The Burns Cu-Au deposit: superimposed porphyry, IOCG and orogenic events

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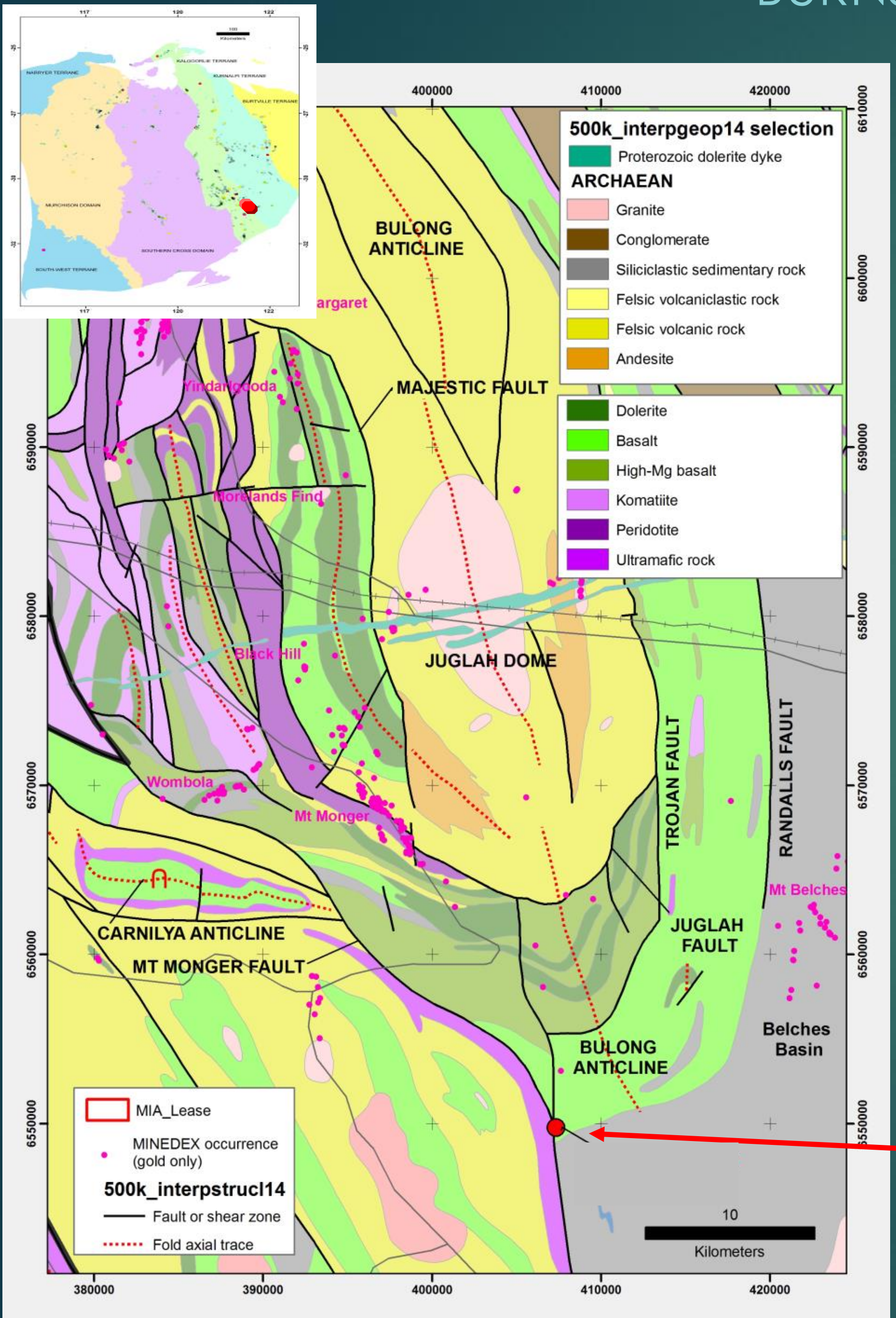
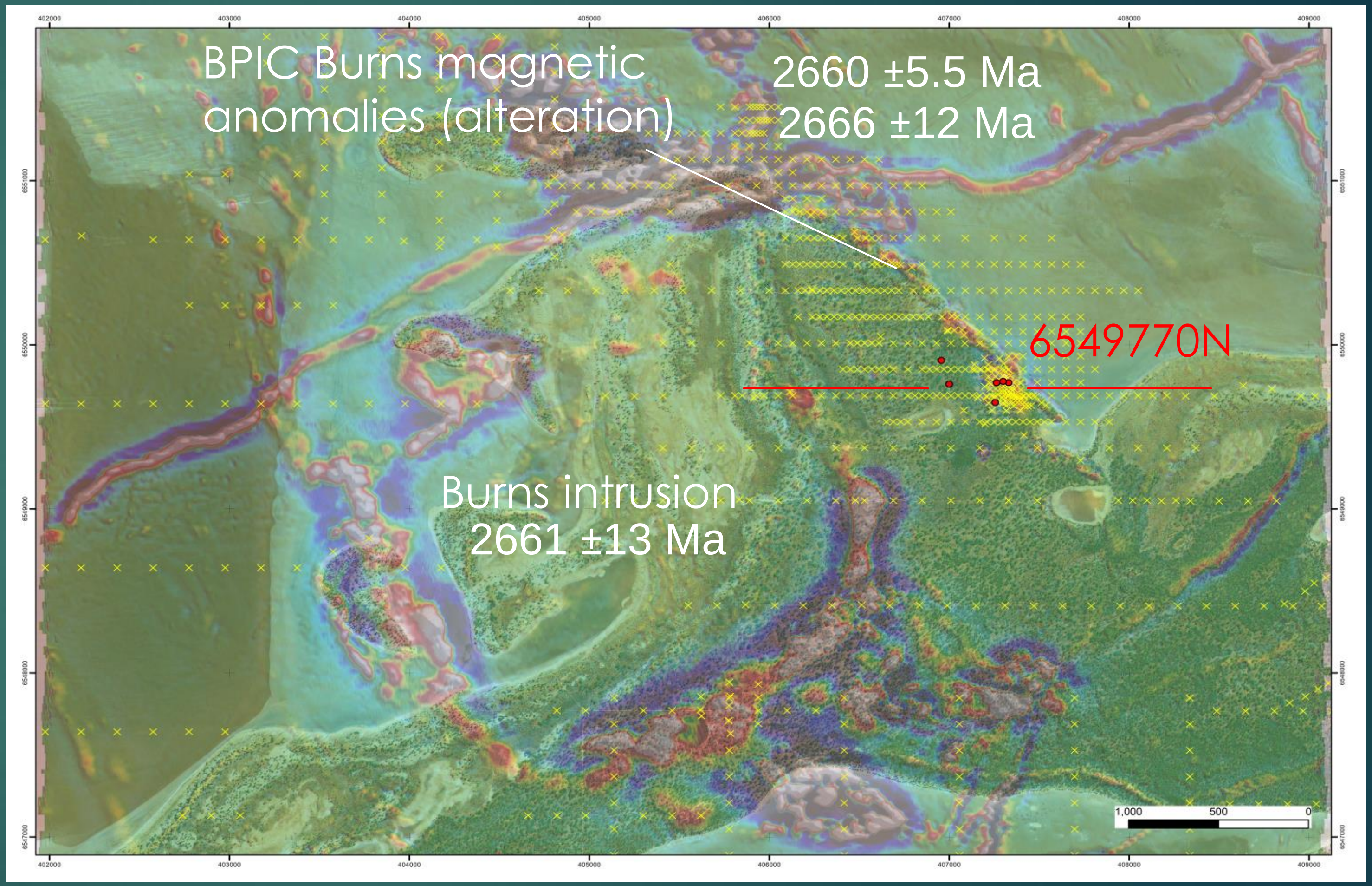
FUNDED BY LEFROY EXPLORATION

23rd NOVEMBER, 2023

BURNS: GEOLOGICAL SETTING

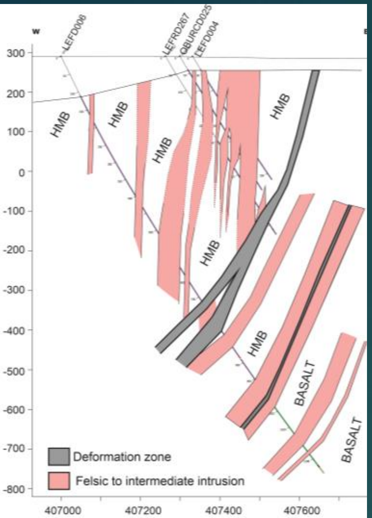


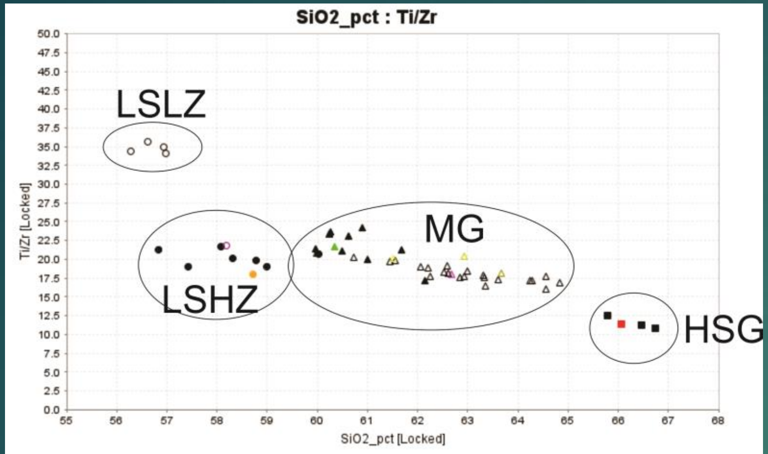
Poor exposure; under salt lake and gypsum dunes
Study of selected diamond drill holes
Section 6549770N



Burns Cu-Au deposit: Triple point (Kalgoorlie Terrane/Kurnalpi Terrane/Mt Belches Basin
Proximal to Mt Monger Fault

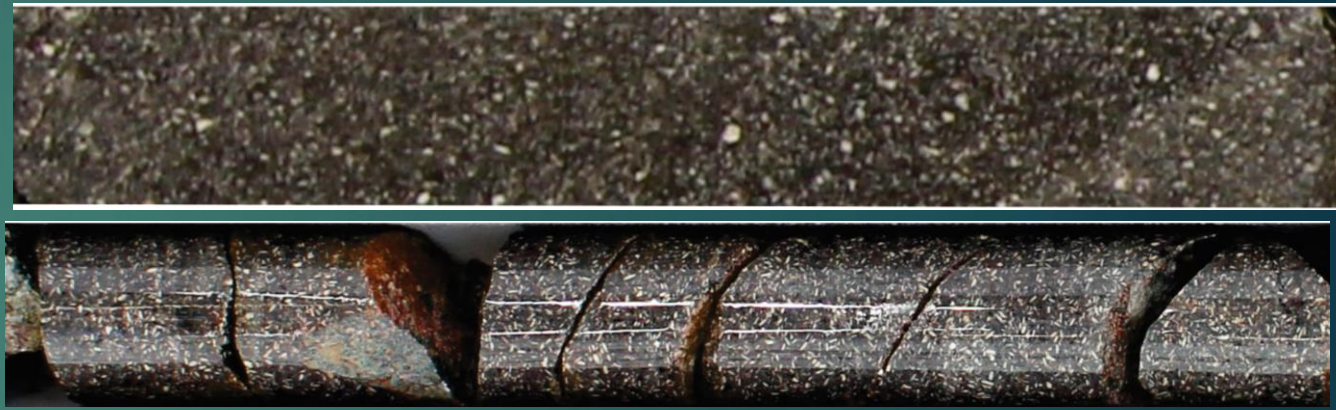
BURNS: **AMPHIBOLE-FELDSPAR** PORPHYRY INTRUSIVE COMPLEX





- Only subtle modal and textural differences observed in the field
- Intrusion samples subdivided on the basis of SiO_2 (%)
- Some variation in phenocryst size and abundance within groups
- Distinctive features
- Low-Si/high-Zr group: trachytic texture
- High-Si group: fine grainsize and abundant mafic xenoliths.

