacement or VAMS?)

Patmungala beds, (?VMS)

Edwards Creek (VAMS)

Warren, 1990; Skidmore, 1996; Hussey et al. 2005; McGloin and Weisheit, 2015

Basin floor-related Mg, Fe, Mn alteration

Basin-floor
hydrothermal alteration

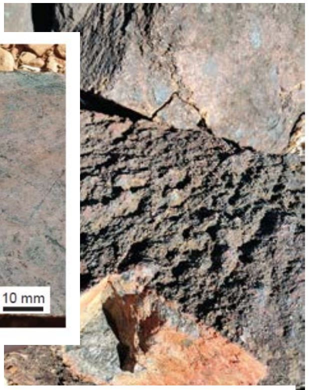
Banded iron

anthophyllite

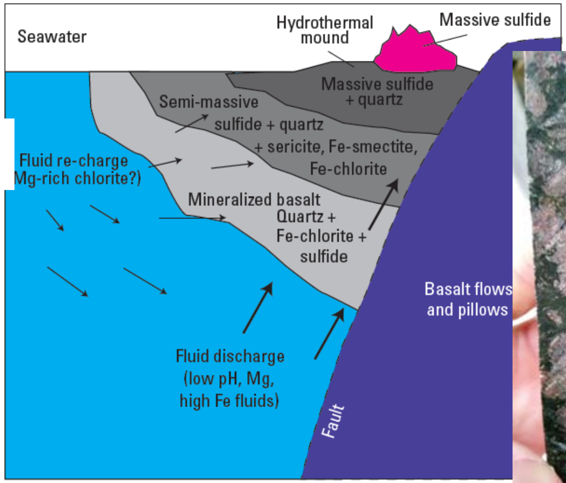
Cord-opx rock

sapphirine

garnetite



Mag-amphibole-spinel rock



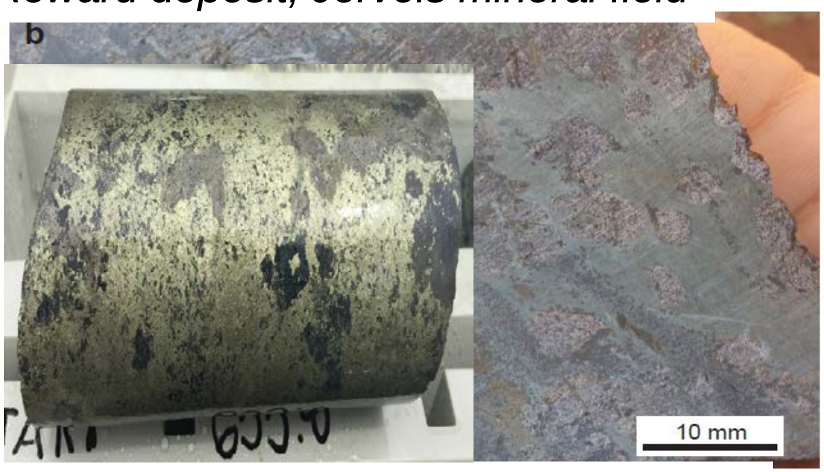
Garnet-biotite rocks

Mg-rich, Si-poor assemblages

Fe and Mn-rich alteration

Epigenetic (peak-*P* metamorphism) magnetite-chlorite + copper

Reward deposit, Jervois mineral field



Rockface prospect, Jervois mineral field

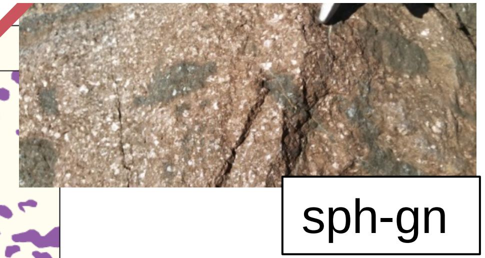
Johnnies Reward deposit

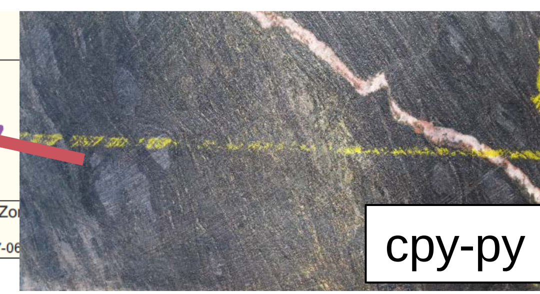
Three alteration styles from Jervois:

- garnetites
- tourmalinites
- magnetite-chlorite

Their significance for ore-forming processes

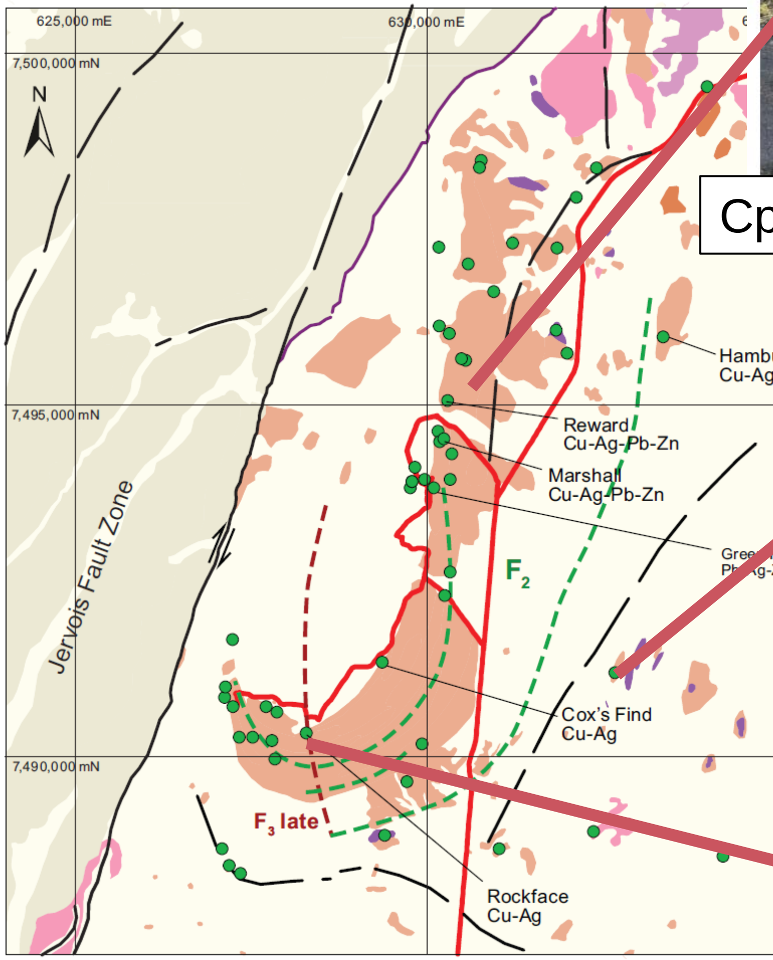
Jervois mineral field: syn-sedimentary ores

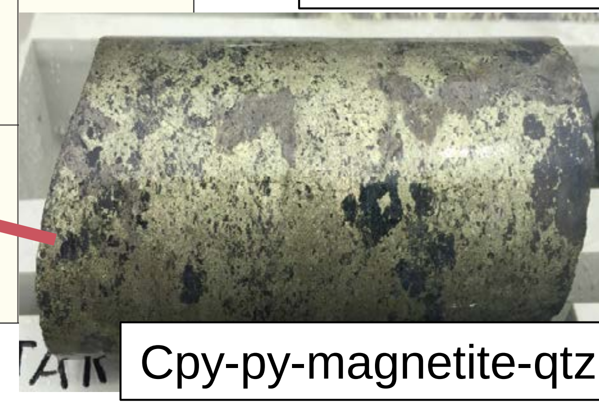




Syn-sedimentary stratabound Cu-Ag-Pb-Zn hosted in metasedimentary Bonya Metamorphics
Metamorphosed: upper amphibolite facies; boudinaged and layer-parallel to main foliation

Jervois mineral field: epigenetic ores



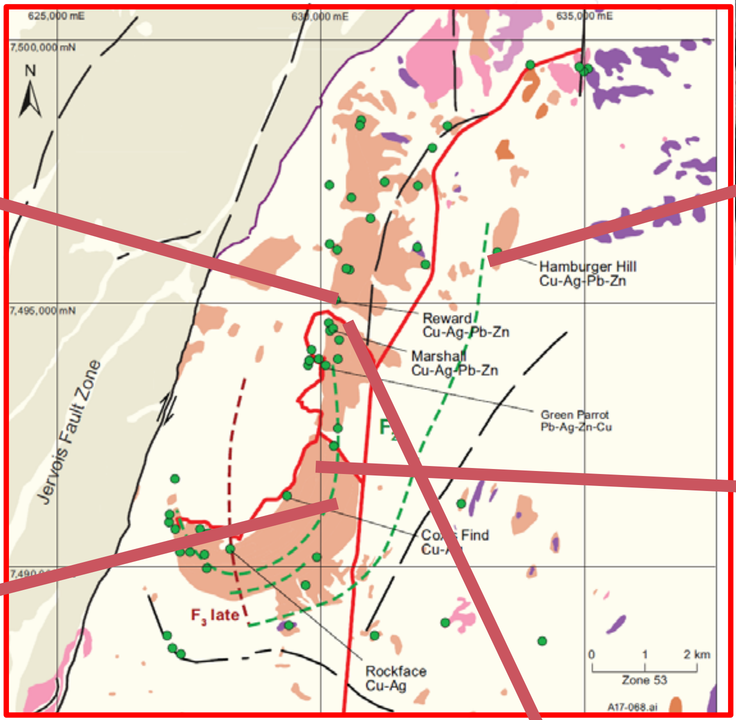


Epigenetic Cu-Ag mineralisation, overprints main foliation and later folding

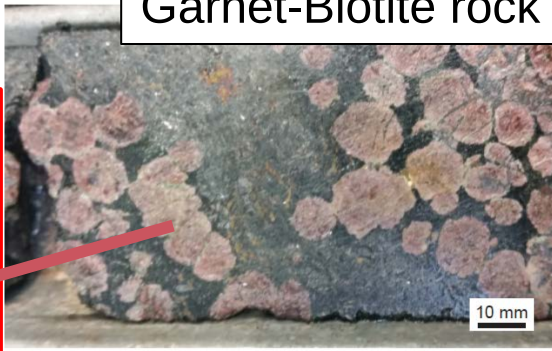
Metaexhalites and associated Fe-Mn alteration

Garnetite (coticule)

tourmalinite



Garnet-Biotite rock



Banded Iron (Algoma)

mixed apatite-spessartine

apatite

Apatite-rich rock

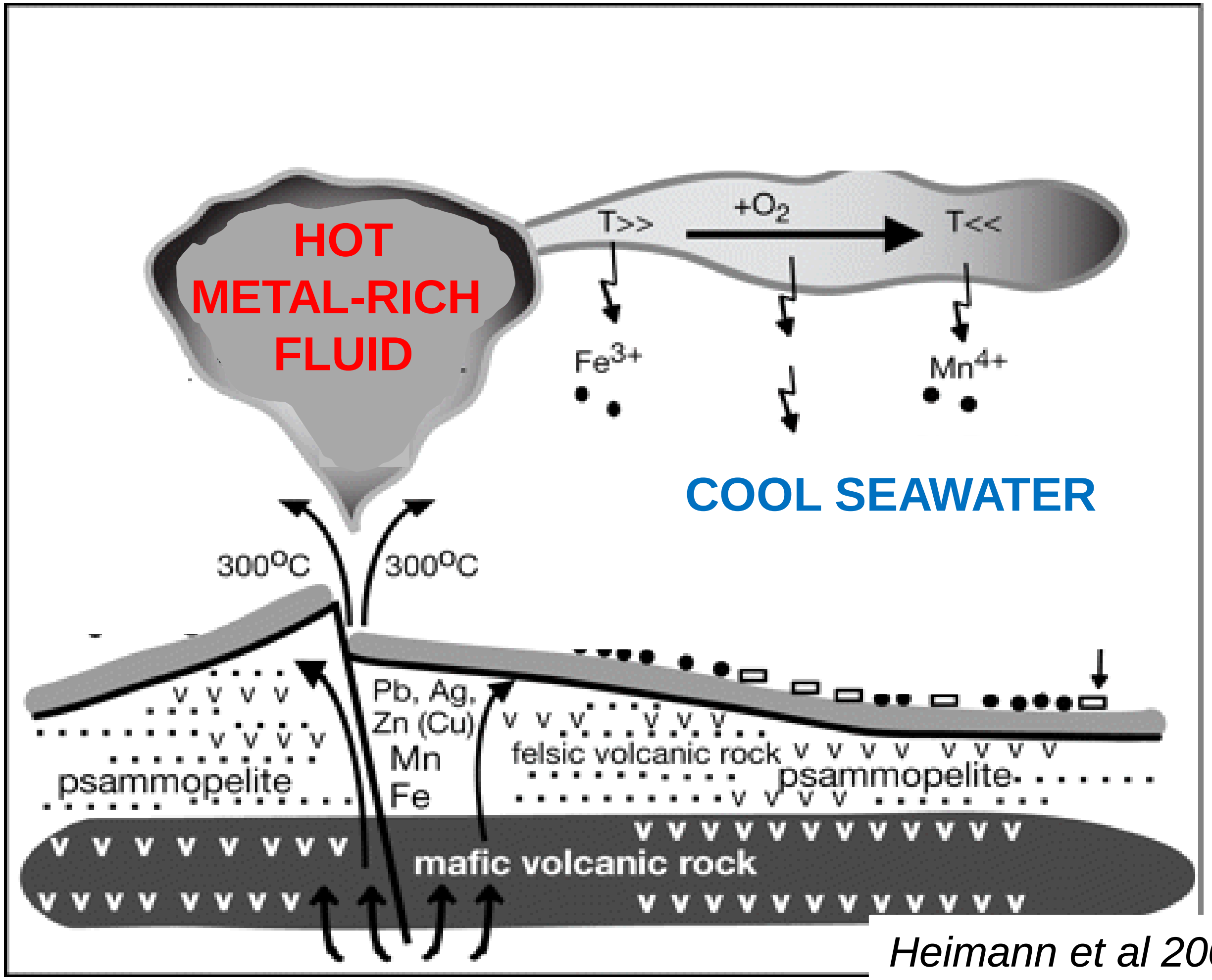
Unusual metamorphosed Fe-, Mn-, B- and P-rich rocks
Almost monomineralic
Host or spatially associated with base metal mineralisation

Metamorphosed hydrothermal chemical sediments

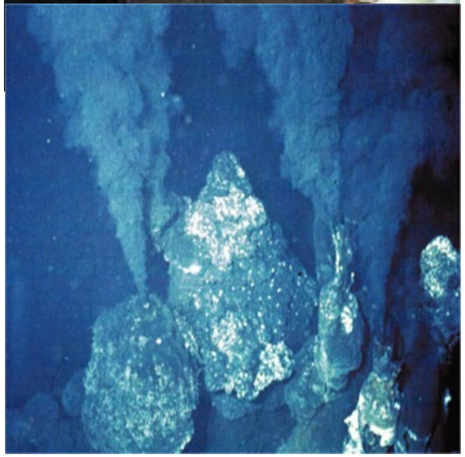
Hot metal-rich fluids exhale on or near cool subaqueous basin floor

Fe-Mn-rich muds = garnetite or garnet-biotite rock; B-rich muds = tourmalinite

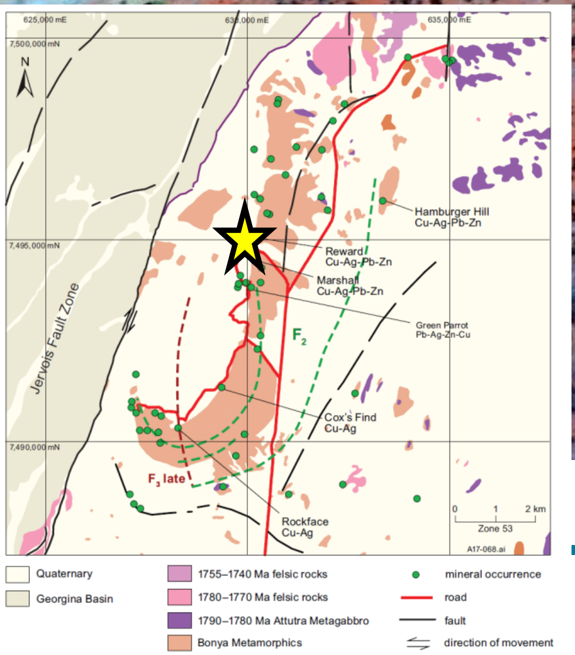
Metaexhalites commonly associated with VMS and BHT deposits