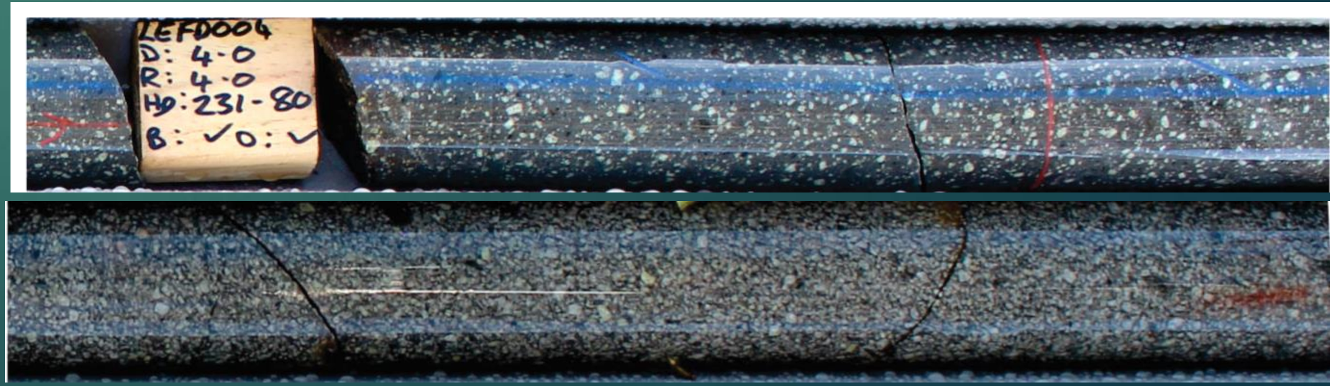
Low-Si/high-Zr intrusions



High-Si intrusion

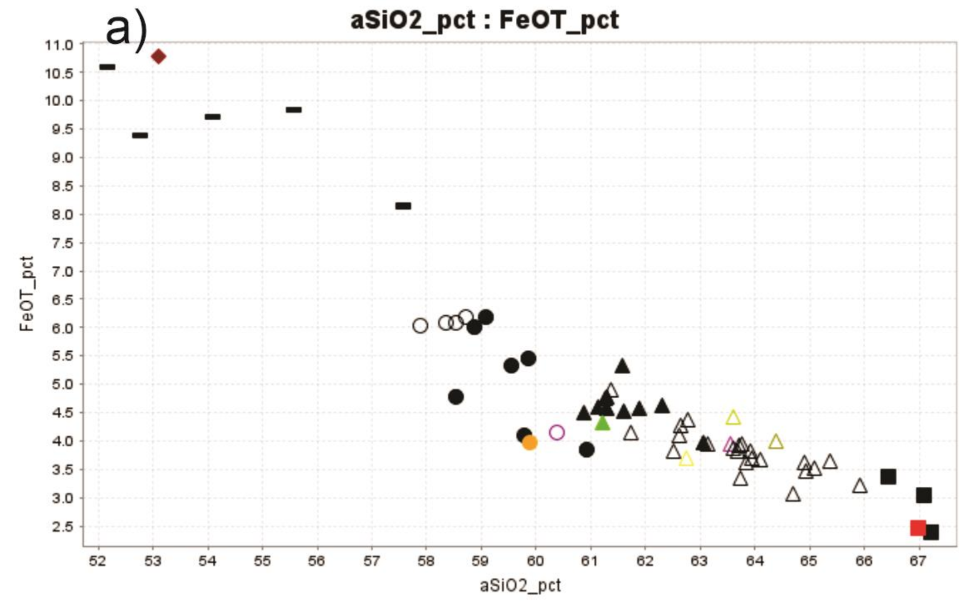
Main group intrusions

Low-Si/low-Zr intrusions

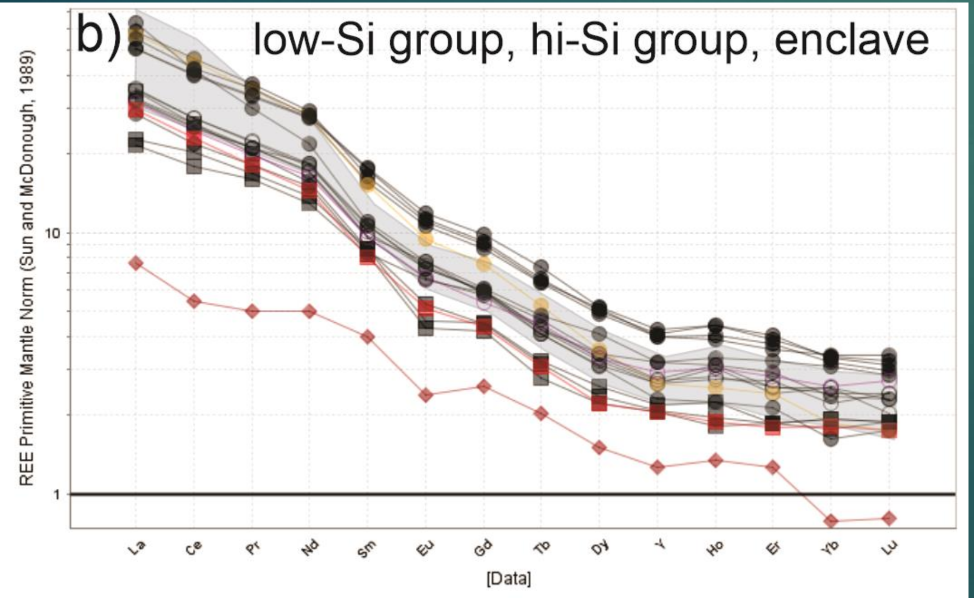


BURNS: WHOLE-ROCK CHEMISTRY

Amphibole fractionation



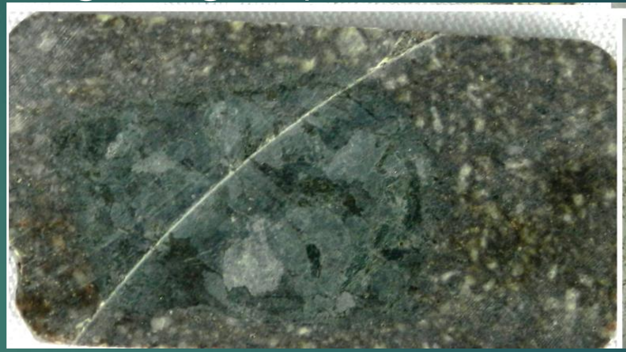
Suppression of plagioclase

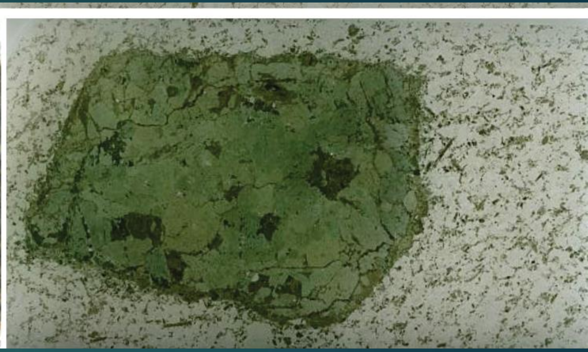


MAFIC ENCLAVES

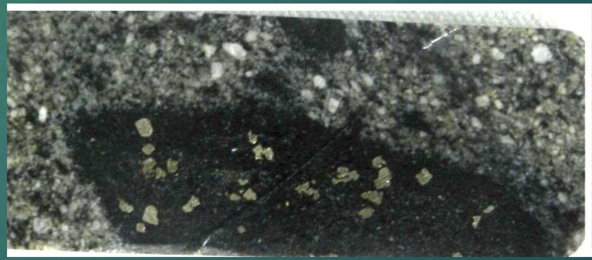
These are not microgranitic enclaves; rather…..

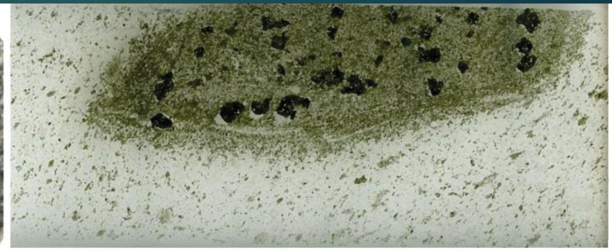
Mafic enclaves are common, but very common in the high-Si group intrusions





The amphibole-rich enclaves are cumulate-textured, meta-hornblendite, suggesting derivation from early-formed components of a deeper hydrous magma chamber

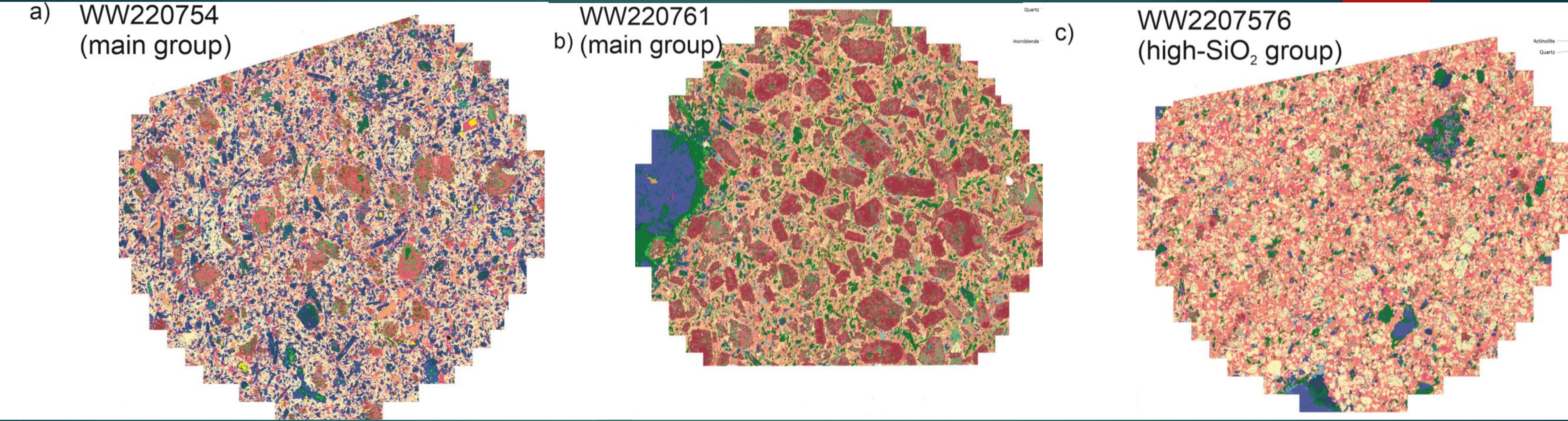




The biotite-rich enclaves; some contain abundant apatite; some are pyritic; biotite-apatite enclaves are unusual (globally); metasomatised interflow metasediment? accidental xenolith from roof of magma chamber?

BURNS: **AMPHIBOLE-FELDSPAR** PORPHYRY INTRUSIVE COMPLEX

TIMA imagery



Actinolite	5.26
Quartz	18.82
Orthoclase	7.18
Albite	15.01
Andesine	23.59
Biotite	11.27

Low-Si/hi-Zr group is Kfeldspar-rich, low Si and alkalic (also high P, Th, Nb, Zr); main group has variable proportions of Kfeldspar and plagioclase; hi-Si group is fractionated and dacitic

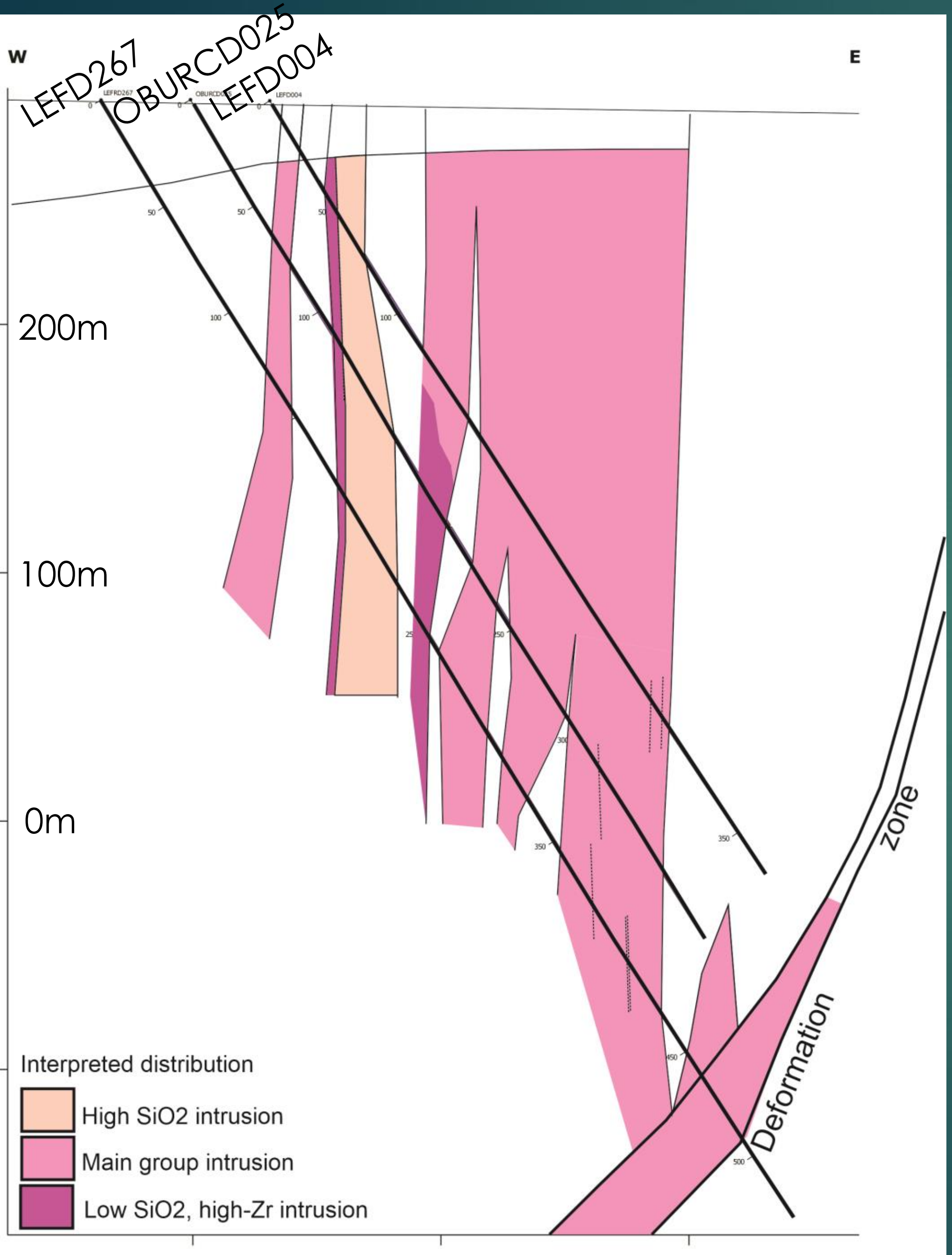
Kfeldpsar is Ba-rich (up to 3.65% BaO), comparable with alkalic intrusions, including Karari syenites

Some main group porphyry intrusions dominated by igneous plagioclase (WW220761); others contain mainly Kfeldspar phenocrysts (WW220754); most have plagioclase and Kfeldspar in various proportions

Igneous hornblende is the other main phenocryst phase; variably altered to actinolite

Amphiboles variably altered to biotite (no igneous biotite) – hydrothermal alteration
Groundmass variably albitic (left), siliceous (centre) and potassic (right) – hydrothermal alteration

BURNS: LITHOLOGICAL CONTACTS – TIMING AND SPATIAL RELATIONS



BPIC components

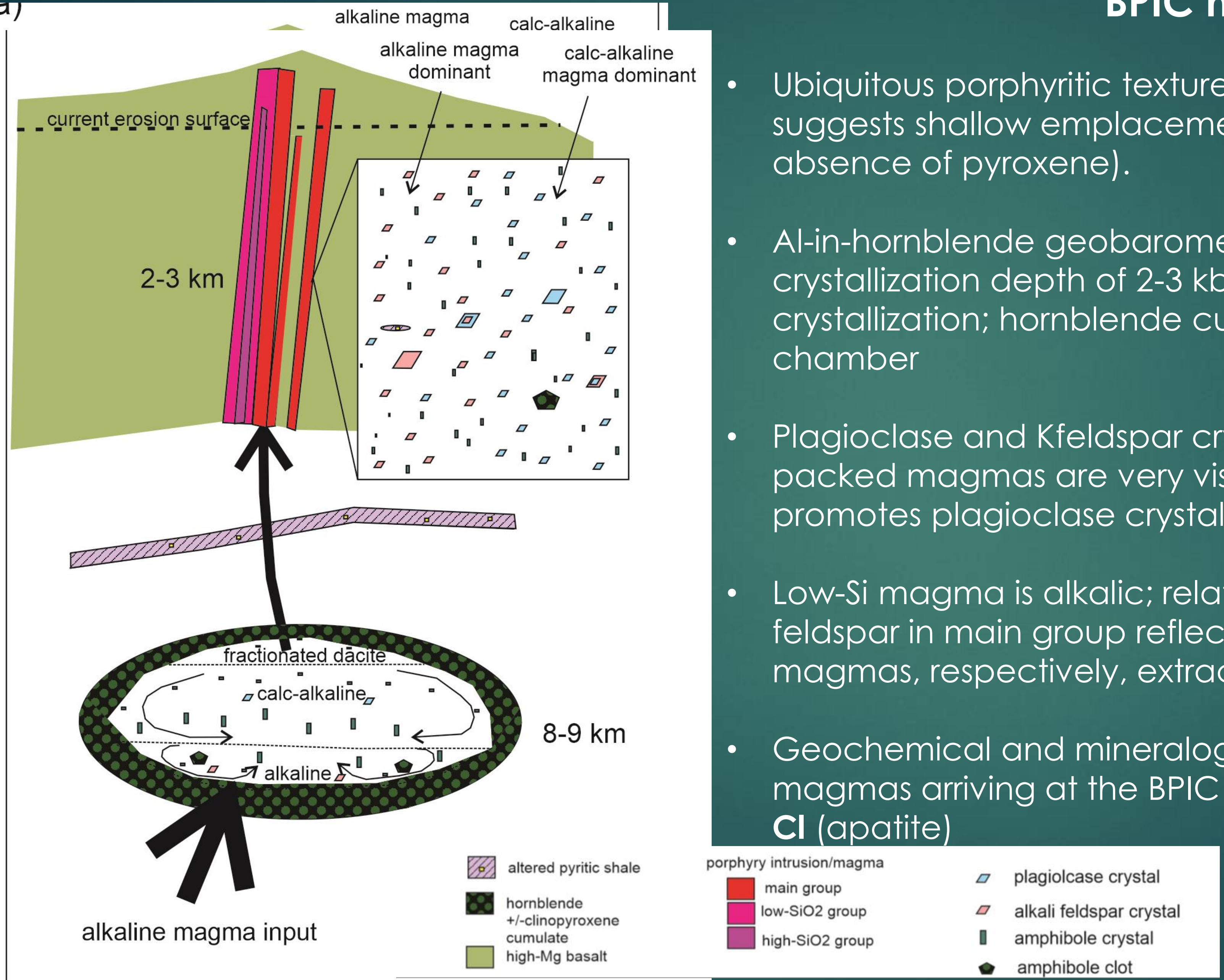
BPIC dominated by main group porphyry intrusions

Internal contacts of main group porphyries are transitional to sharp, and indicate multiple intrusive pulses during construction

Low-Si and High-Si intrusions show sharp contacts with each other and main group porphyries

Emplacement sequence: main group > low-Si/hi-Zr gp > high-Si gp.