Heimann et al 2009



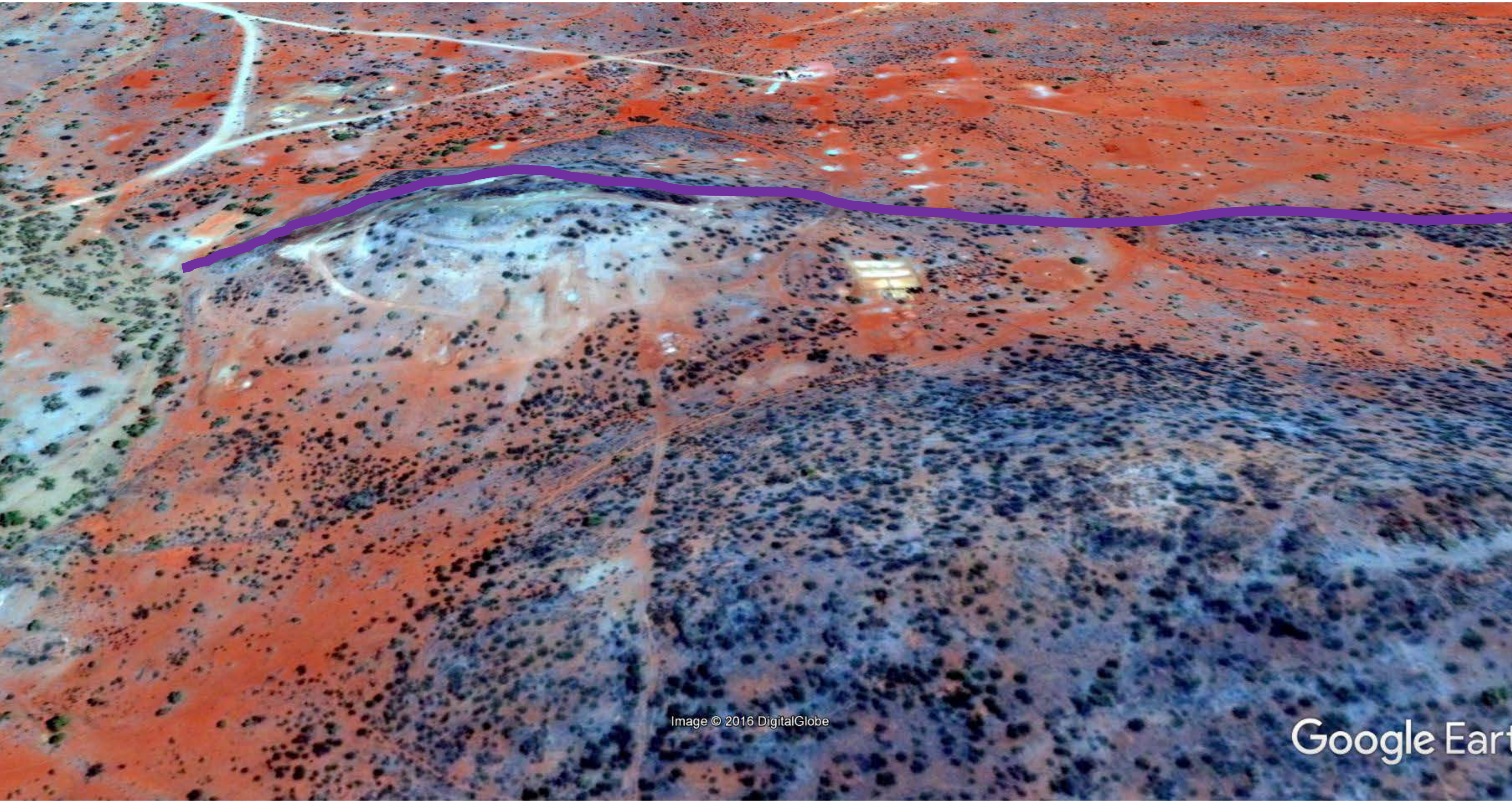
Reward Cu-Ag-Pb-Zn deposit



LOOKING WEST

100 m

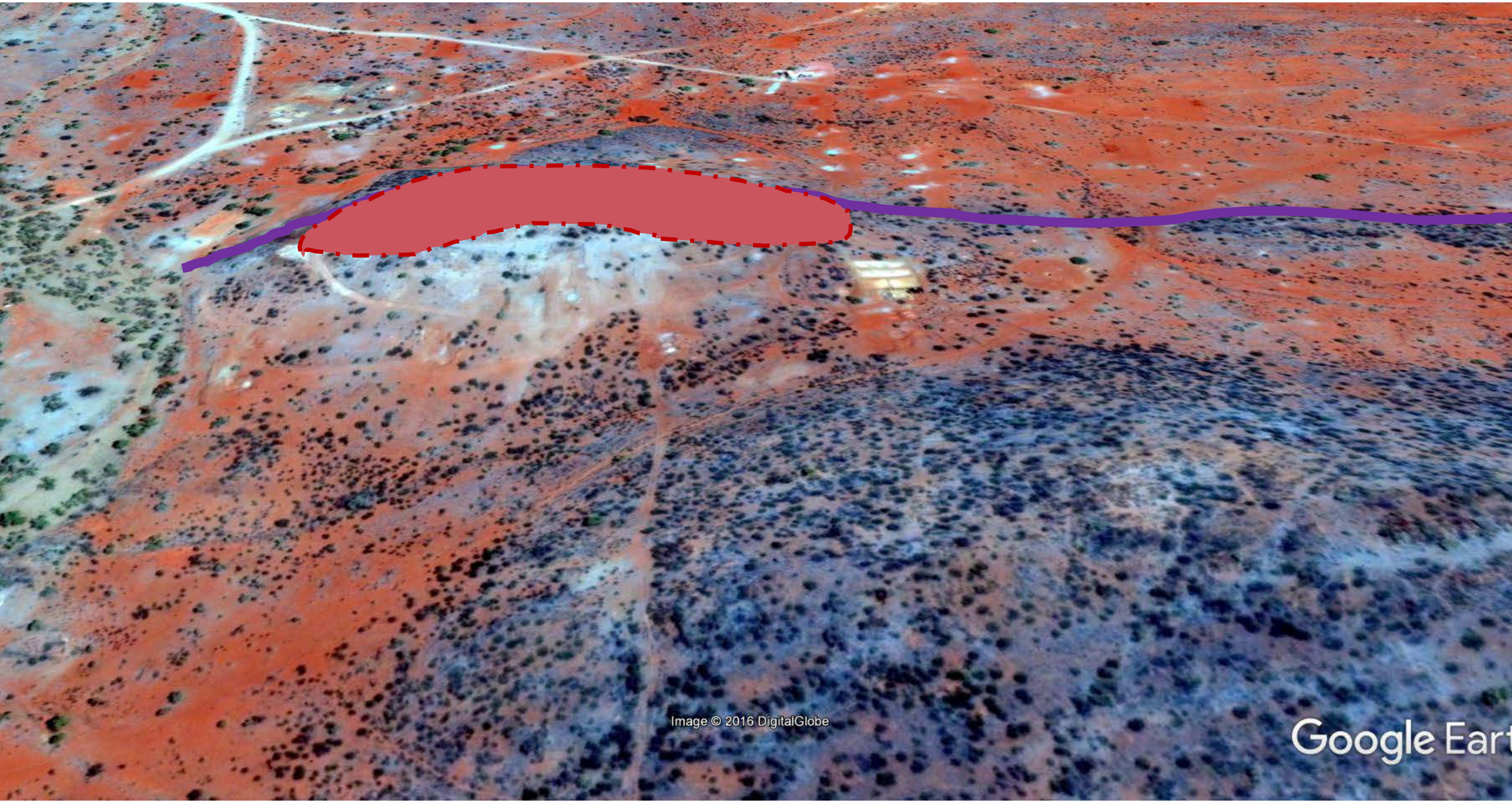
AGES2017



100 m

LOOKING WEST

Anomalous Fe and Mn enrichment



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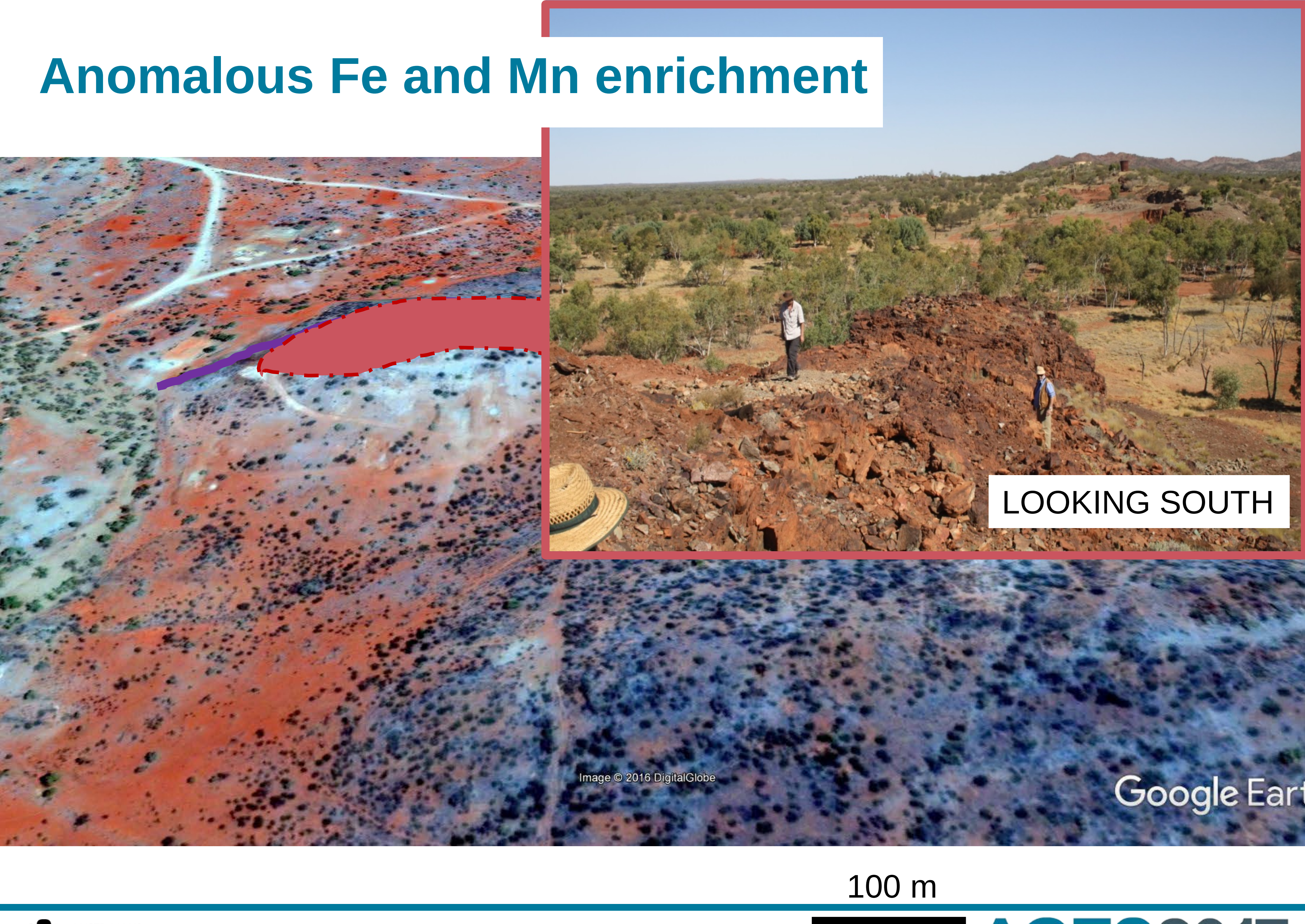

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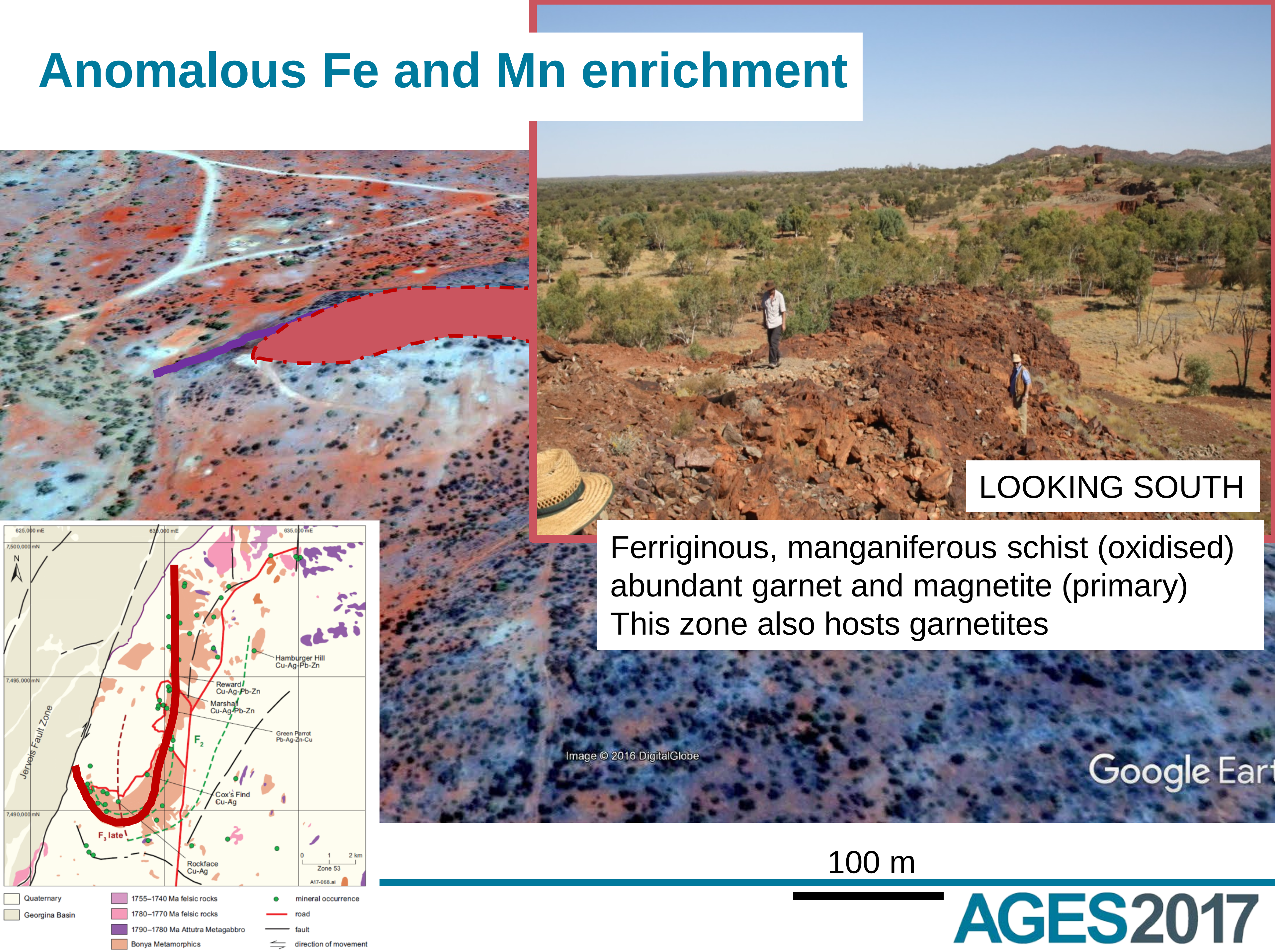
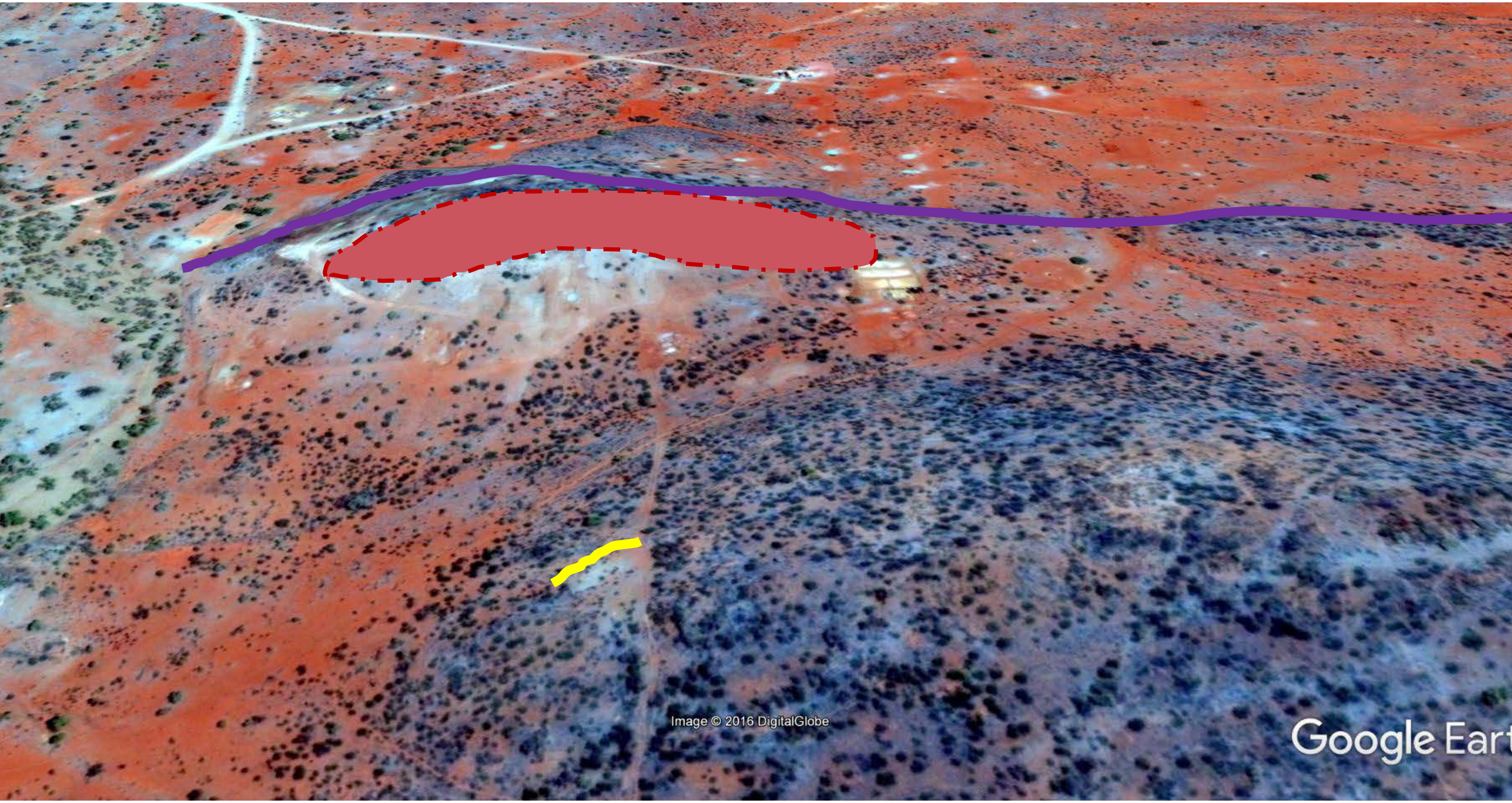


Ferriginous, manganiferous schist (oxidised)
abundant garnet and magnetite (primary)
This zone also hosts garnetites

100 m

AGES2017

Tourmalinites

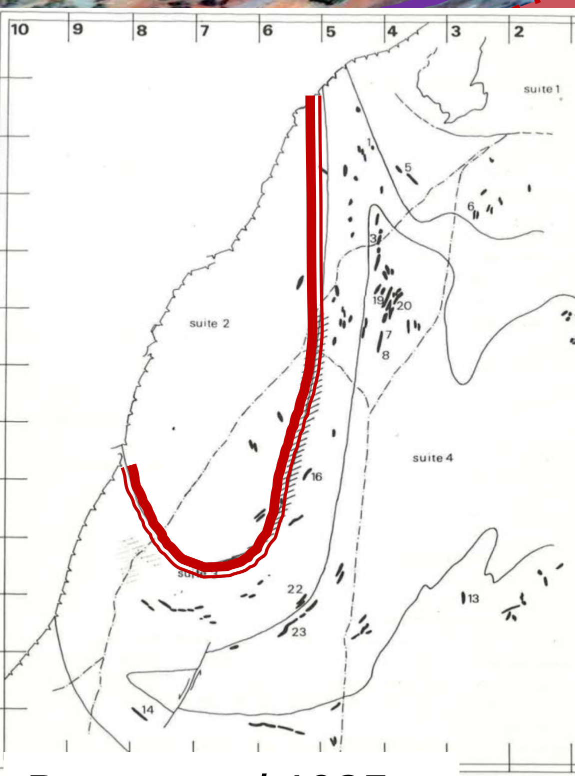


100 m

LOOKING WEST

Tourmalinites

Thin: commonly < 1m layered quartz-tourmaline bands deformed by main foliation, interlayered in schist



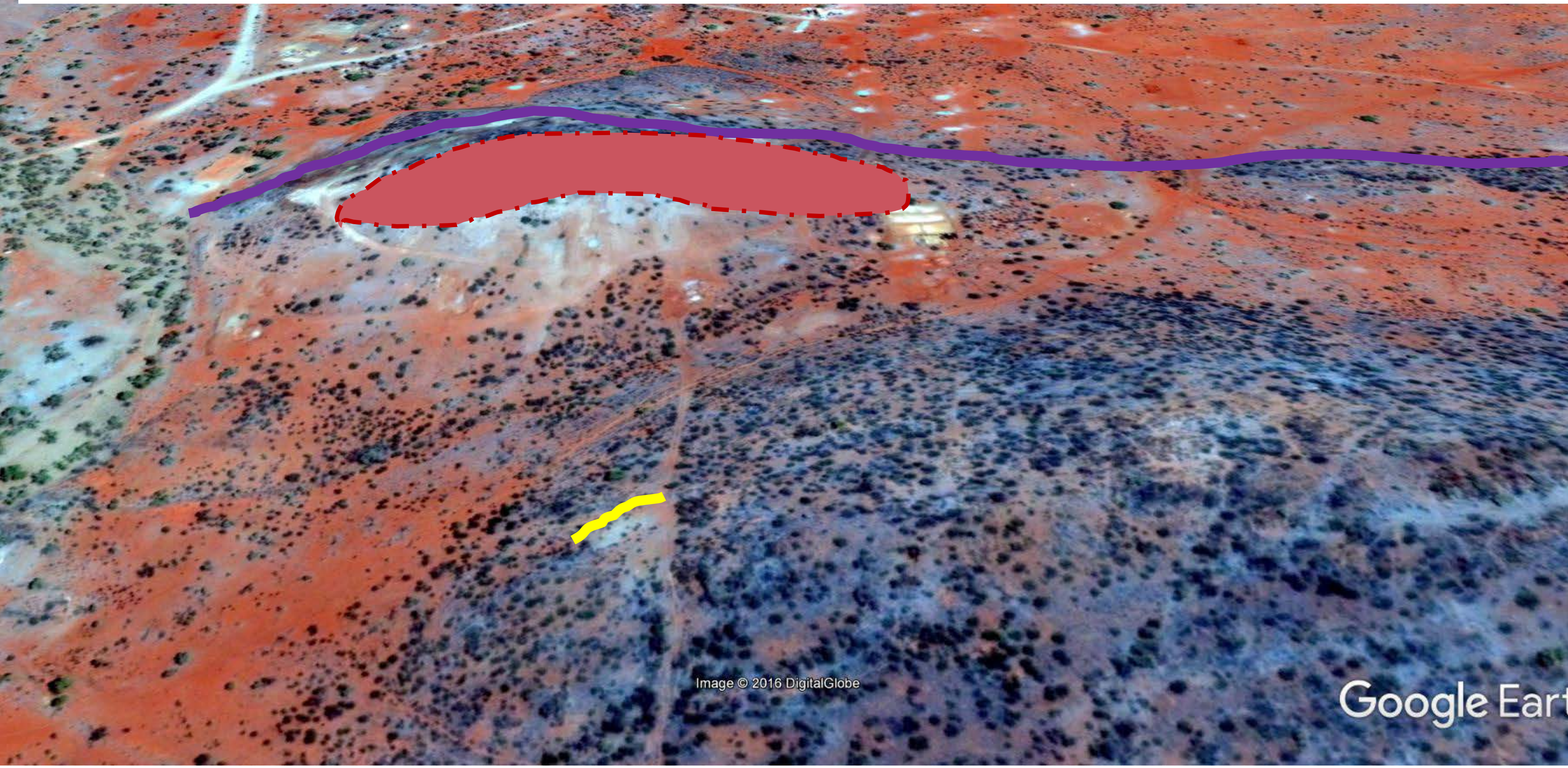
Peters et al 1985

100 m

LOOKING WEST

Spotting metaexhalites

important: they indicate fossil hydrothermal fluid zones and nearby ore
easily weathered (eg ferruginous/manganiferous schist)
or mistaken for more common rock types (amphibolite, chert, graphitic sediments, BIF)
Potential across the Aileron to find more



100 m

LOOKING WEST

Garnets and garnetites

Several garnet phases found regionally; only some link to syn-sedimentary mineralisation
(Unusual stratabound banded garnet or garnet-dominant massive assemblages)

Unmineralised garnet-bearing calc-silicate and schist (S_2 foliated)

Garnets and garnetites

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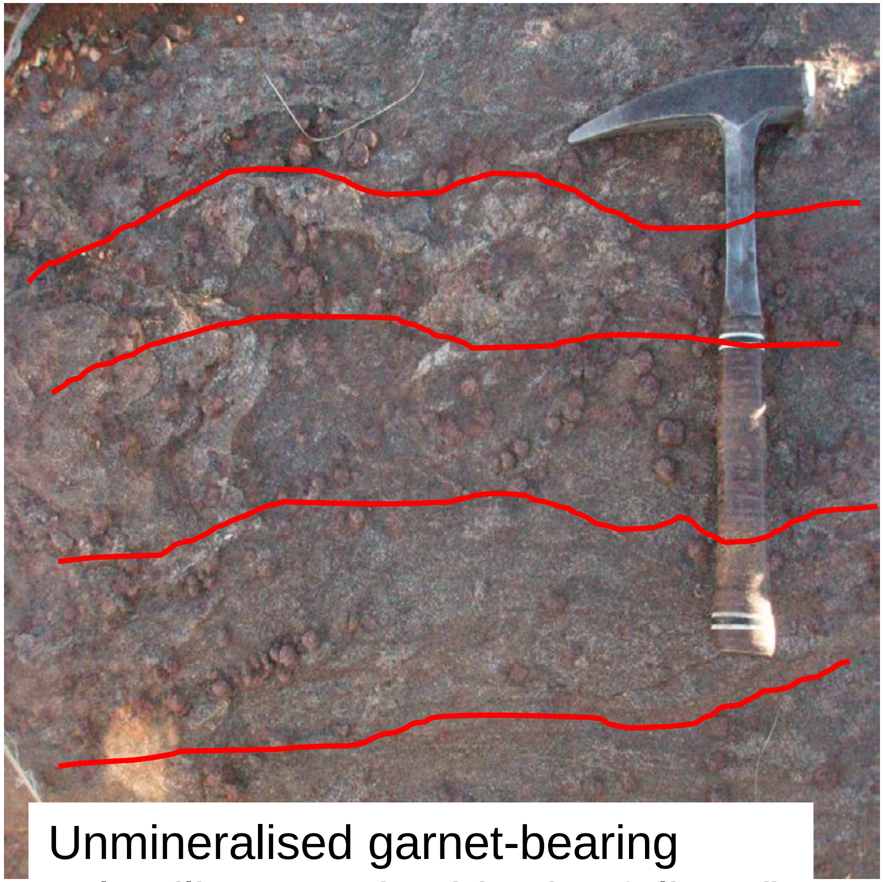

Unmineralised garnet-bearing calc-silicate and schist (S_2 foliated)

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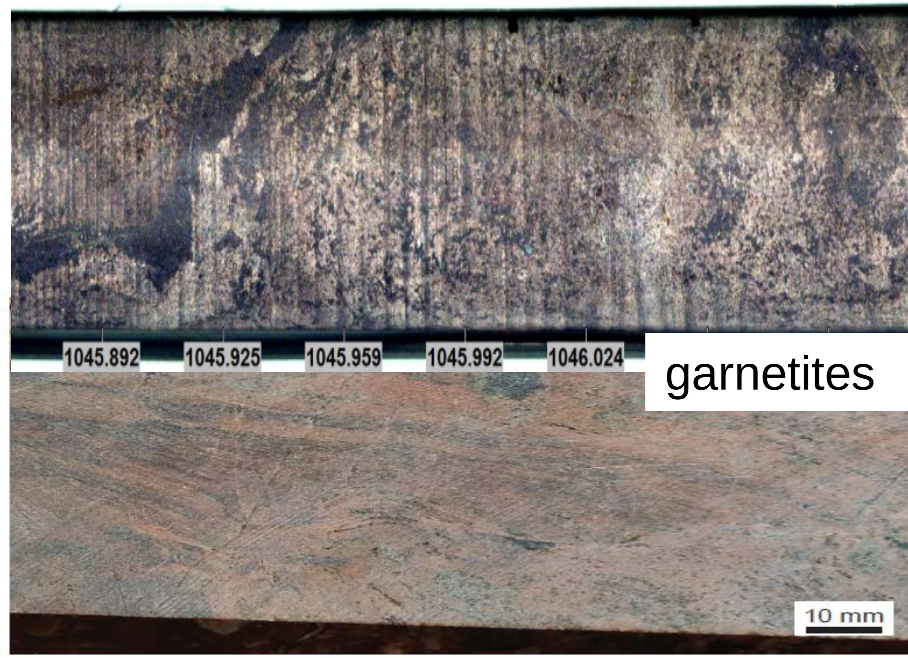
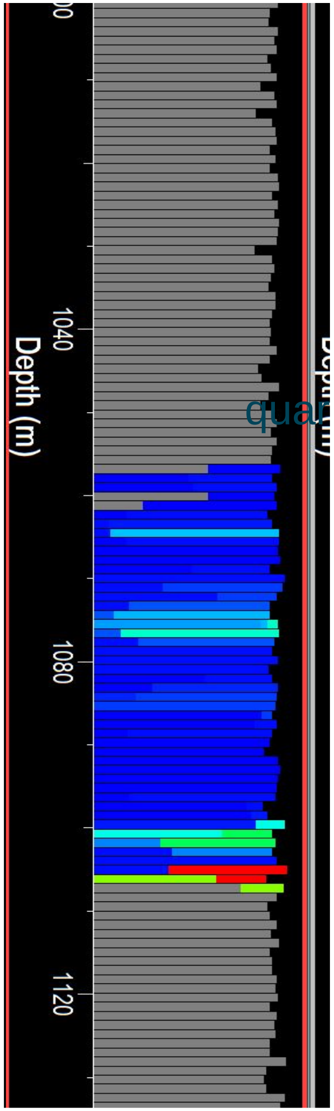


garnetites

metalliferous garnet-biotite schist

Hylogger results: garnets at Reward deposit

Depth (120 m)