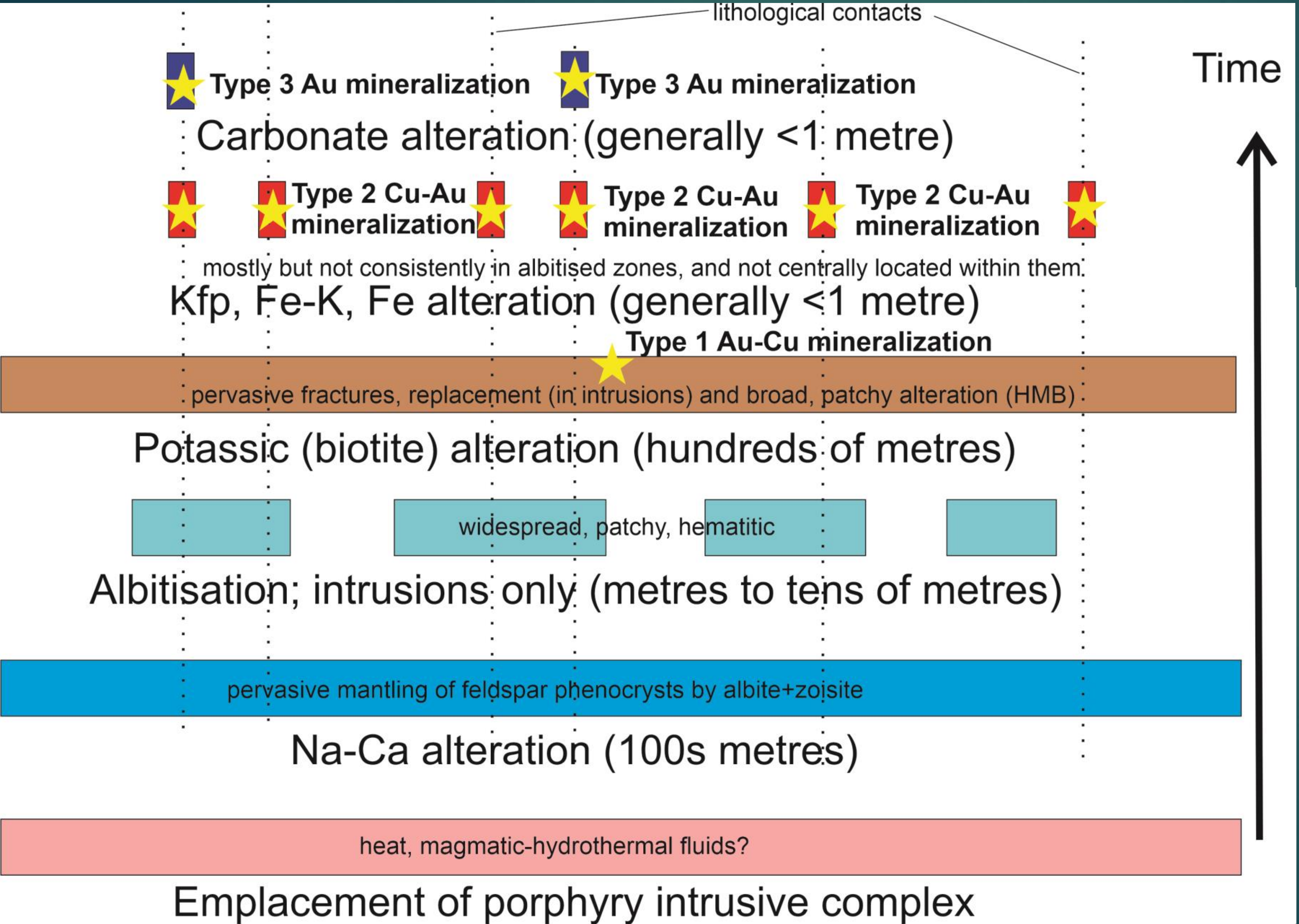
Burns: **amphibole-feldspar** porphyry intrusive complex: a model



BPIC magmatic model

- Ubiquitous porphyritic textures and local flow-textured groundmass suggests shallow emplacement (minm P of ca 0.5 kbars inferred from absence of pyroxene).
- Al-in-hornblende geobarometer (**Mutsch et al., 2016**) indicates a crystallization depth of 2-3 kbars (8 – 9 km) in the absence of plagioclase crystallization; hornblende cumulates formed in subjacent staging chamber
- Plagioclase and Kfeldspar crystallized in situ at P = 0.5 to 1 kbar – crystal-packed magmas are very viscous and difficult to mobilise (loss of P promotes plagioclase crystallization)
- Low-Si magma is alkalic; relative proportions of plagioclase and alkali feldspar in main group reflect mass ratio of calc-alkaline and alkalic magmas, respectively, extracted from the mid-crustal magma chamber
- Geochemical and mineralogical studies indicate that the mixed magmas arriving at the BPIC were **hydrous, oxidised and carried S and Cl** (apatite)

Burns Cu-Au deposit: Hydrothermal history



Progressively contracting hydrothermal system

Penultimate inputs are 3 types of Cu and Au ore fluids

<u>Overview</u>

Carbonate-rich veins and alteration on some reactivated contacts (**Au ± Cu**)

Cm- to metre-scale Kfelsdspar-actinolite-magnetite alteration on porphyry/HMB contacts (**Cu-Au**)

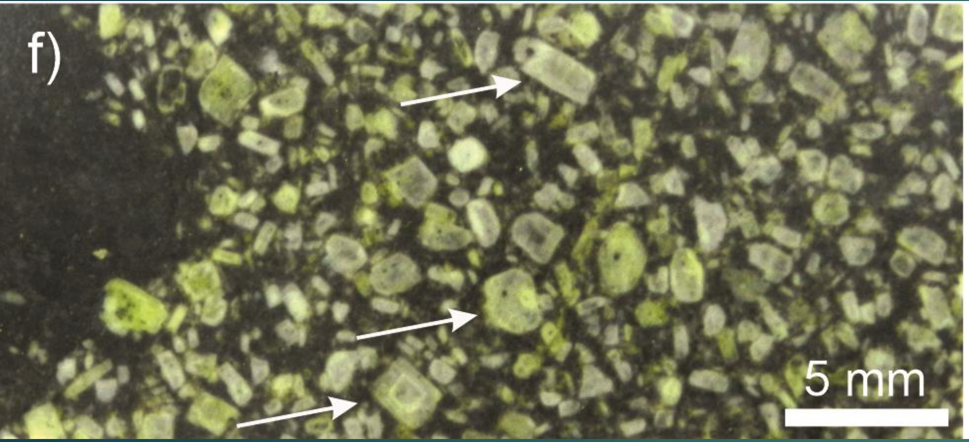
Potassic (biotite) alteration throughout porphyry intrusions and HMB; selective **Au-Cu** mineralization

Metre – to 10s of metre-scale albitisation of porphyry intersections

Pervasive (district-scale?) Na-Ca alteration of porphyry intrusions and HMB

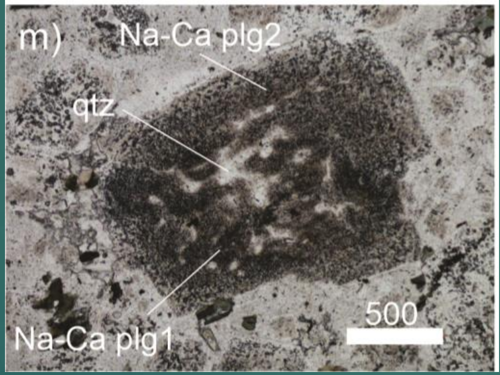
Magma emplacement
Heat, fluid mobilisation, magmatic fluid input?

Na-Ca alteration assemblage: albite+zoisite+actinolite



Metasomatic mantles of albite+zoisite on feldspar phenocrysts; micro-voids (Plumper & Putnis, 2009)

Relict igneous oligoclase and (Ba-)Kfeldspar cores; including some compound cores.

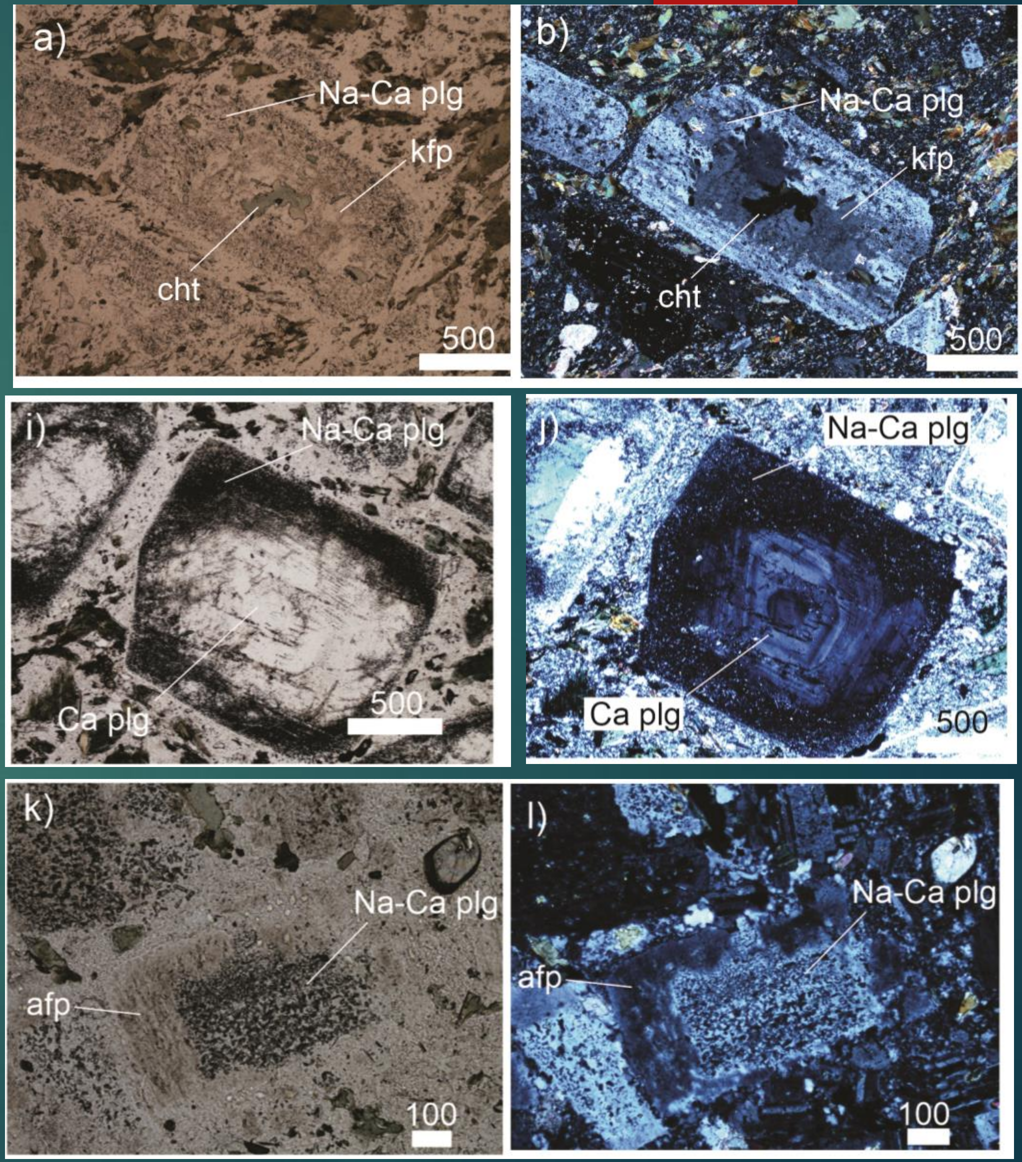


Also high-Si intrusions but these show perthitic overgrowths on the albite+zoisite mantles, and sieved plagioclase cores.