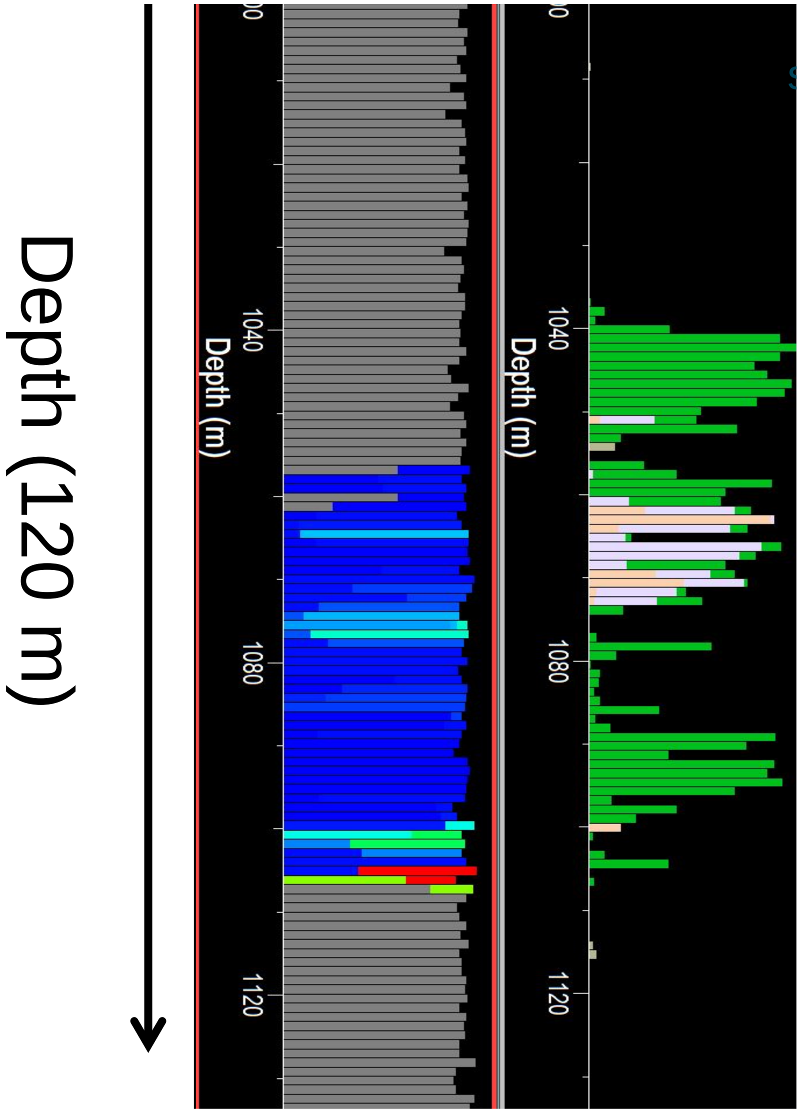


unmineralised schist/metacarbonate

Mineralisation

Smith et al 2016

Hylogger results: garnets at Reward deposit



60m garnet-zone: unusual chemistry

Spessartine
Mn-Al-rich

Grossular
Ca-Al-rich

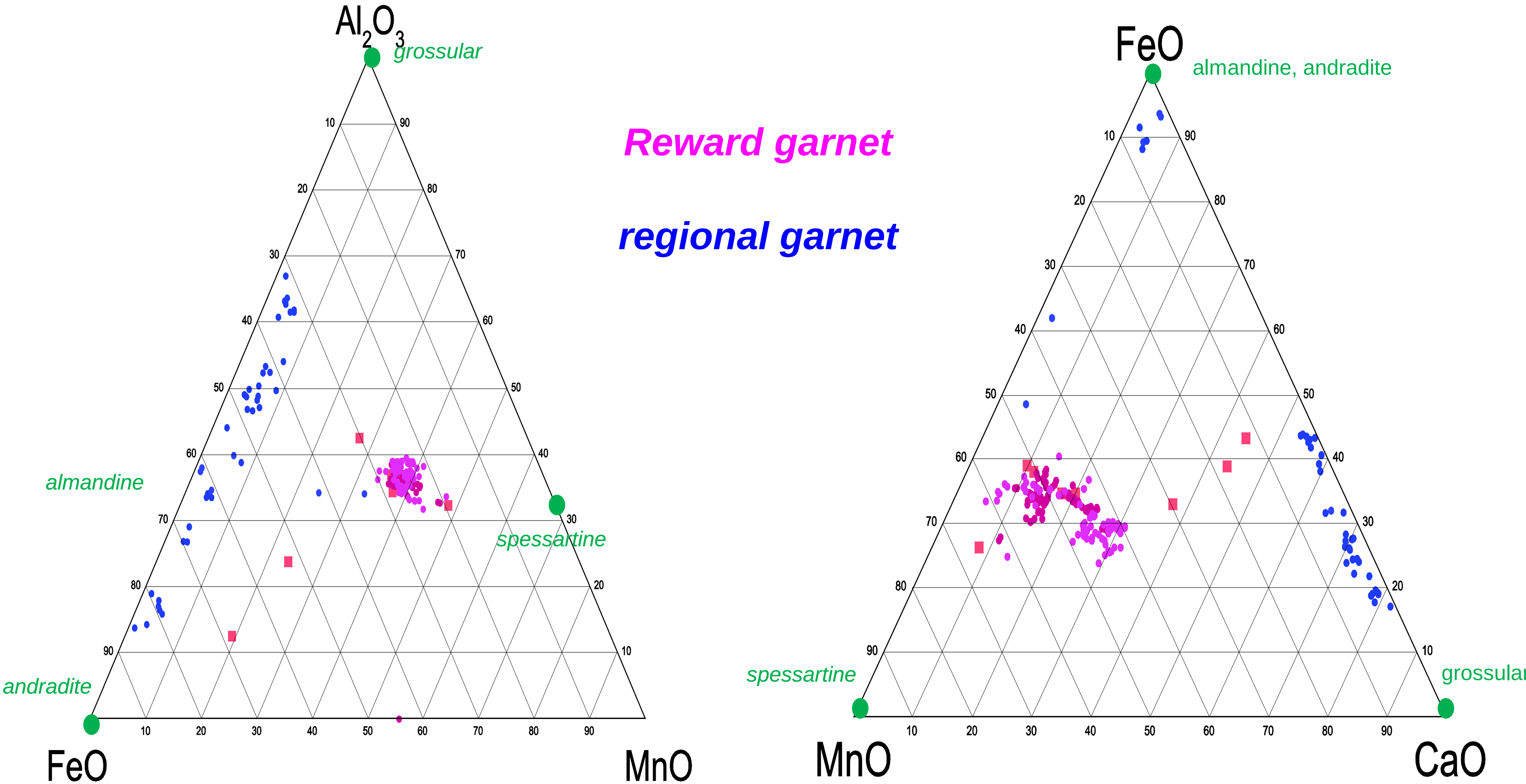
Andradite
Fe-rich, Al-poor

Smith et al 2016

Potential geochemical ore vectors

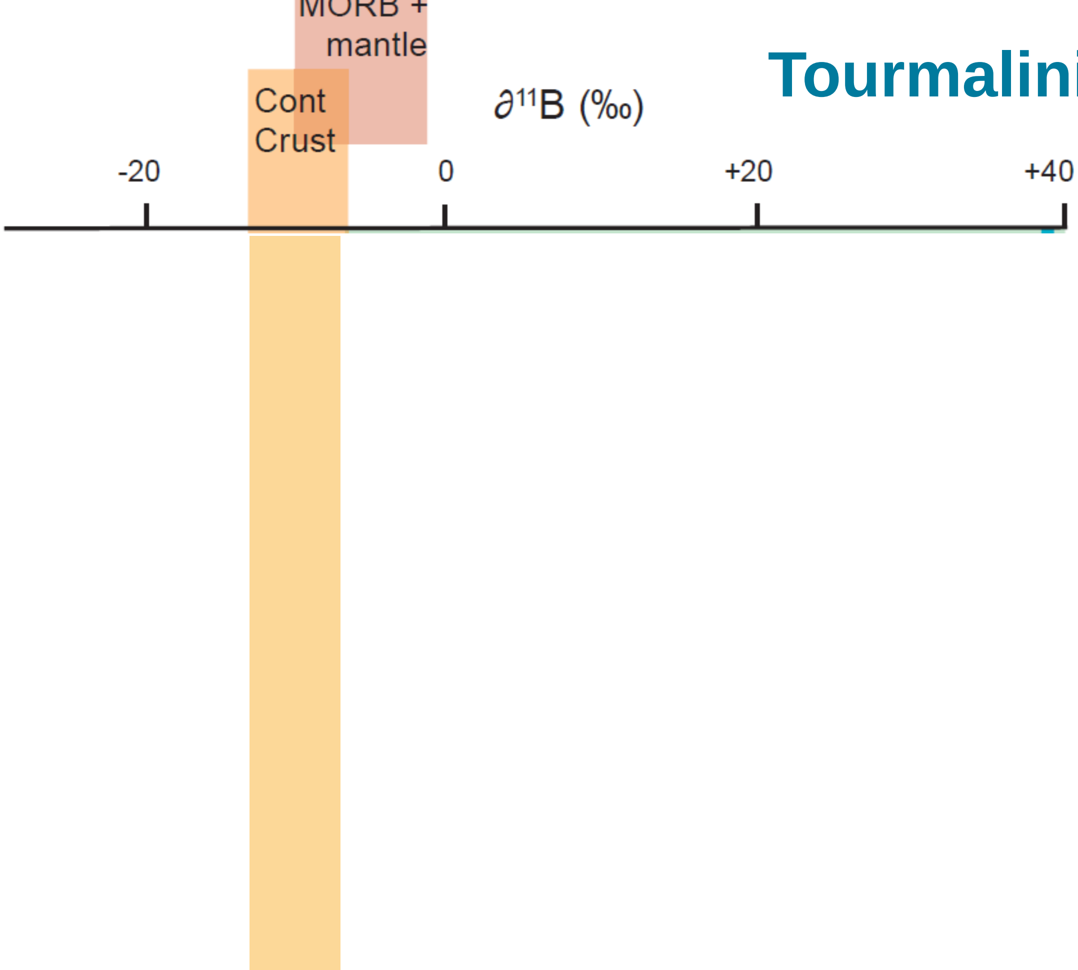
Potential for use of trace elements, and other metamorphic minerals

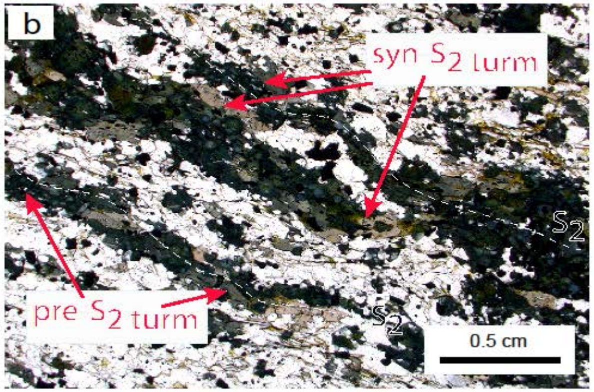
Staurolite, gahnite, tourmaline, magnetite

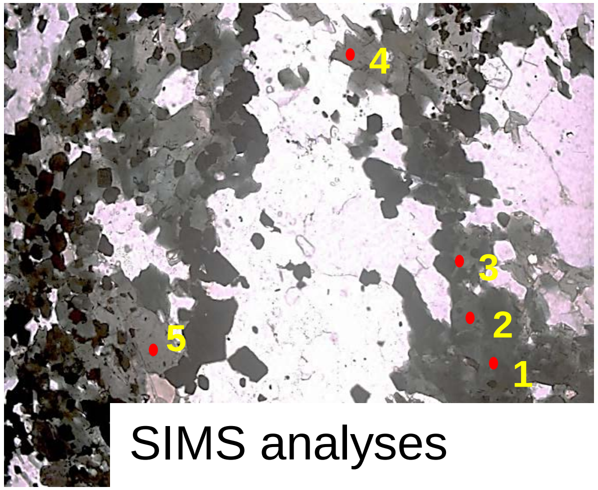


Smith et al 2016

Tourmalinites: boron isotopes

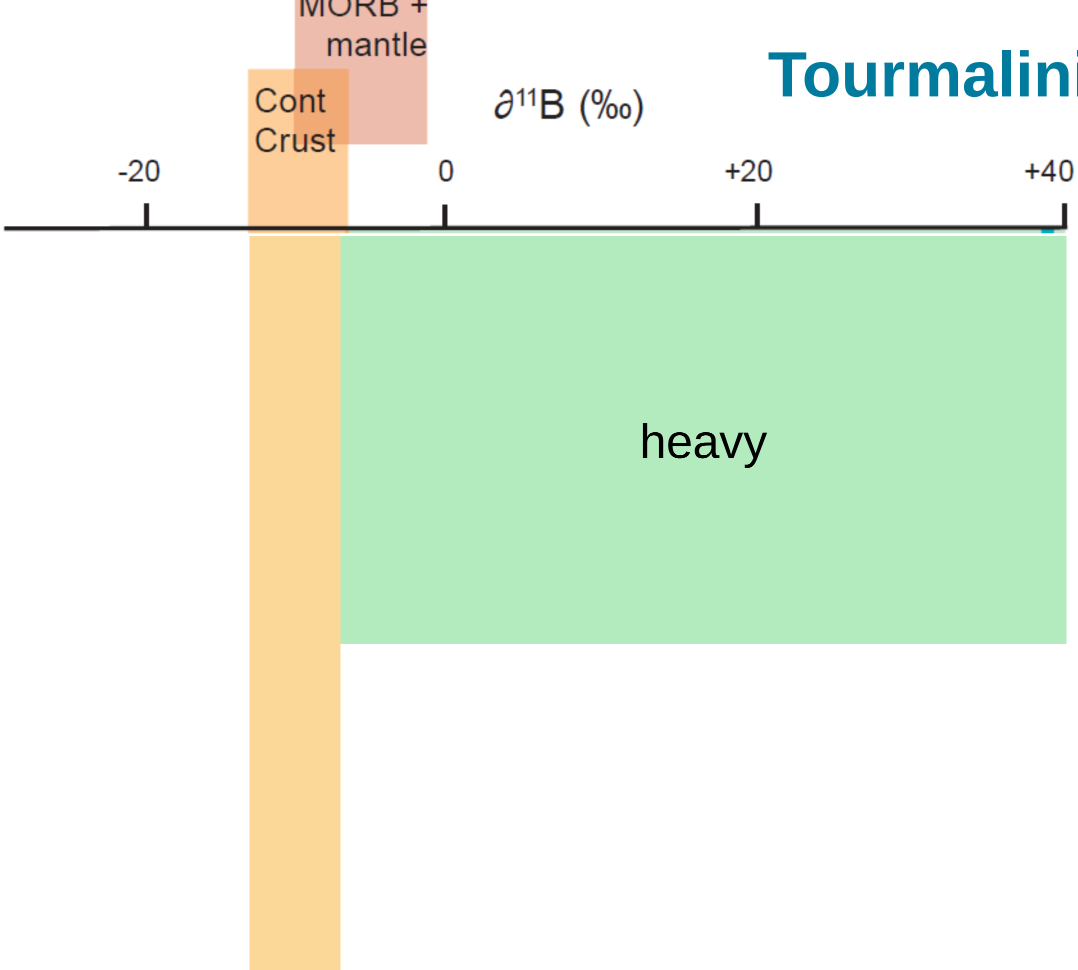






SIMS analyses

Tourmalinites: boron isotopes



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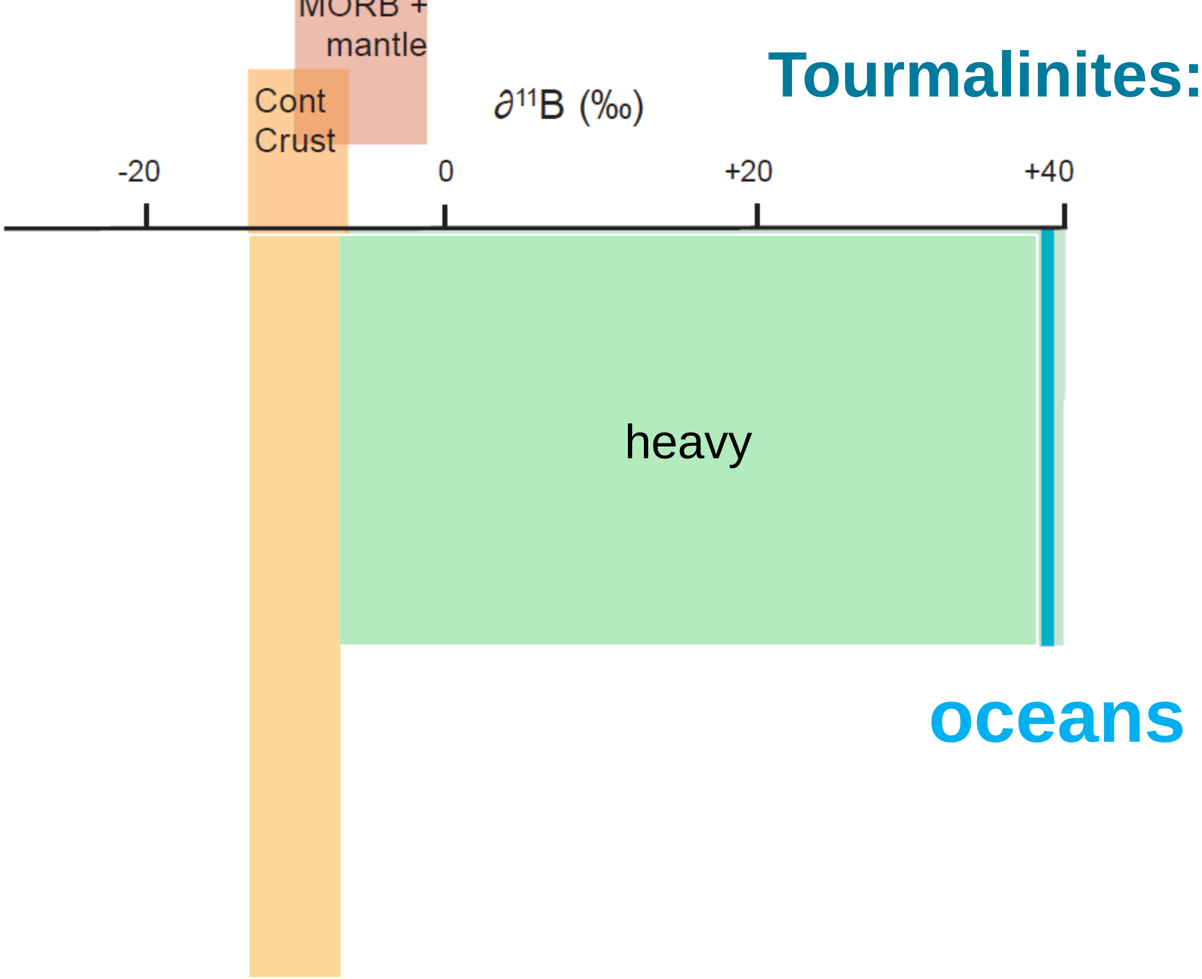

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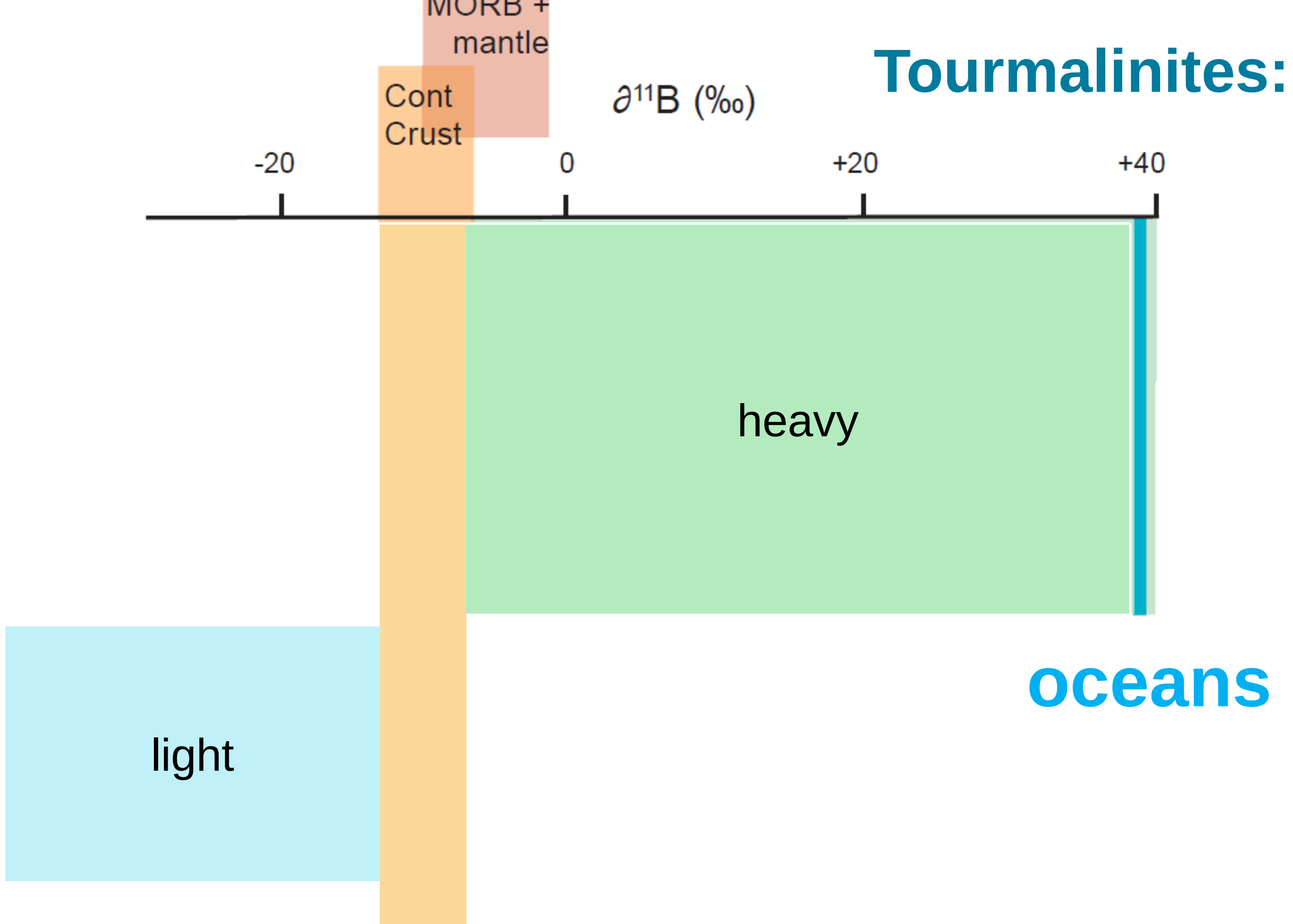

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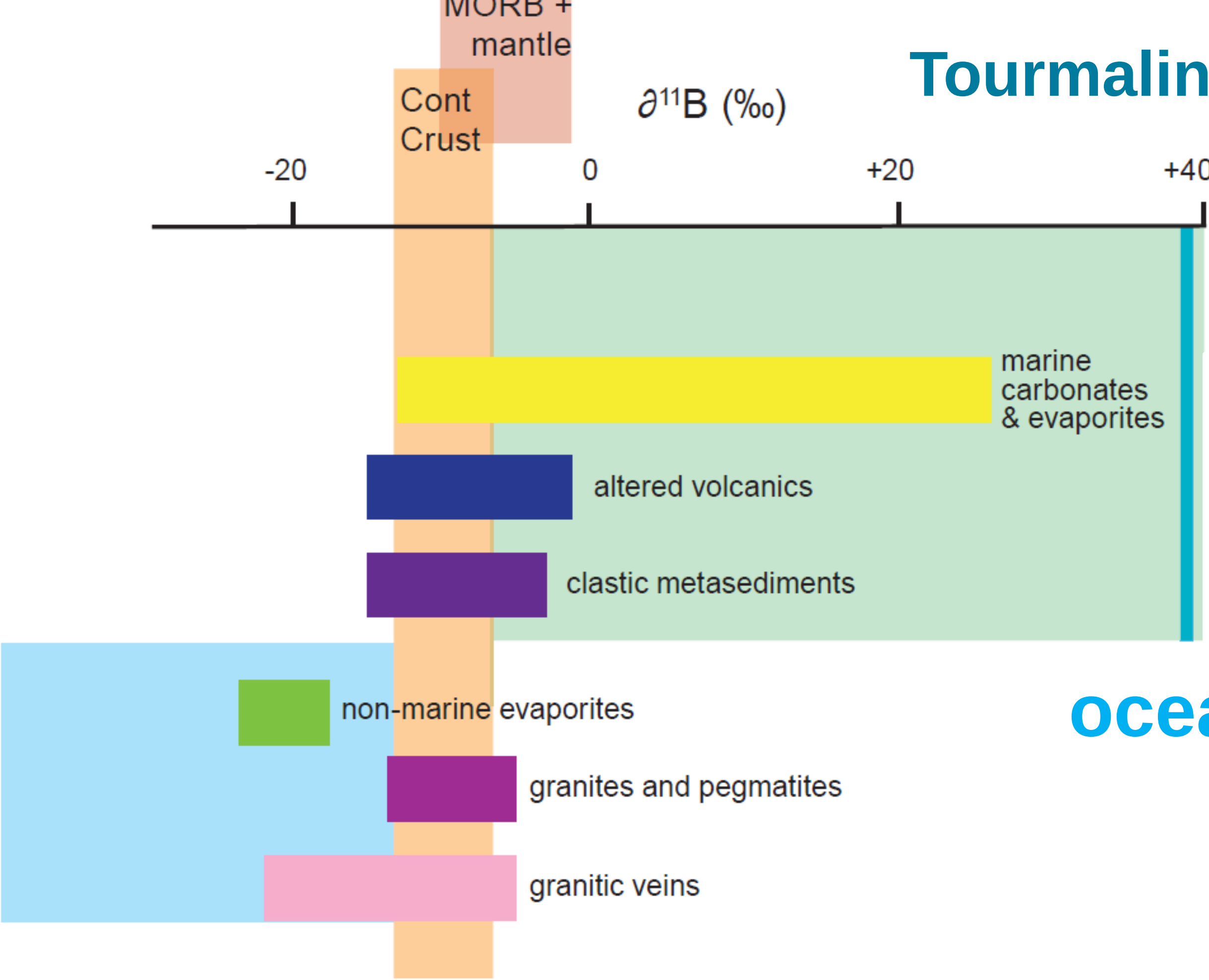
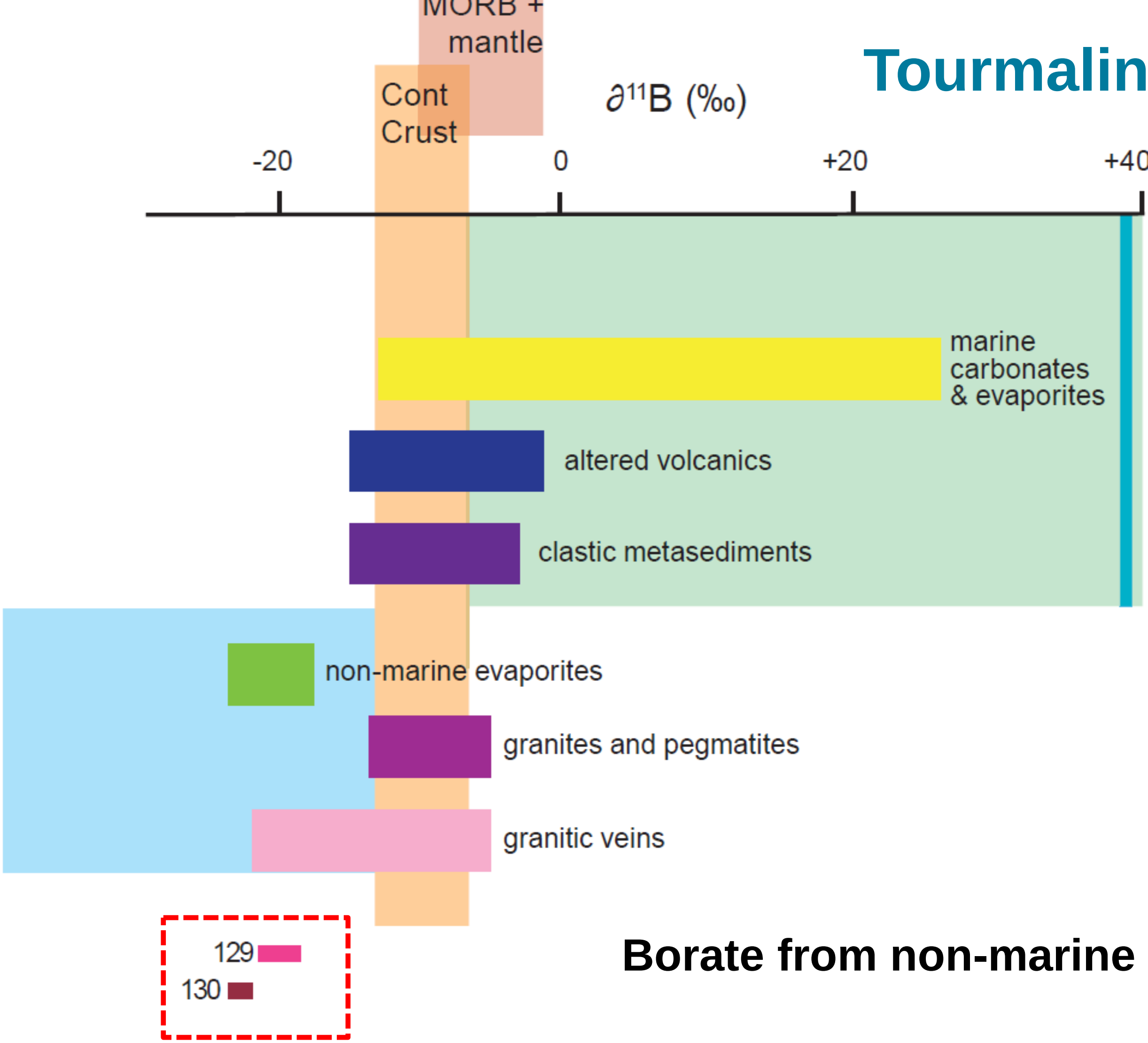


oceans

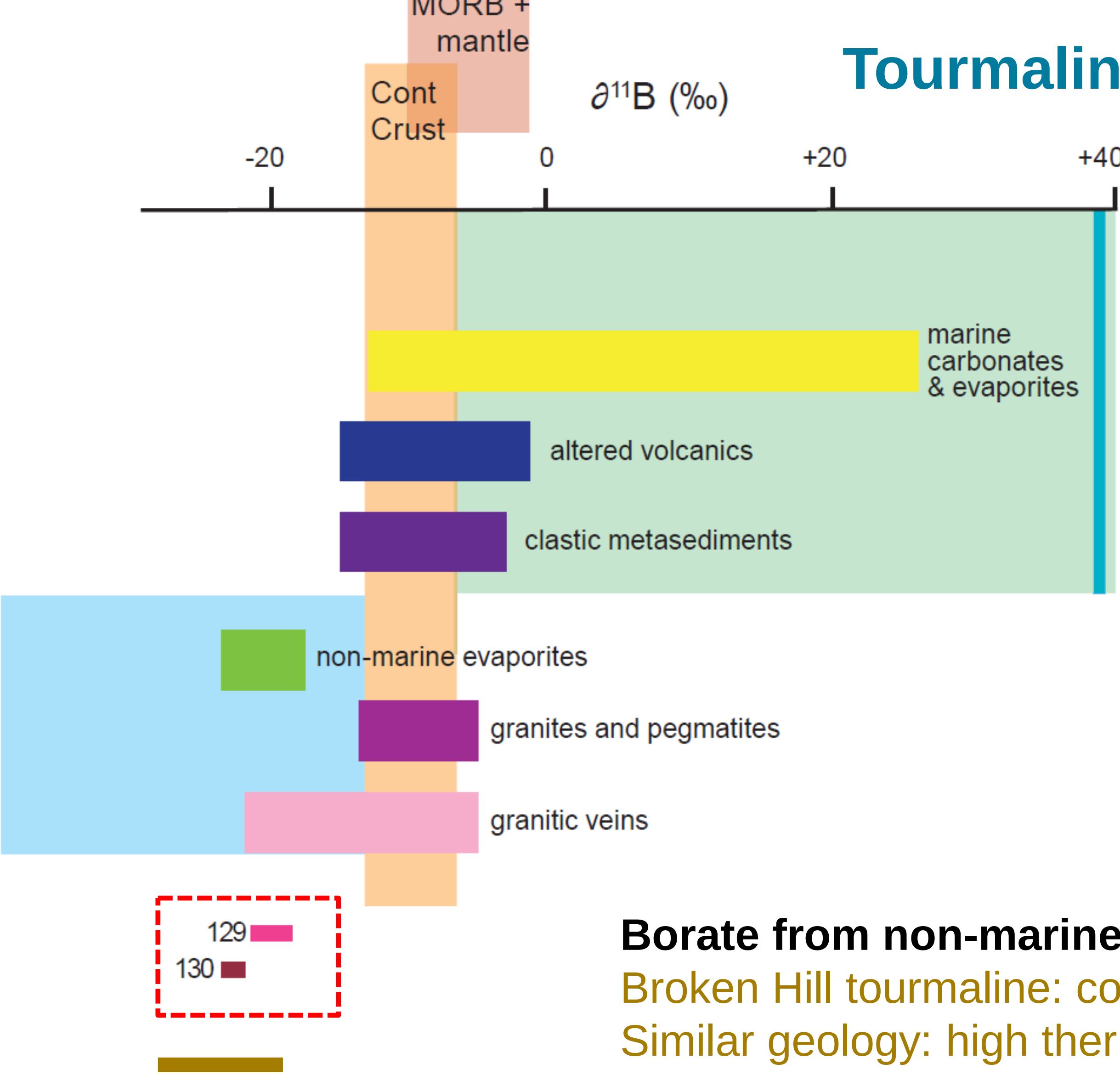
Tourmalinites: boron isotopes

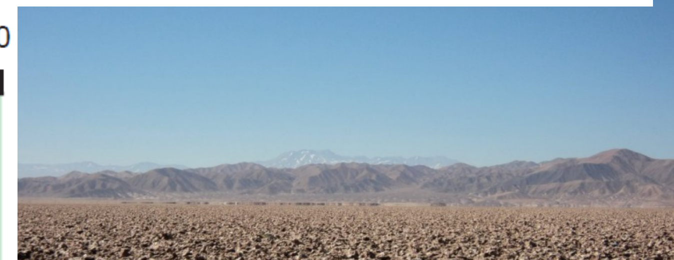


Borate from non-marine evaporites (no S-type granites)

Trumbull et al in prep
McGloin et al in prep

Tourmalinites: boron isotopes





Borate from non-marine evaporites (no S-type granites)

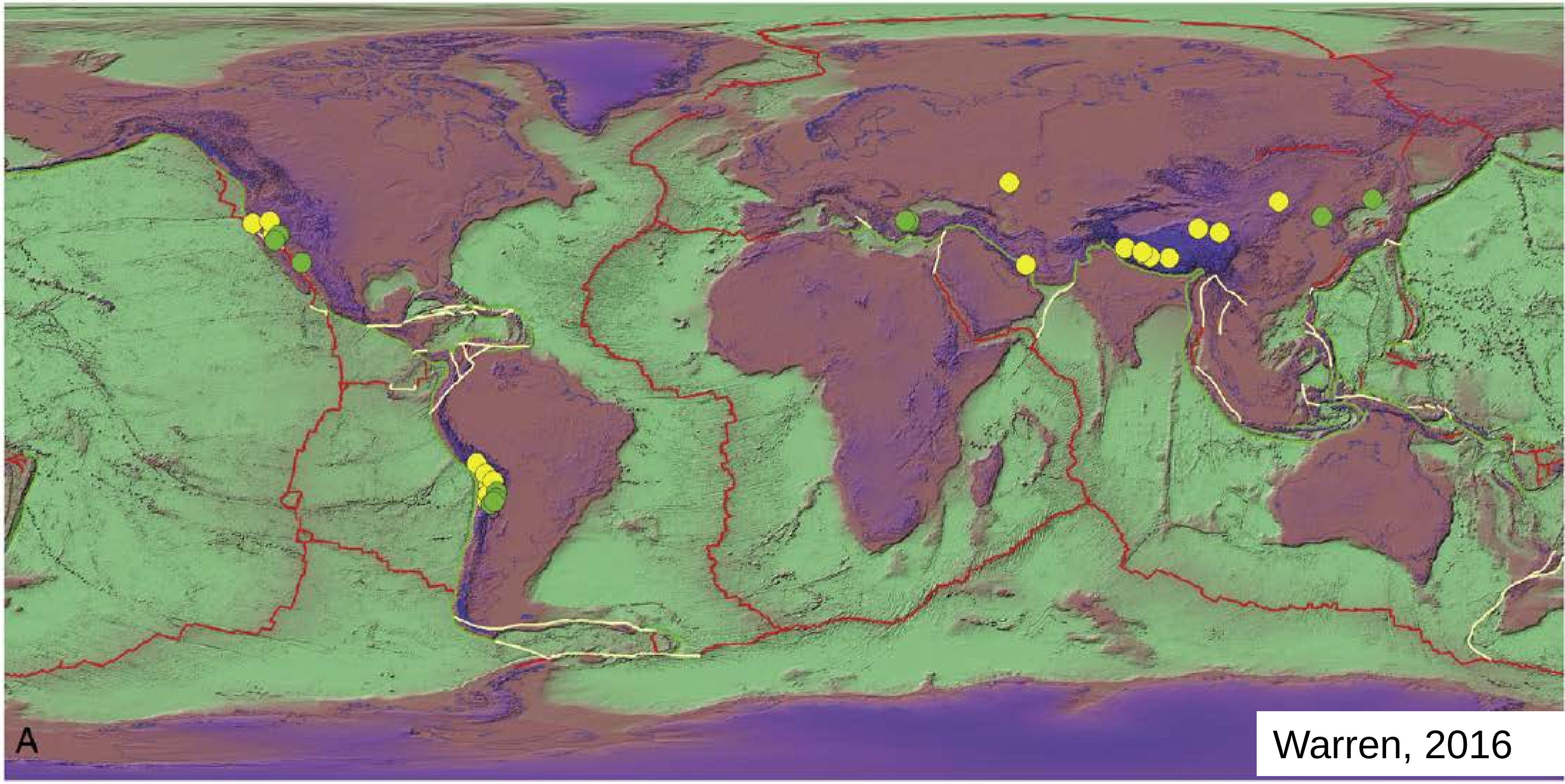
Broken Hill tourmaline: consistent $\delta^{11}B$ values