Low-Si/high-Zr intrusion

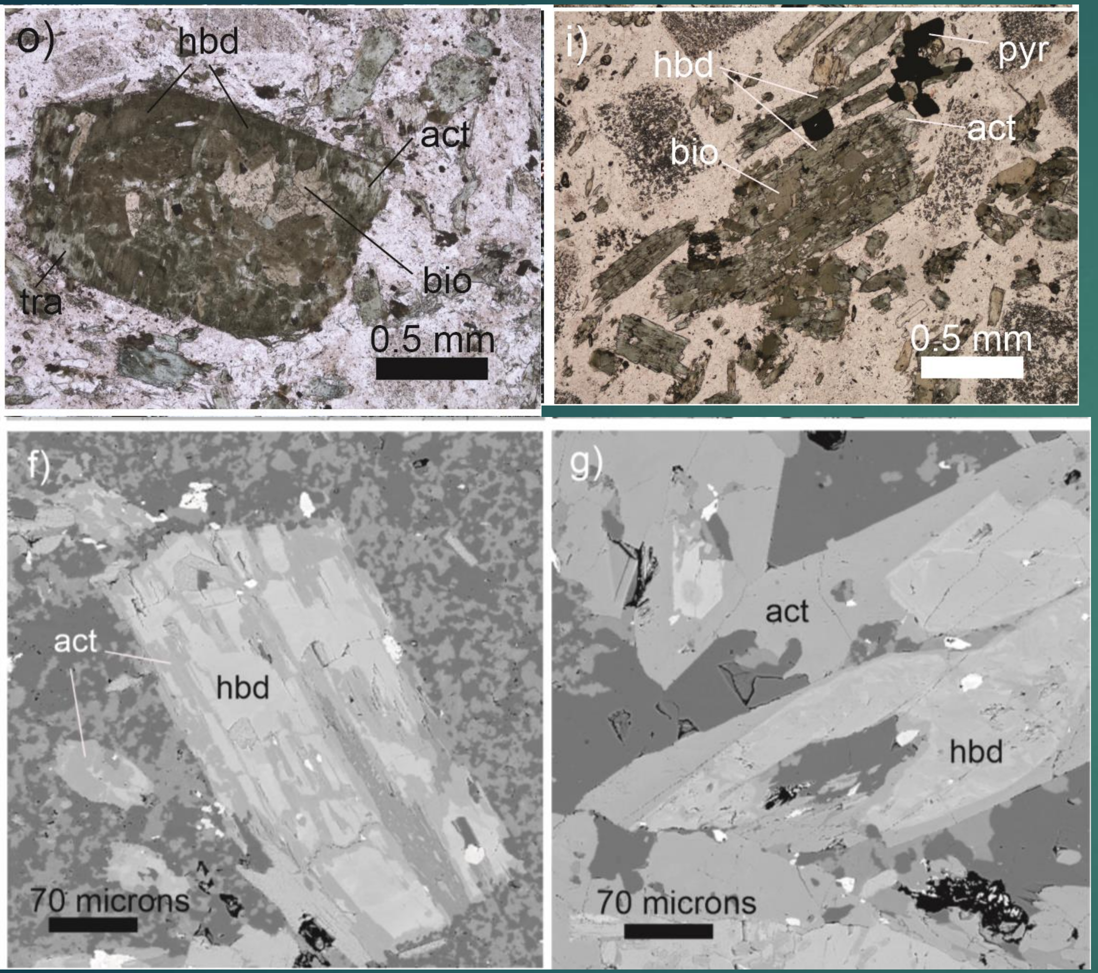
Main group intrusion

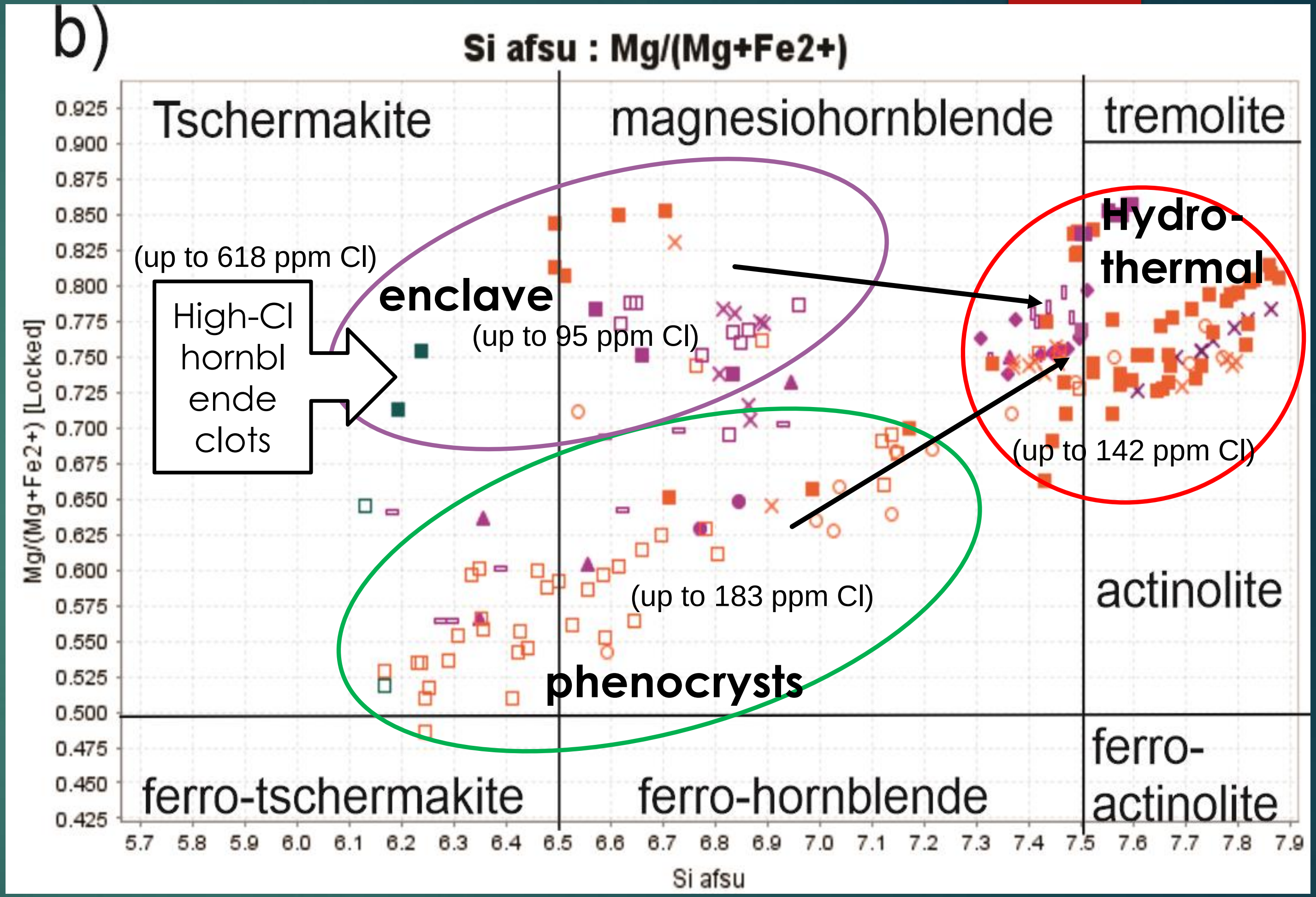
High-Si intrusion



Replacement of igneous plagioclase by albite + zoisite and Kfeldspar by albite + biotite may be isochemical, or release some Ca and K

Na-Ca alteration assemblage: albite+zoisite+actinolite





Igneous hornblende is variably altered to actinolite, also part of the Na-Ca alteration – releases Fe to fluid

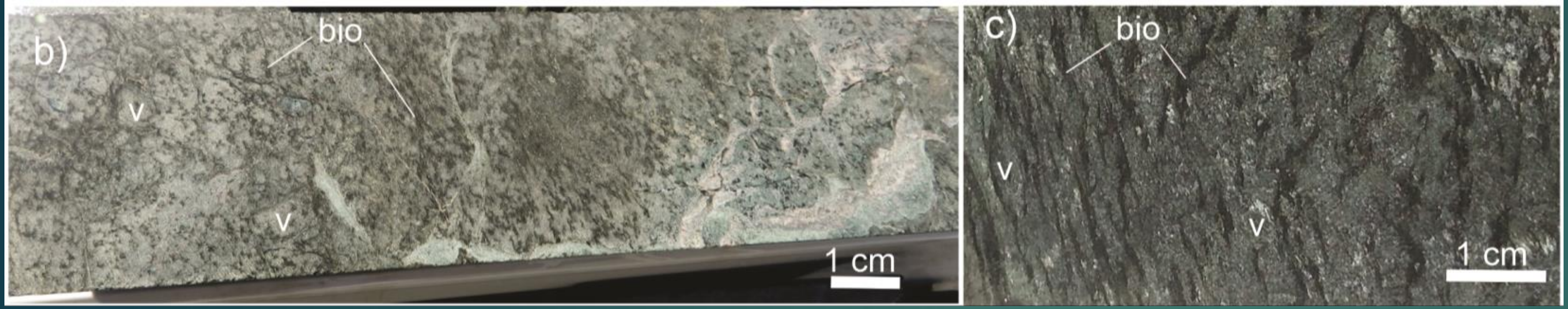
The dominant actinolite + albite + epidote mineralogy of HMB probably a result of the same Na-Ca metesomatism

Igneous hornblende in cumulate-textured, hornblende-rich enclave has higher Mg/(Mg+Fe) and Al than igneous hornblende phenocrysts