Similar geology: high thermal gradient, metaexhalites, non-marine evaporites

Slack et al 1989
Trumbull et al in prep
McGloin et al in prep

Importance of terrestrial evaporites and borate

Paleoenvironment is very specific to evaporate borate in salt pan
– arid, within ~25 degrees of equator
Areas of high relief and topography (intermontane basins; not sea level)
Isolated basins: not marine chemistry



Warren, 2016

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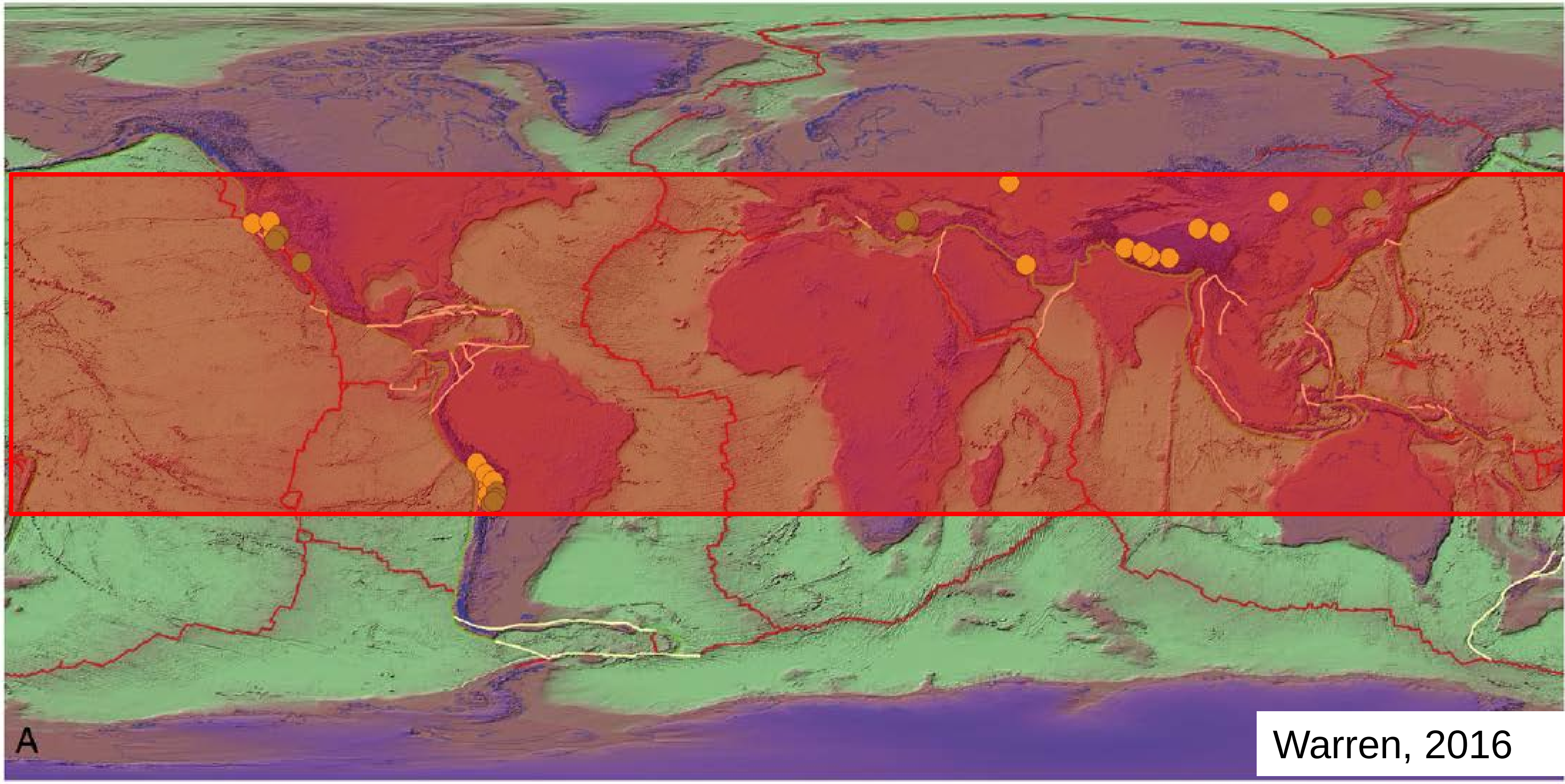

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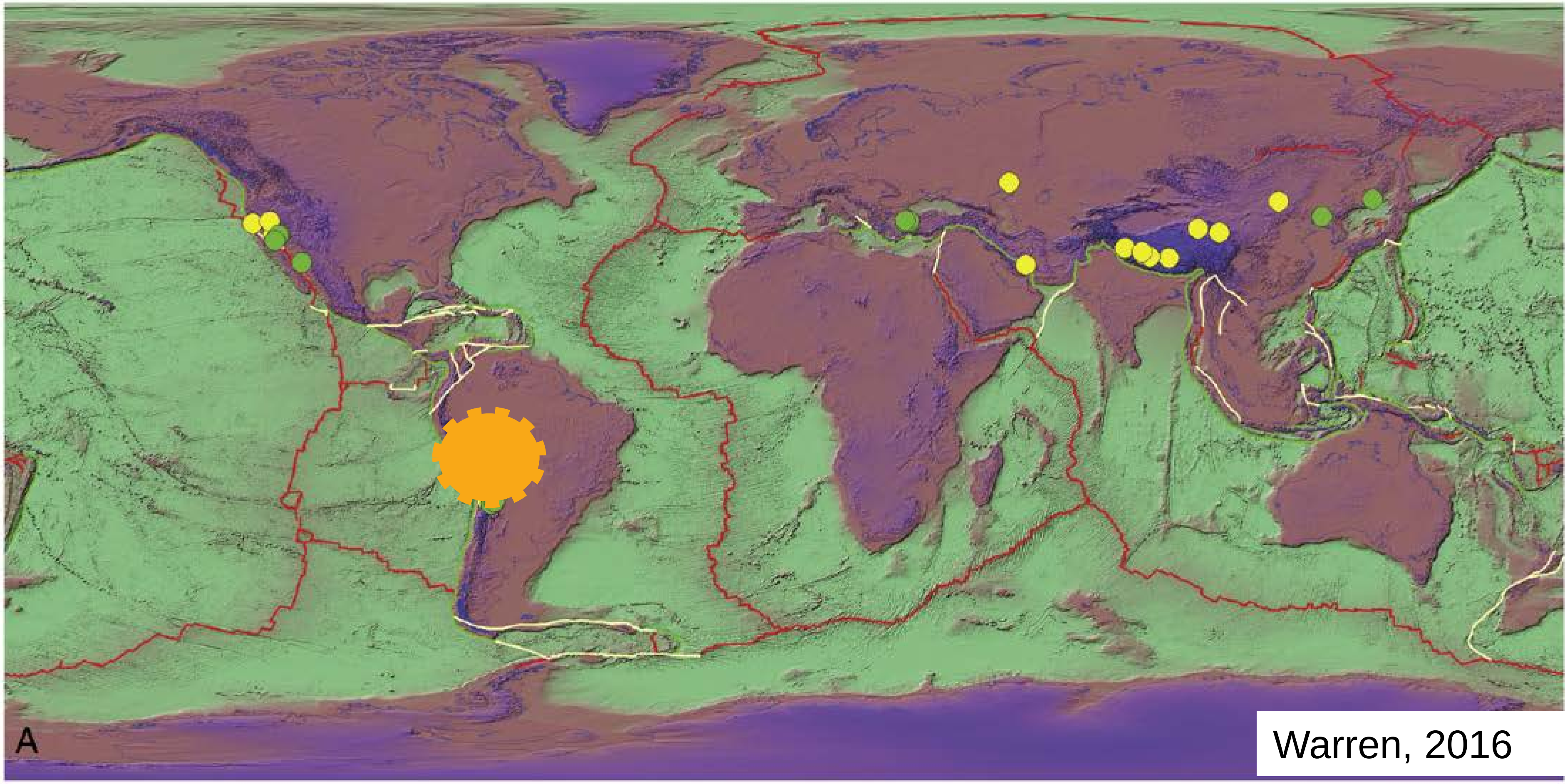


Salar deposits, Andes

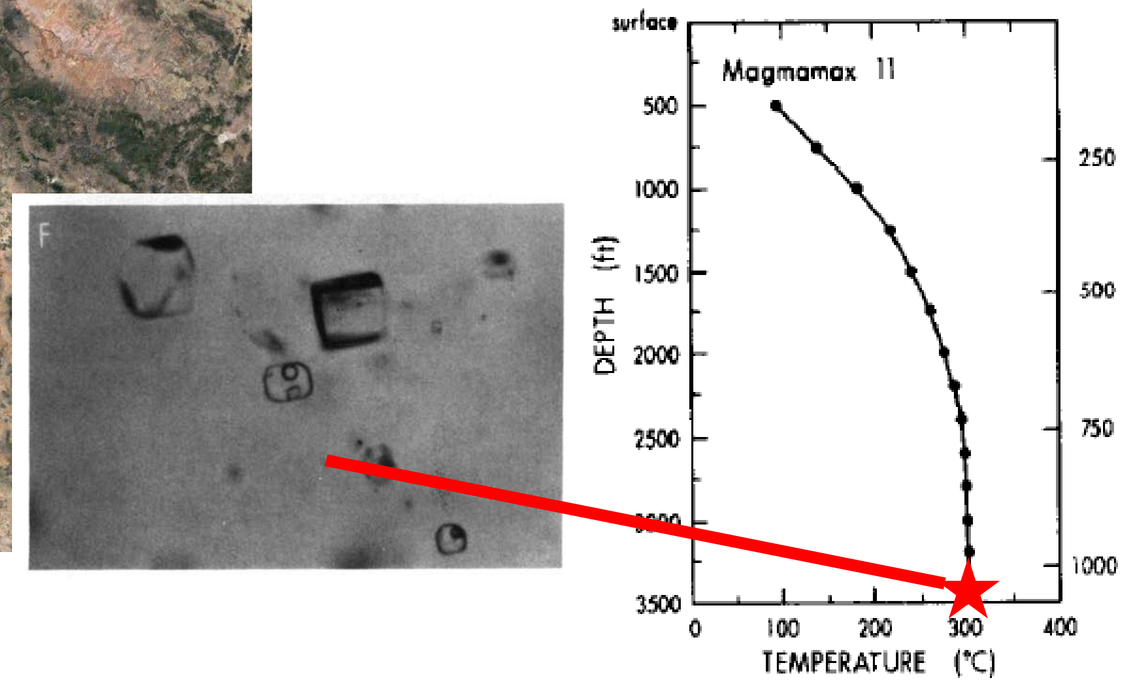
intermontane, arid, geothermally-active isolated basins

Active or formerly active volcanic/geothermal areas required for anomalous boron

High salinity Li-rich brines: great for metal transport; B-rich = borate

Salton Sea Geothermal Field, USA

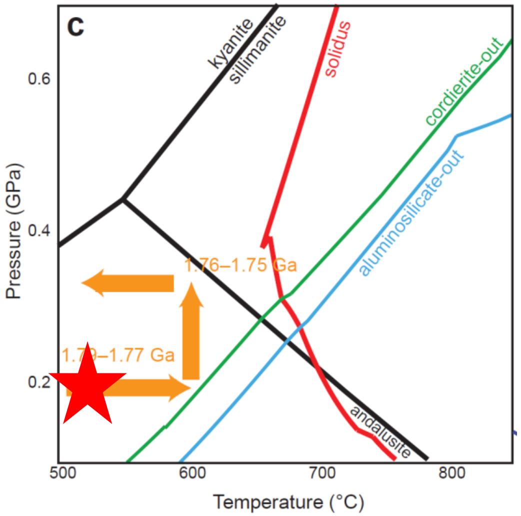
Ignore precise tectonic setting
Similarities to Broken Hill (Slack et al 1989) (and Jervois)
isolated high-T gradient basin, terrestrial evaporites, active bimodal magmatism at depth
Highly saline high temperature brines; active base metal deposition

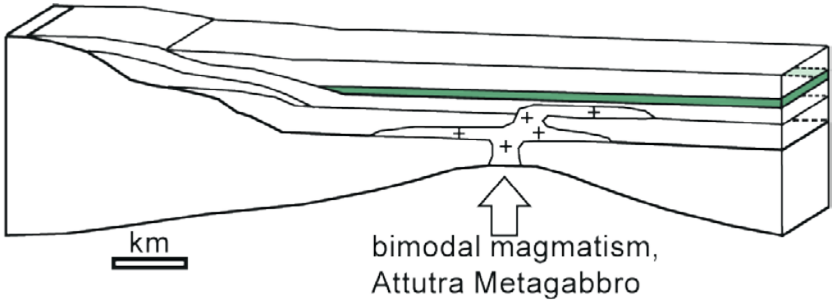


McKibben et al 1988

Geothermal wells drilled to 3-4 km depth: Encountered active greenschist hydrothermal metamorphism
Evaporites leached (hornfelsed) suggesting fluid release as connate brines;
remaining fluid inclusions indicate high temperature saline fluids
Deeper levels: garnet-actinolite-biotite assemblages

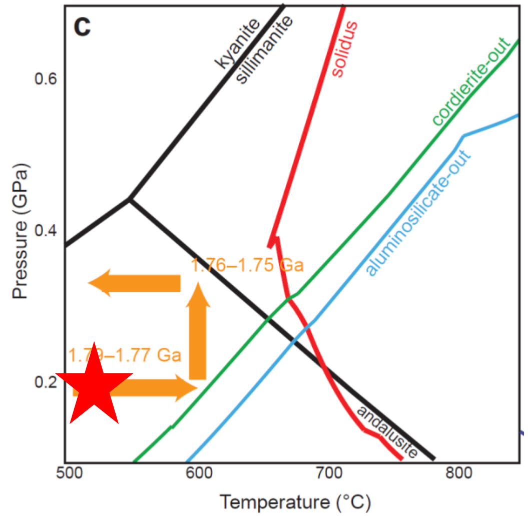
“Active metamorphism”

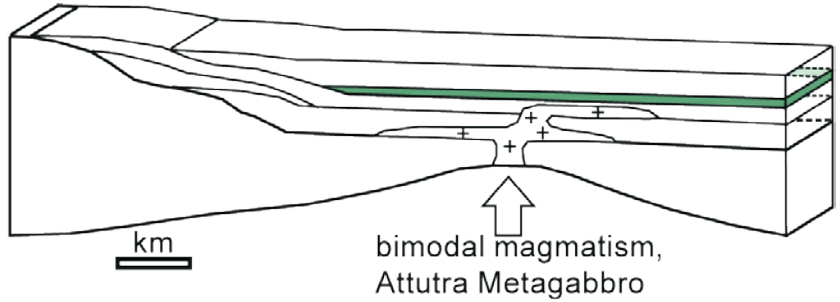


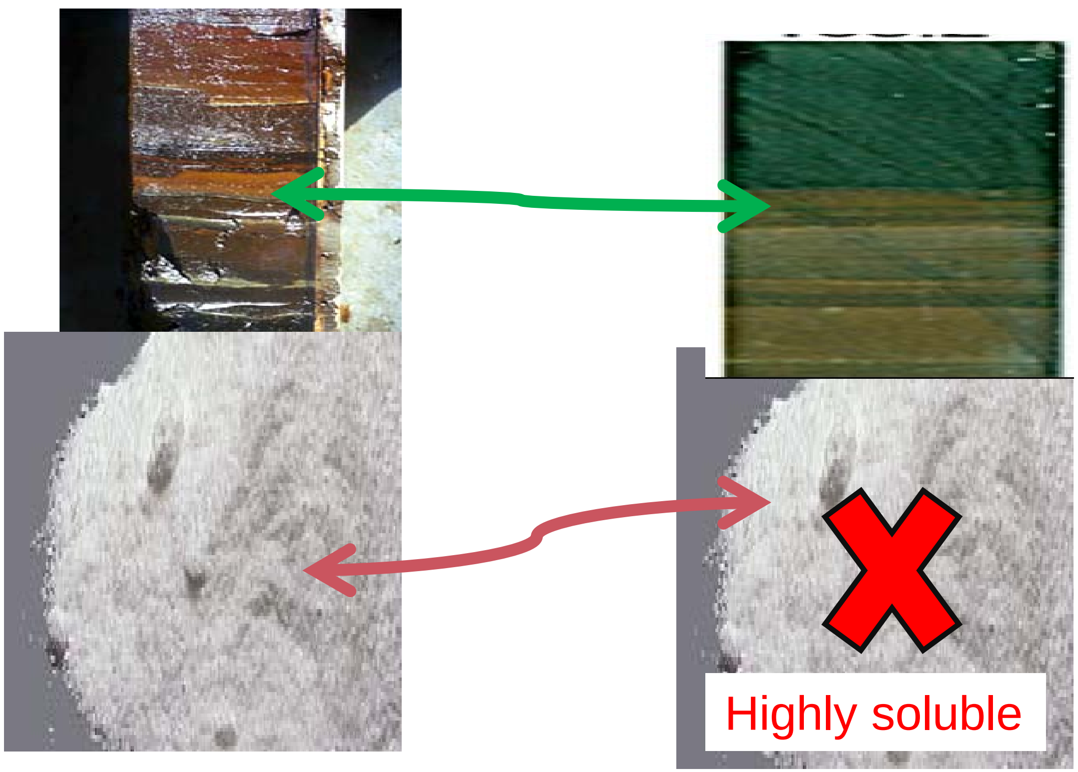


Basin floor

“Active metamorphism”

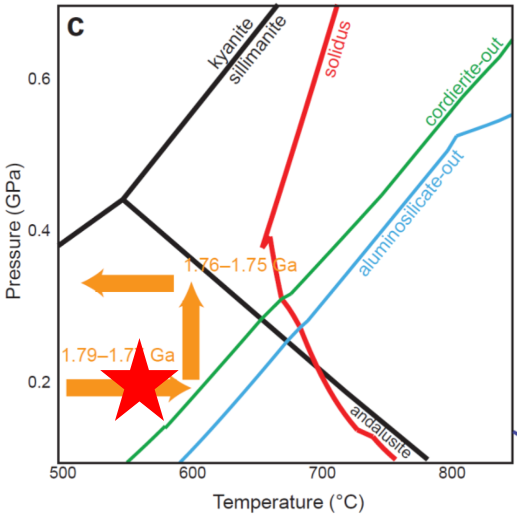


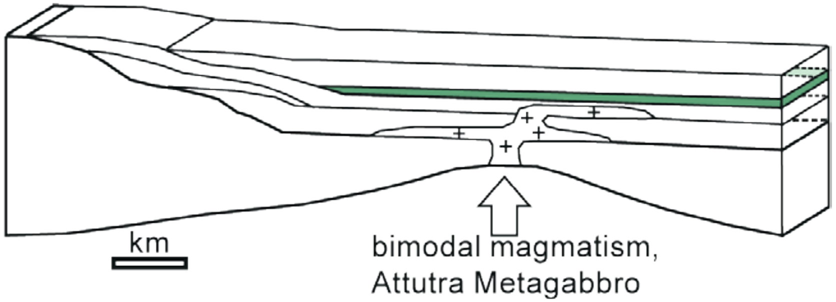


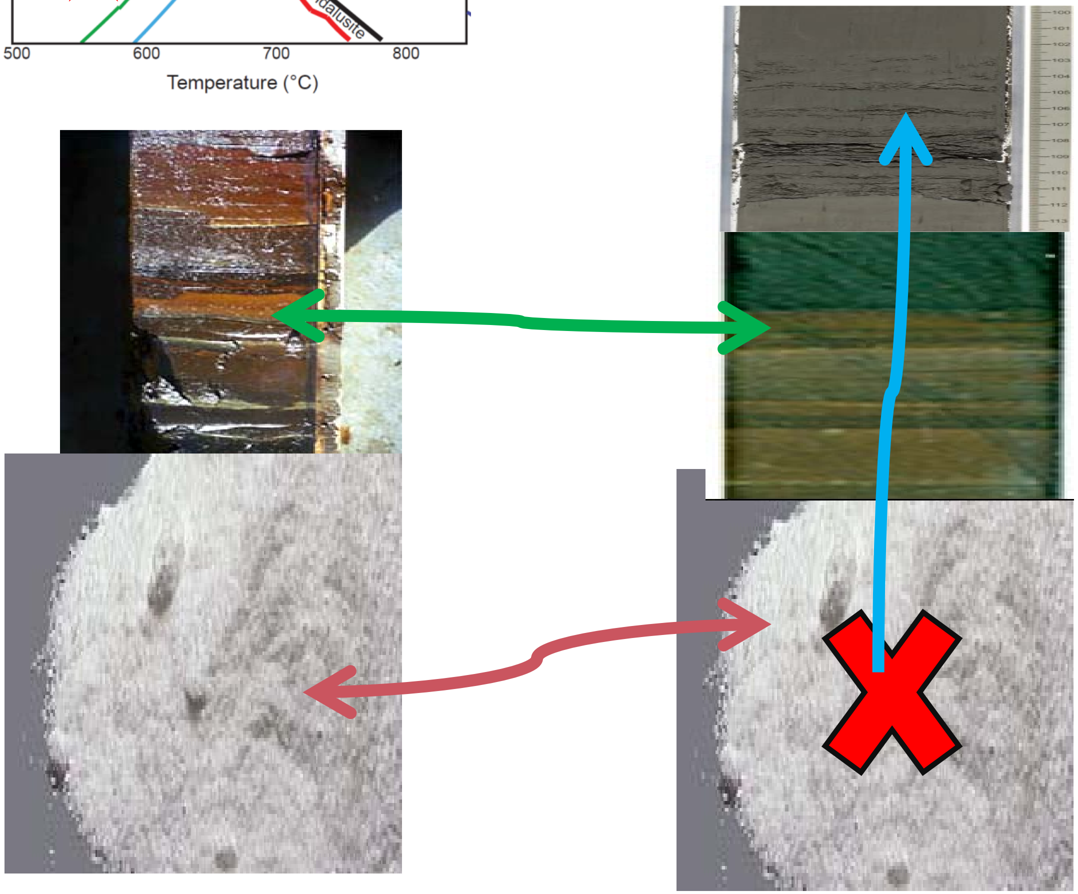


Basin floor → Lower greenschist

“Active metamorphism”

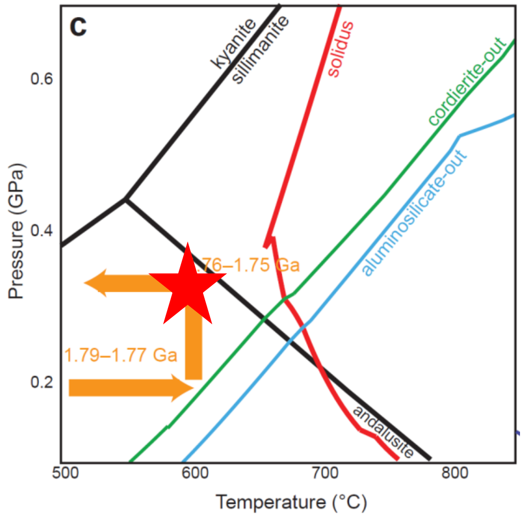


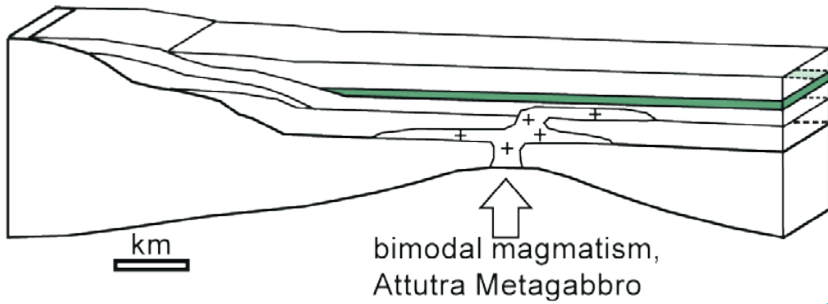


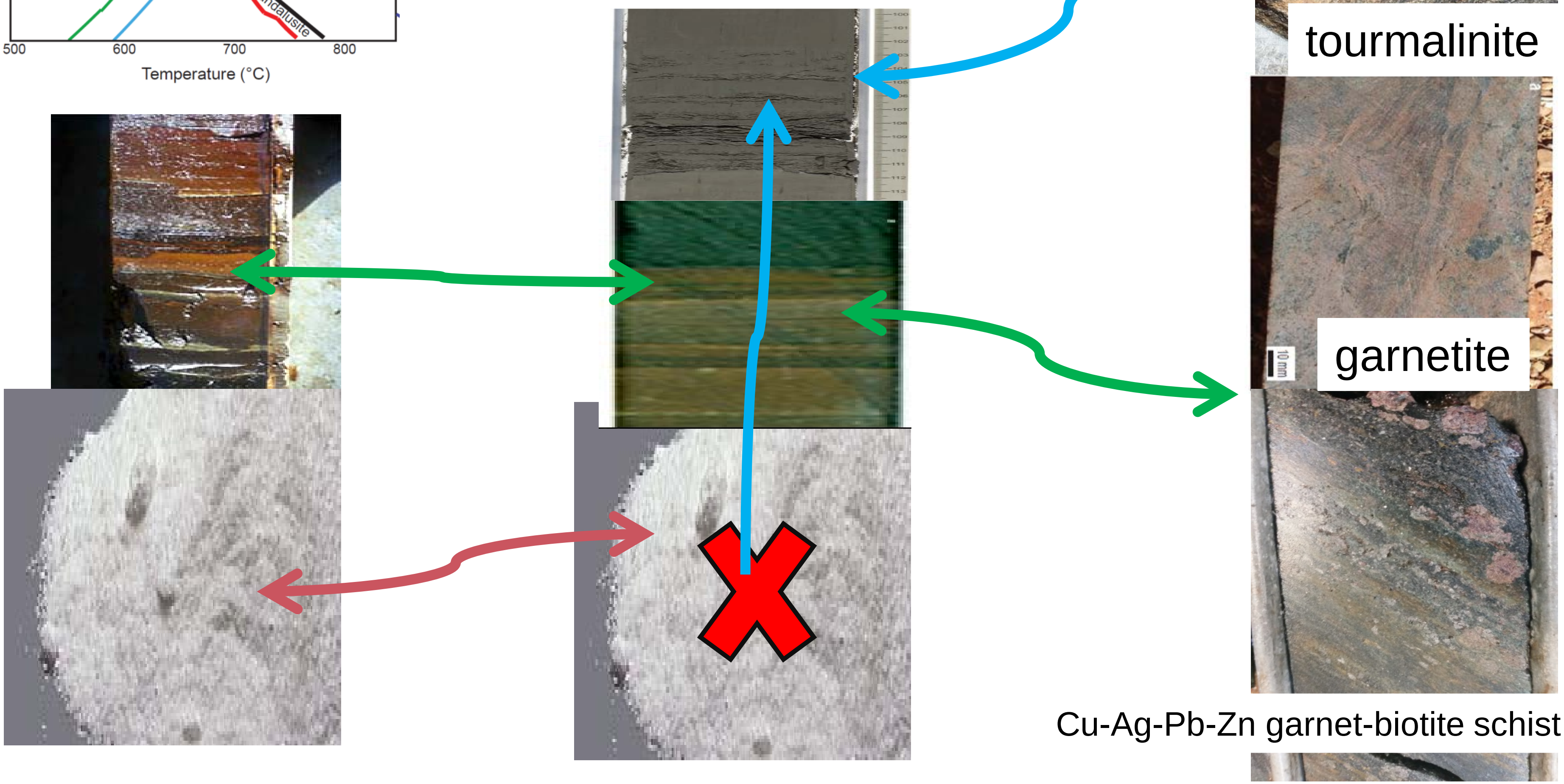


Basin floor → **Lower greenschist**

“Active metamorphism”

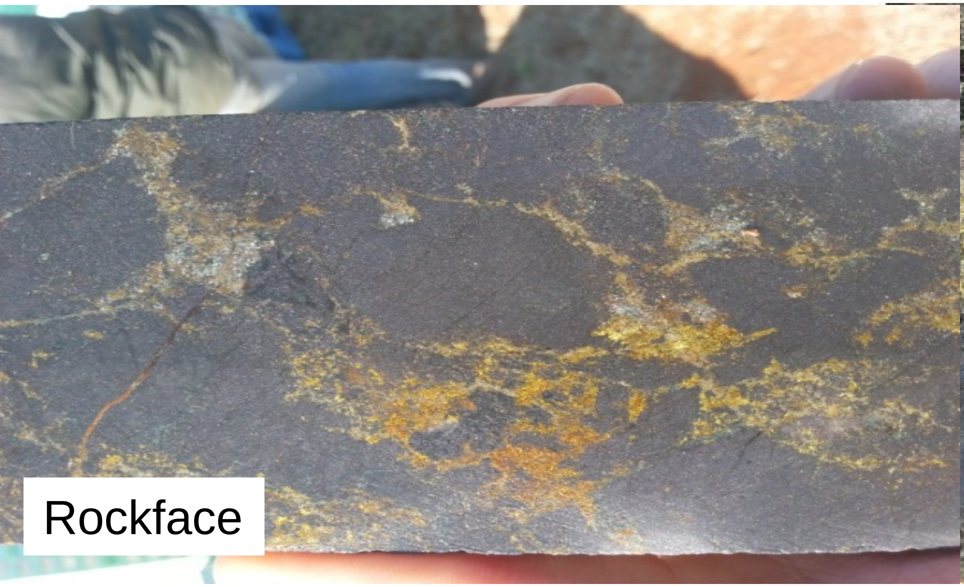






Basin floor → Lower greenschist → Upper amphibolite

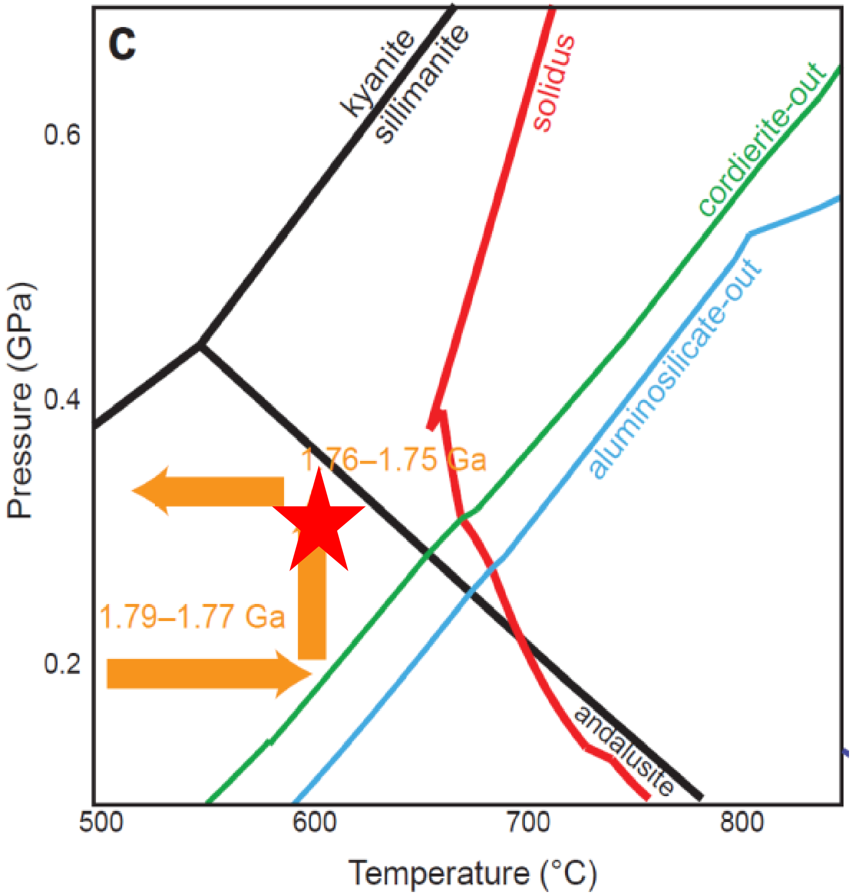
Copper-related magnetite-chlorite alteration



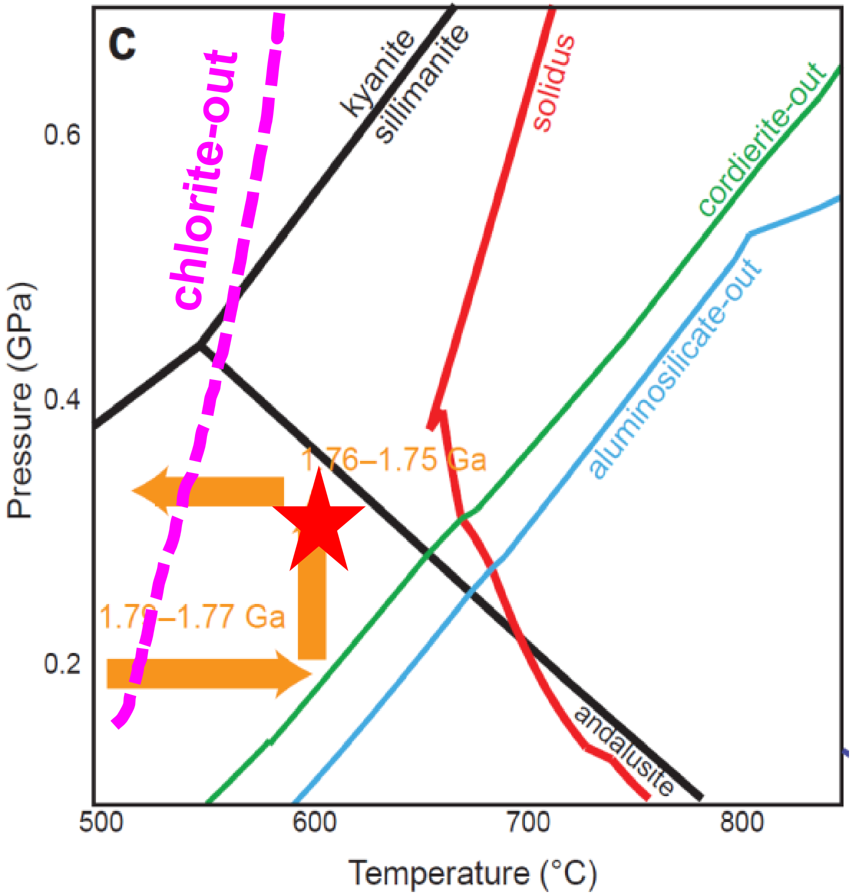
Epigenetic timing….distinct from syn-sedimentary ores