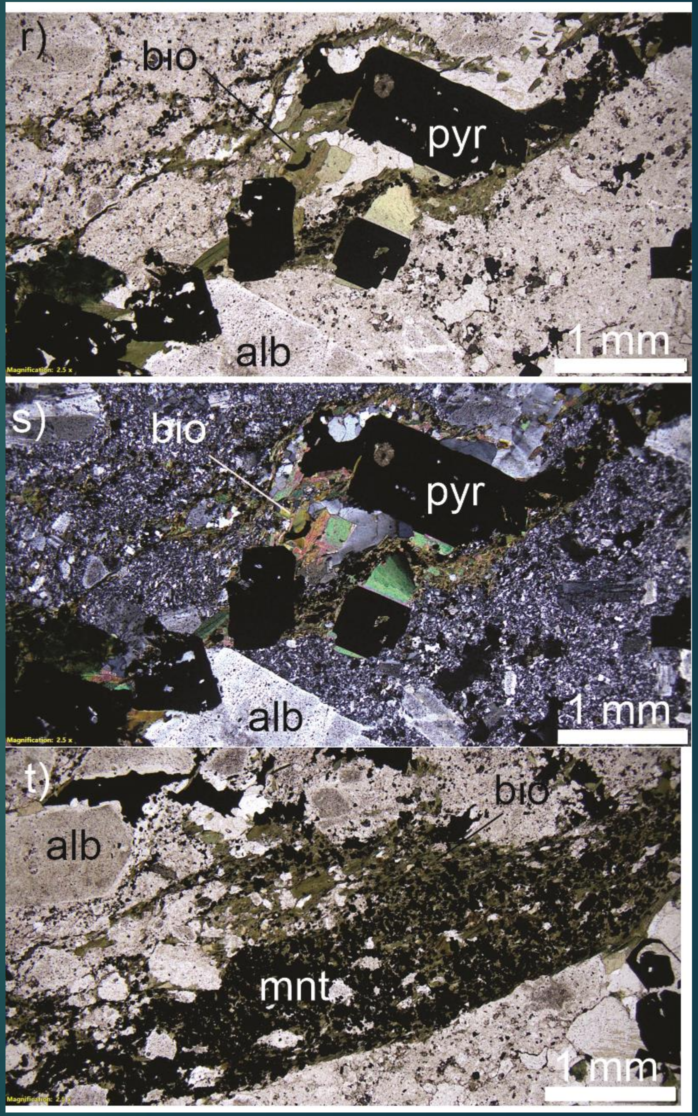
Hornblende crystals are phenocrysts AND dispersed hornblende from mafic enclaves

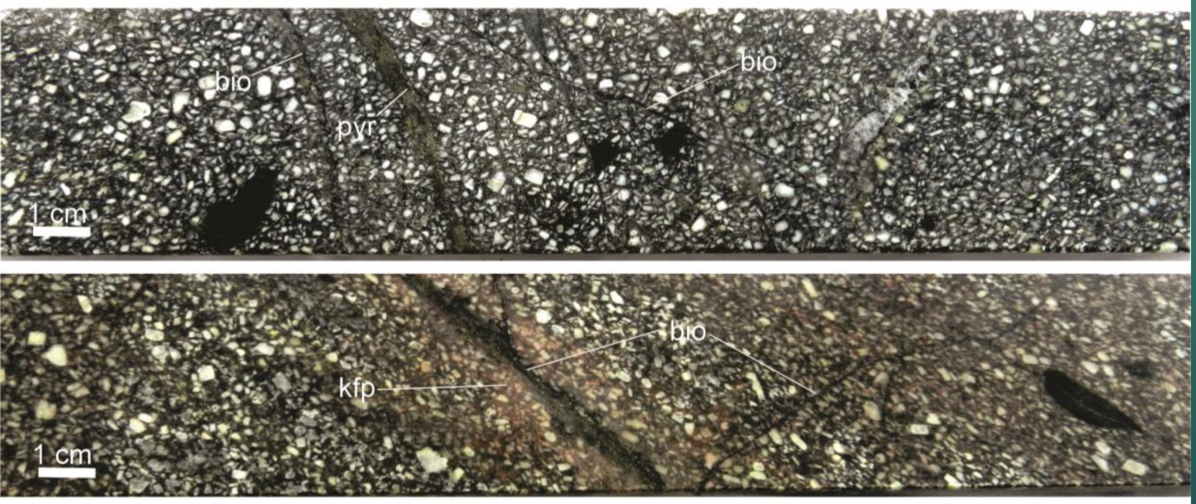
BURNS: POTASSIC (BIOTITE) ALTERATION

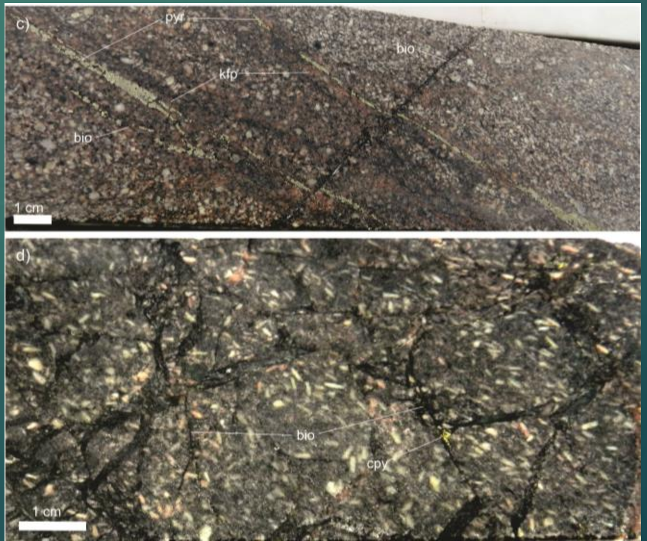
Potassic (biotite) alteration forms broad patchy zones within HMB (more Fe, Mg); tends to focus in matrix between varioles



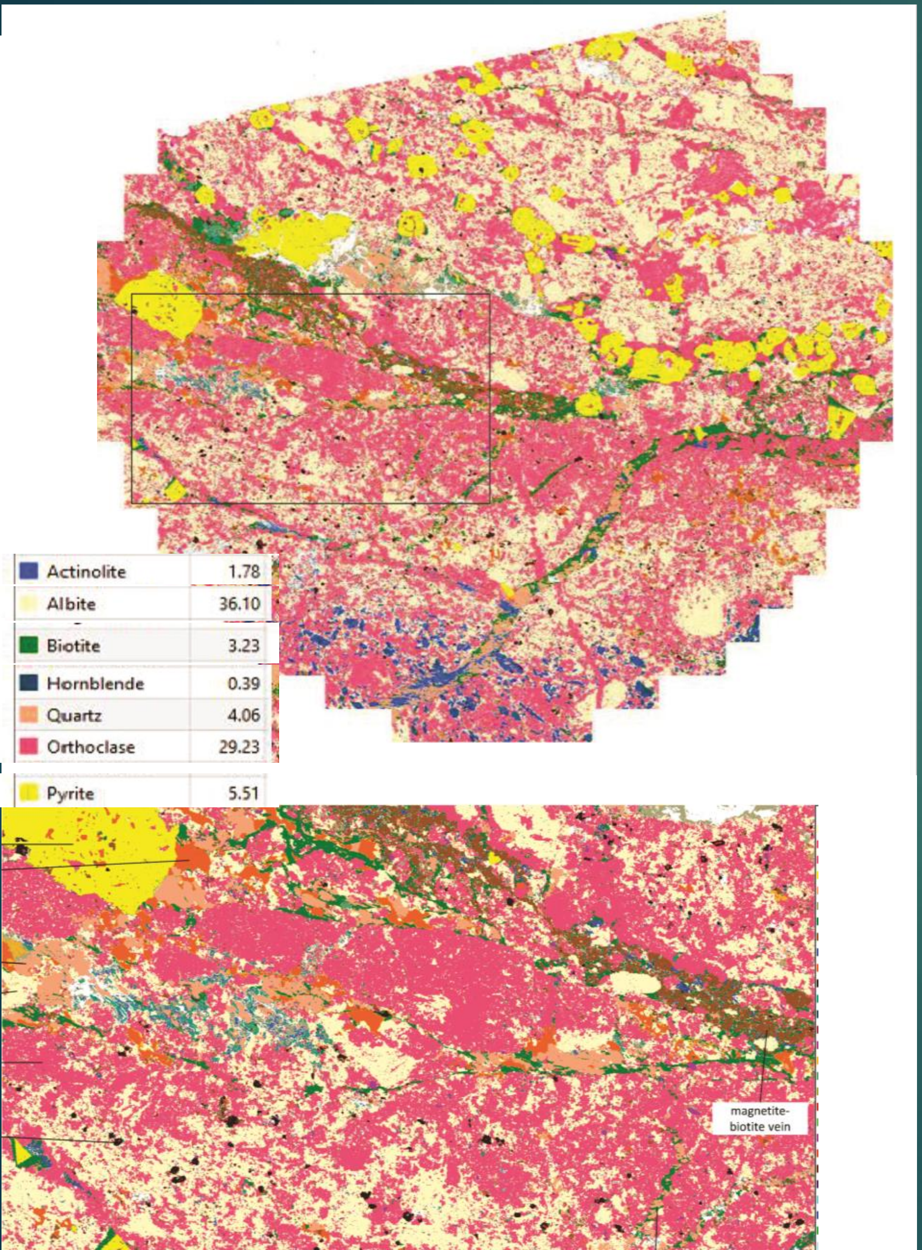
- Potassic (biotite) alteration in porphyry intrusions forms disseminations, pseudomorphs after amphibole, stringers and veinlets
- Widespread but variably developed in porphyry units
- Local development of biotite-magnetite and biotite-pyrite±chalcopyrite – mineralization
- Magnetite, chalcopyrite replaced by pyrite in thicker mm-scale veinlets
- Kfeldspar replaces albite in pyritic veinlets