Cu-Ag±Au mineralisation (none or little Pb-Zn; remobilised)
Forms veins and massive textures
Younger timing, not deformed, veins cross-cut main foliation and later folds
Magnetite-chlorite alteration is problematic…

Peak-*P* metamorphism ca 1.76 Ga: upper amphibolite facies conditions



Peak-*P* metamorphism ca 1.76 Ga: upper amphibolite facies conditions



Chlorite removed before peak-*P* metamorphism;

Magnetite-chlorite alteration not consistent with this *P-T-t* path; must have formed through retrograde, fluid-assisted process
Evidence for this…

Hamburger Hill prospect

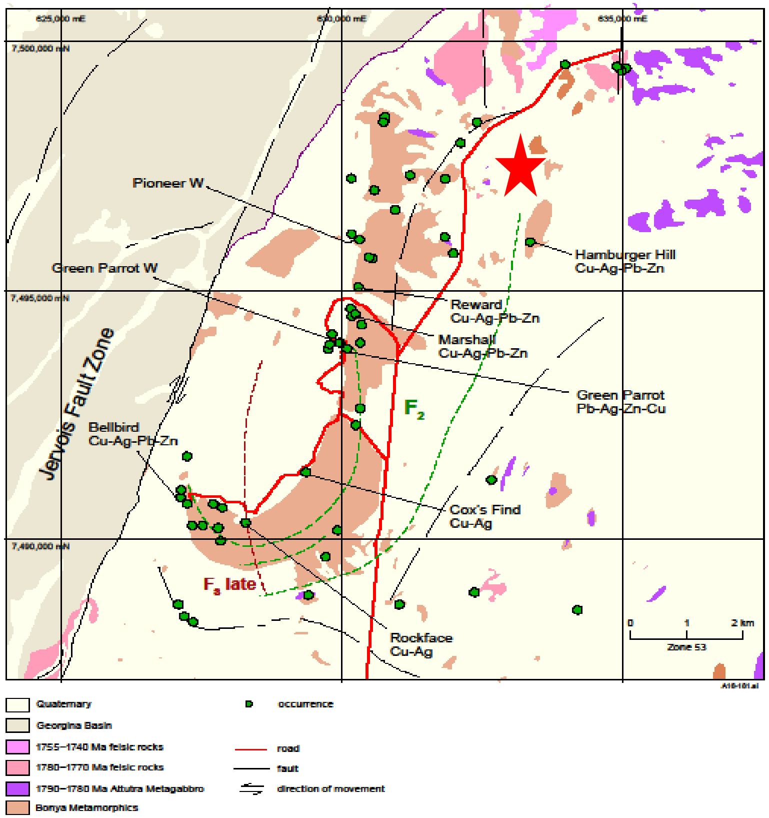
Away from syn- and post-metamorphic alteration (no veins, pegmatites)

Same polymetallic Cu-Ag-Pb-Zn as J-Fold

Garnet–biotite-rock

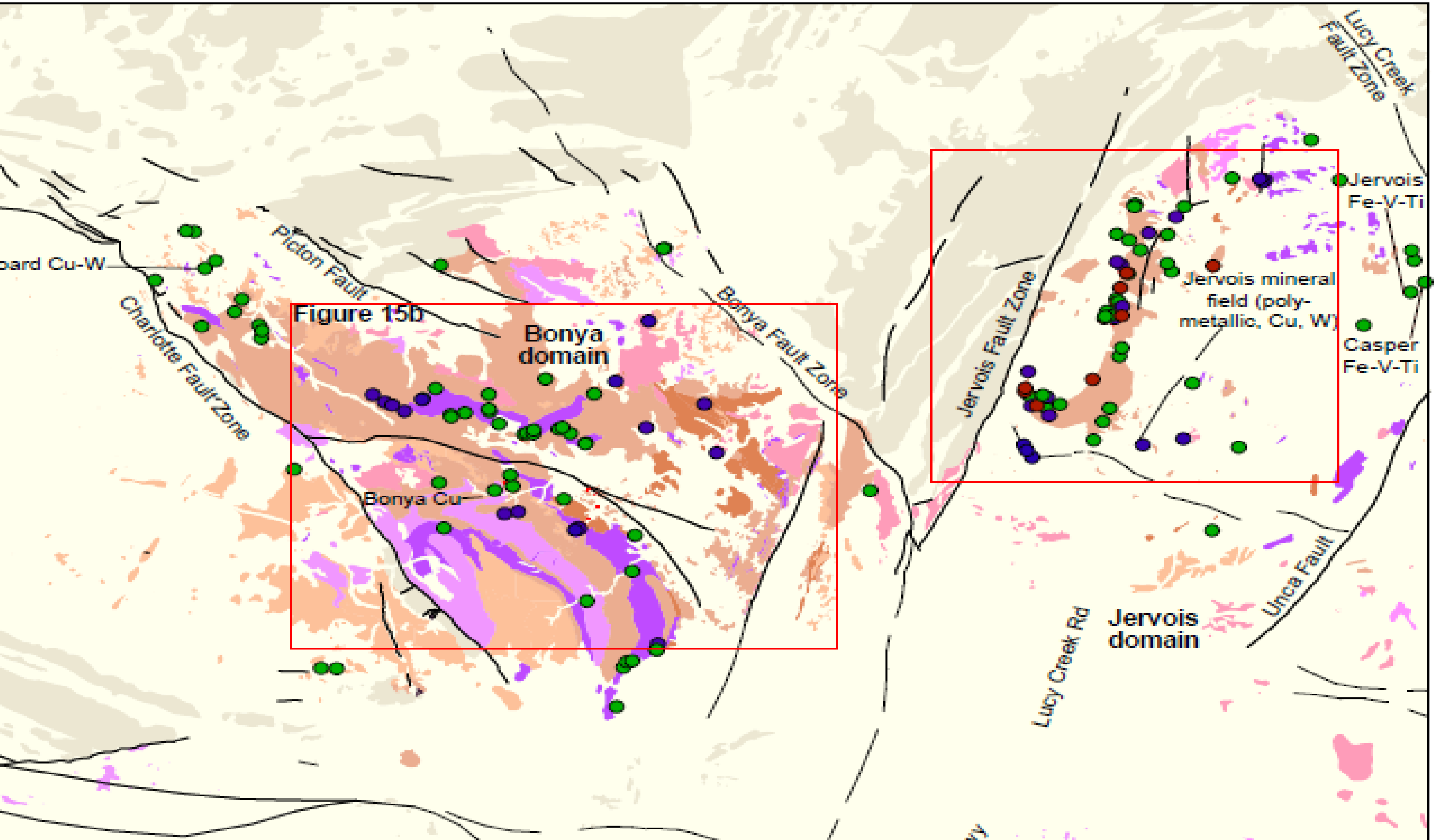
No magnetite/chlorite – consistent with *P-T*-t path

What's different about the J-Fold then?



Regionally **>50 epigenetic Cu** occurrences
Share same timing, structural control, host rocks as magnetite-chlorite-Cu in J-Fold
but magnetite, Pb and Zn enrichment appears unique to the J-Fold

Why is this?



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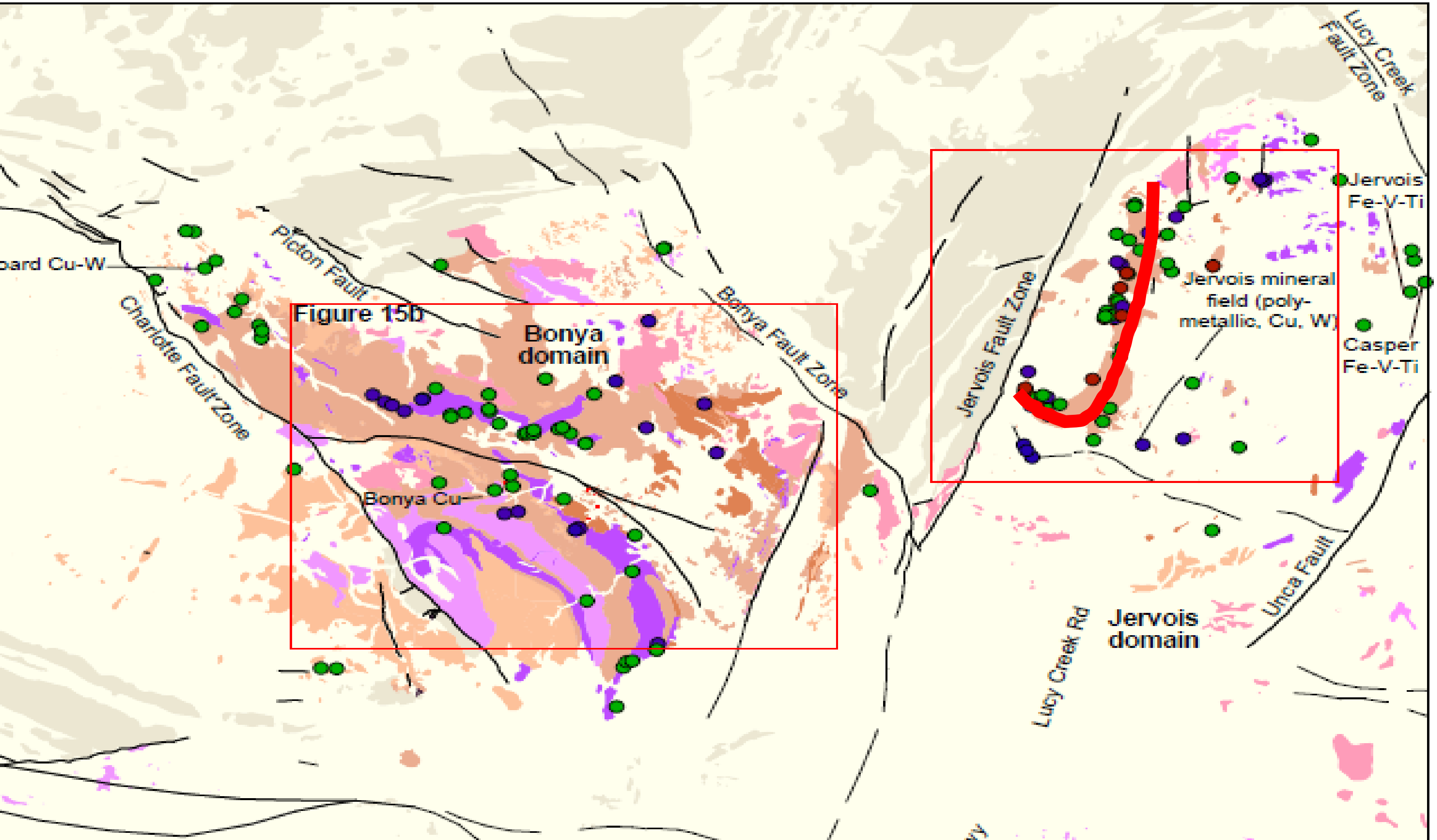
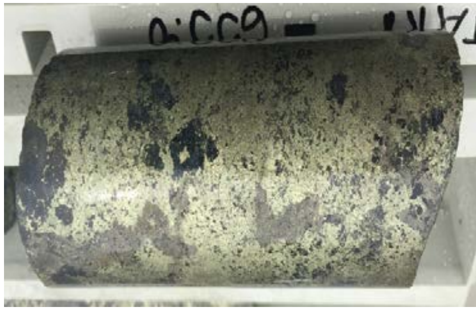


Fluid-assisted retrograde alteration at Rockface

Garnet-biotite

magnetite-chlorite-biotite

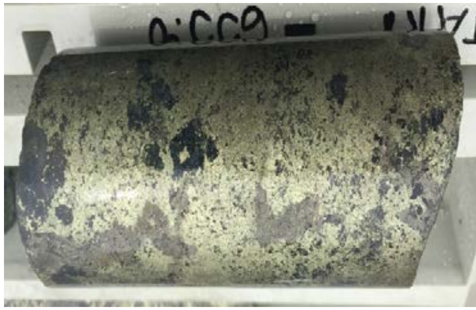
magnetite-cpy-py-qtz



cpy-py

Fluid-assisted retrograde alteration at Rockface





Garnet-biotite | magnetite-chlorite-biotite | magnetite-cpy-py-qtz | cpy-py

Fluid-assisted retrograde alteration at Rockface

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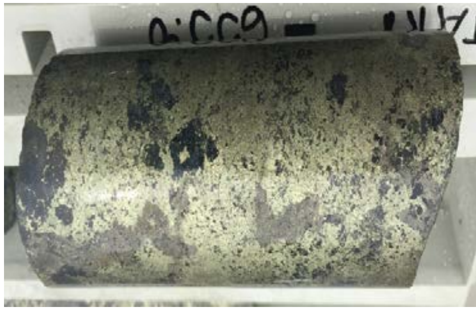

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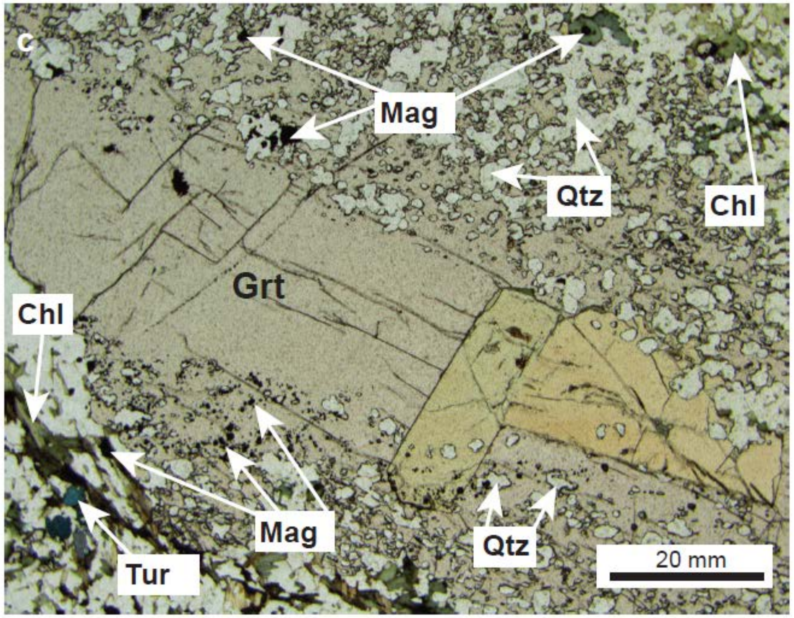


Fluid-assisted retrograde alteration at Rockface

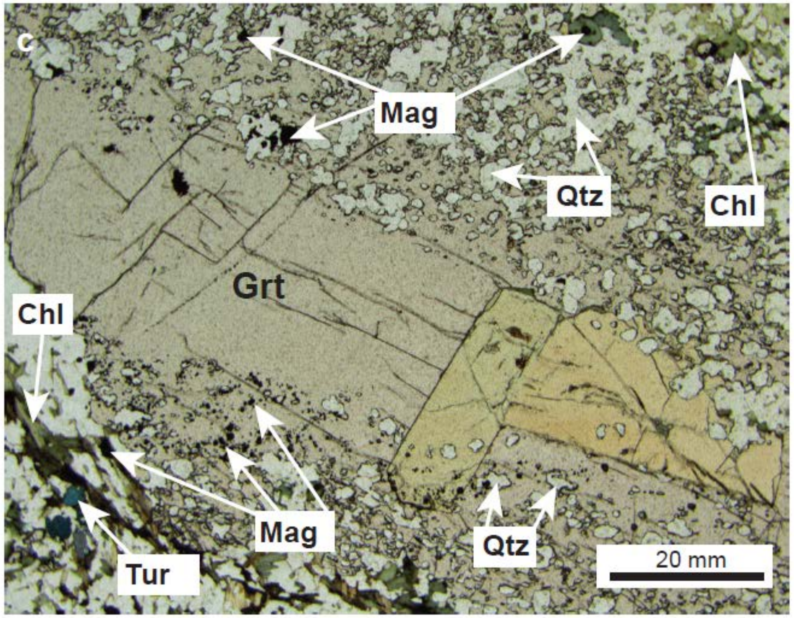
Does precursor syn-sedimentary alteration control magnetite-related Cu mineralisation?
Chemical/structural traps?
Do these processes deconstruct the genesis of one type of “IOCG” deposit?

Garnet-biotite

magnetite-chlorite-biotite

magnetite-cpy-py-qtz

cpy-py



Thank you

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