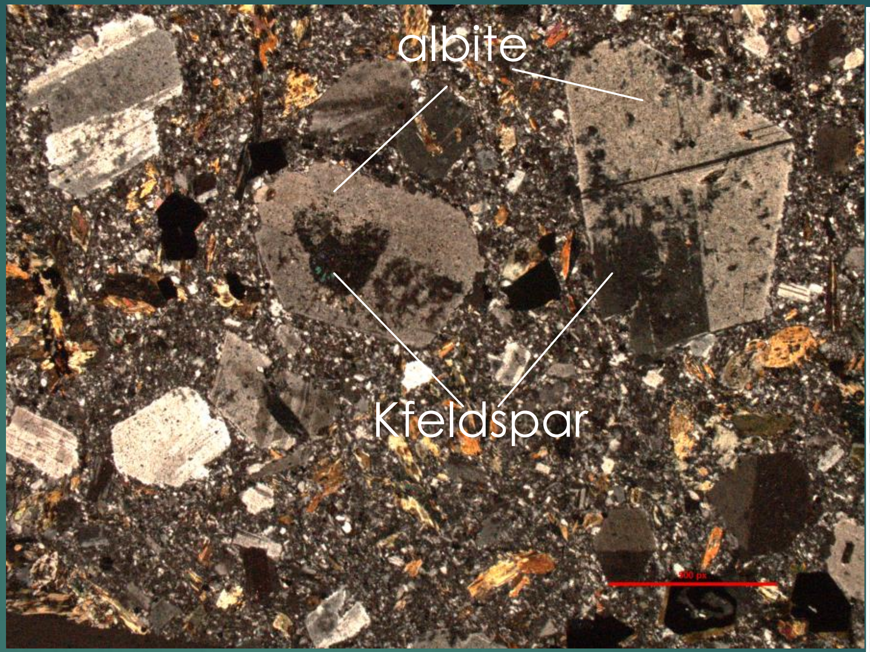


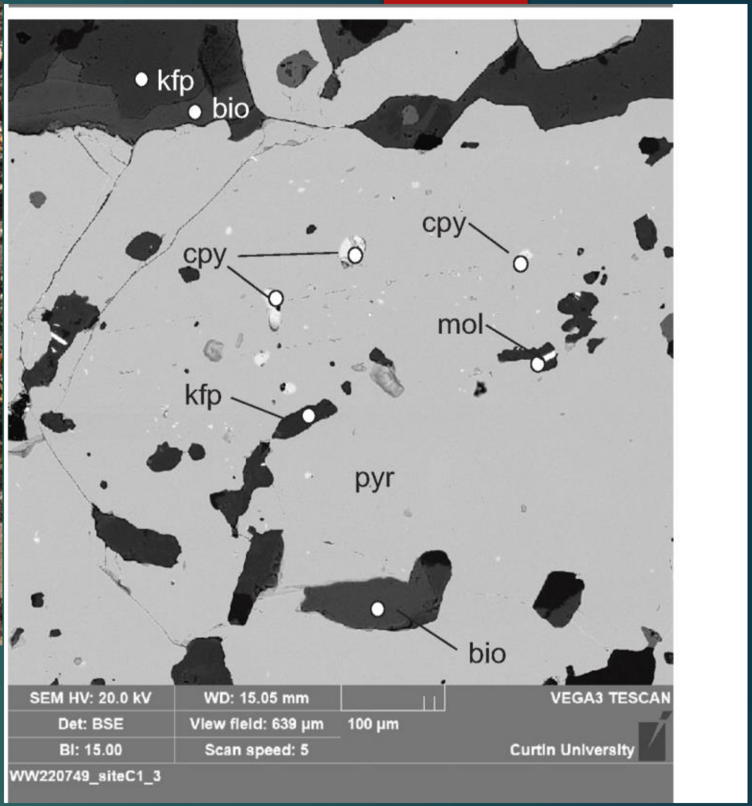




BURNS: CU-AU MINERALIZATION – **TYPE 1. INTRUSION-HOSTED BIOTITE-PYRITE**







Intrusion-hosted pyritic biotite veinlets, stringers and fracture networks

Proximal biotite ±Kfeldspar alteration Zone

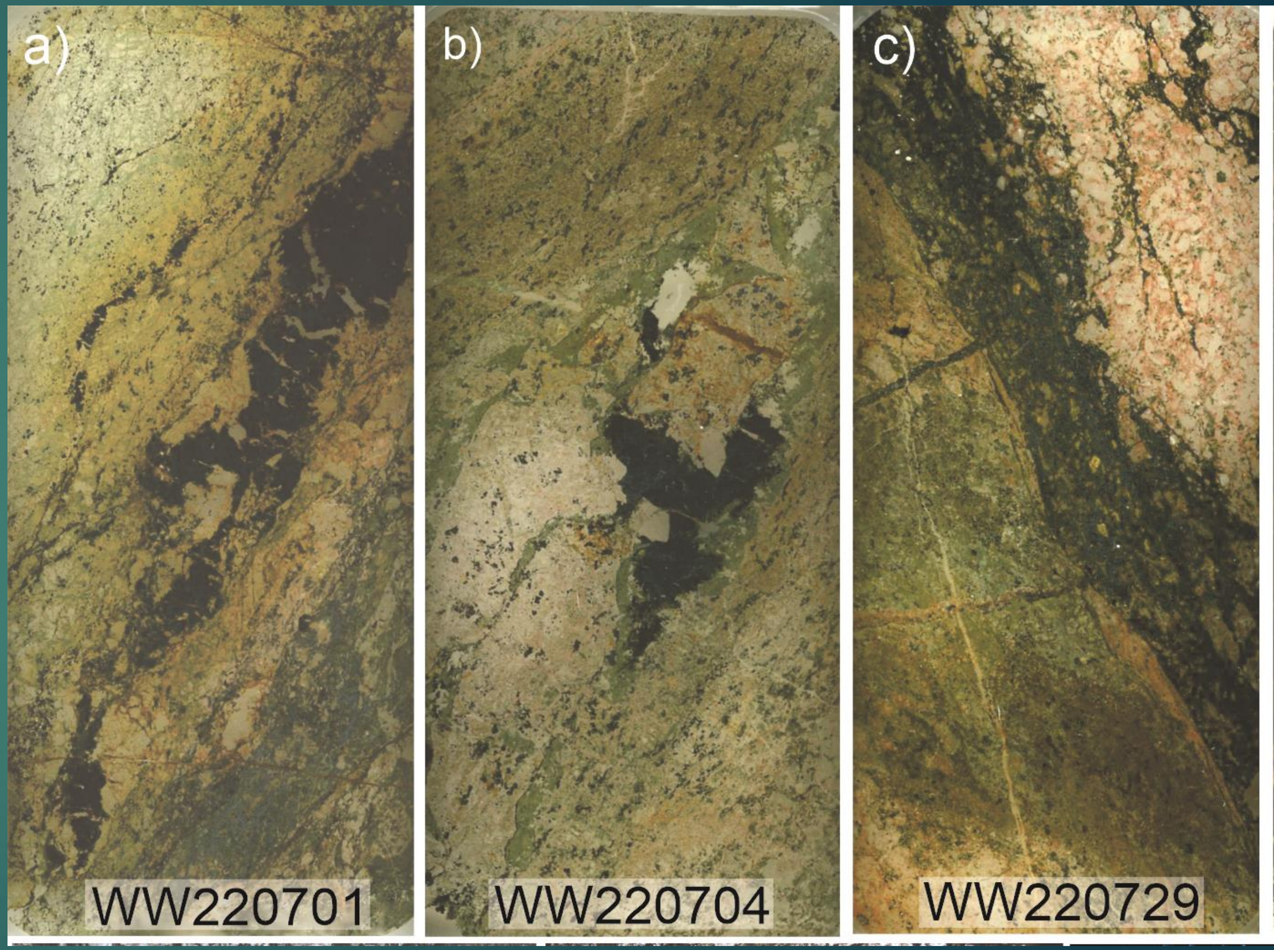
Patchy to complete Kfeldspar replacement of hydrothermal albite at proximal/medial transition

Inclusions of chalcopyrite, molybdenite and native gold in pyrite.

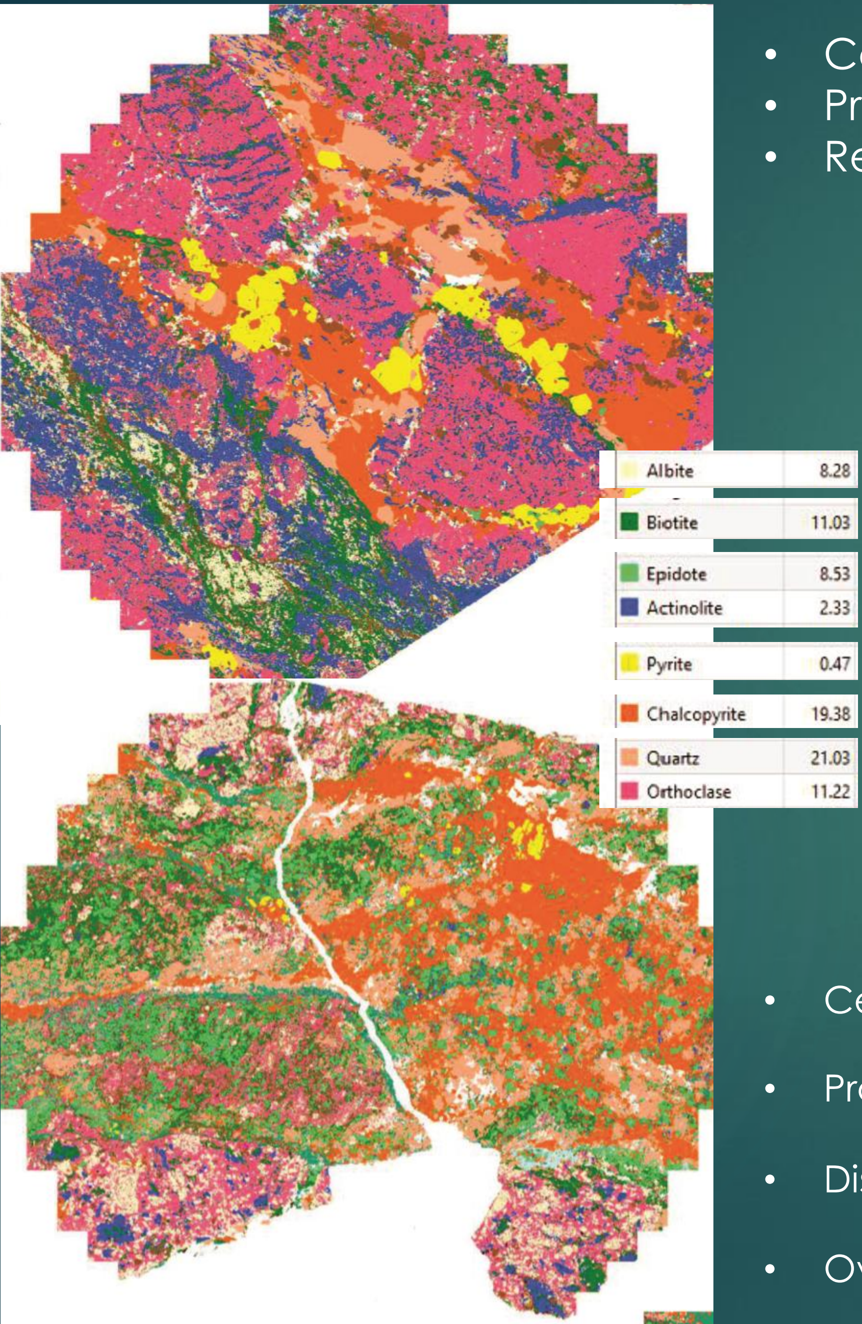
BURNS: CU-AU MINERALIZATION – **TYPE 2. HMB- & INTRUSION-HOSTED K-FE ALTERATION**
(over-printed by barren biotite-epidote)

POTASSIC – KFELDSPAR – ALTERATION/K-FE ALTERATION/FERRUGINOUS ALTERATION

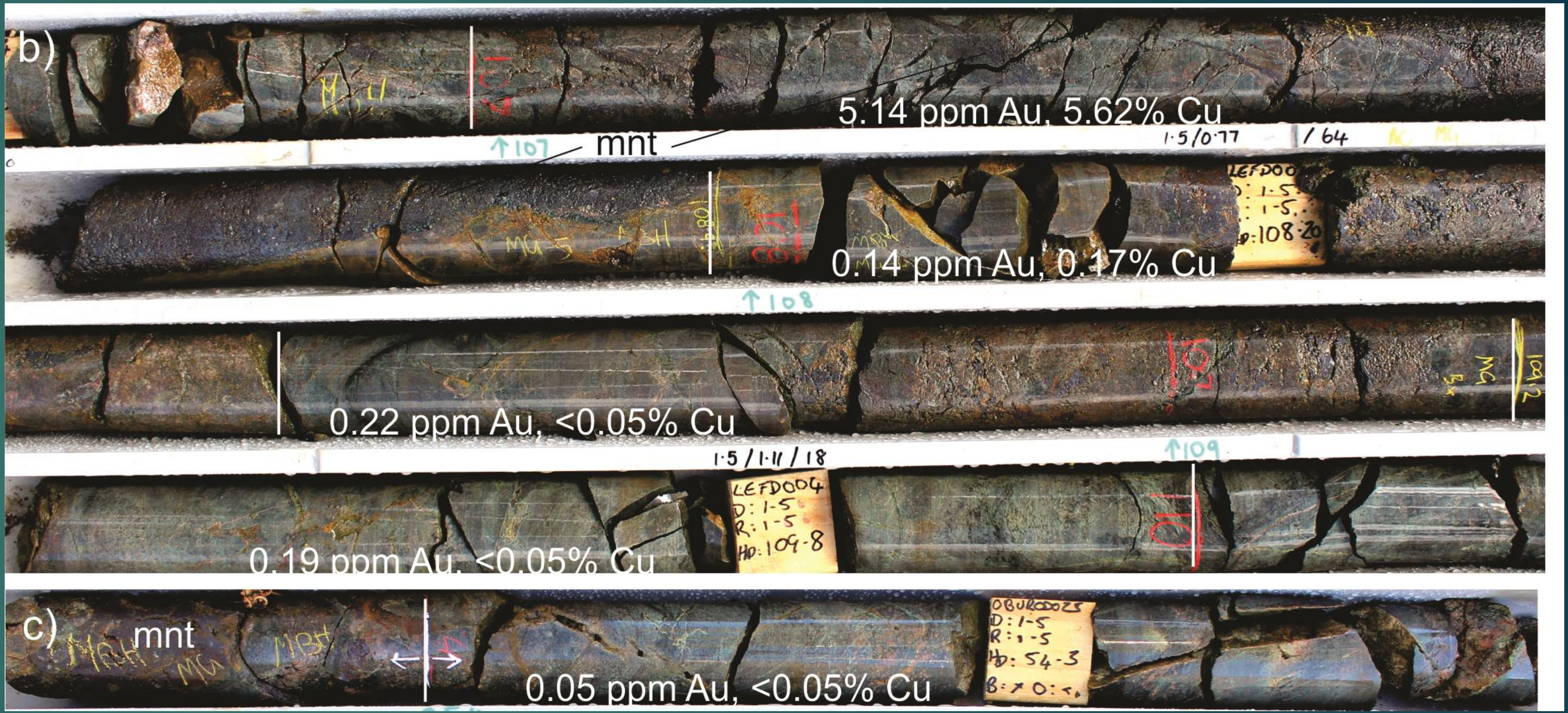
- Commonly on porphyry/HMB contacts
- Hosted by brittle-ductile shears, quartz-sulfide veins
- Breccias common
- Proximal Kfeldspar/actinolite/magnetite and chalcopyrite + pyrite
- Proximal Kfeldspar replaces albite in medial albitisation zone
- The dominant form of Cu-Au mineralization at Burns?



BURNS: CU-AU MINERALIZATION – **TYPE 2. HMB-HOSTED K-FE ALTERATION**



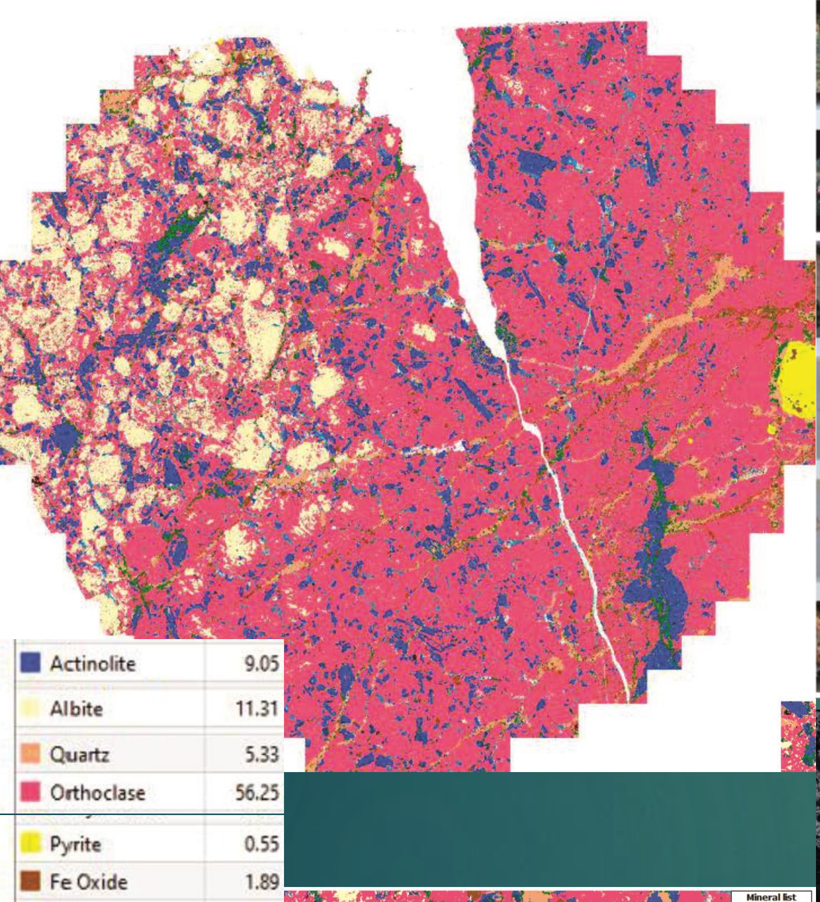
- Central quartz-chalcopyrite-pyrite vein
- Proximal Kfeldspar+actinolite
- Relict of distal biotite+albite alteration

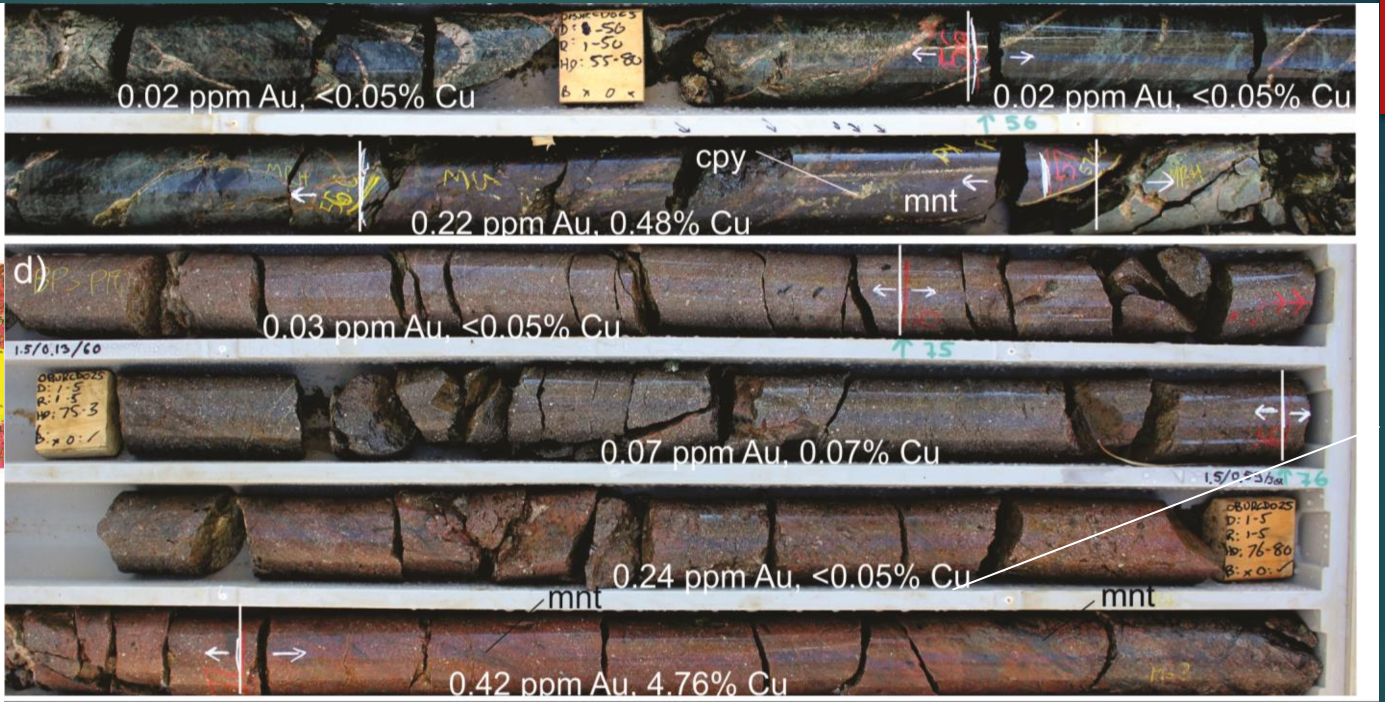


- Central quartz-chalcopyrite vein
- Proximal Kfeldspar ±actinolite
- Distal albite alteration (amphibole-albite-Kfeldspar)
- Overprinted by barren biotite + epidote in this example

K-Fe alteration in high-Mg basalt

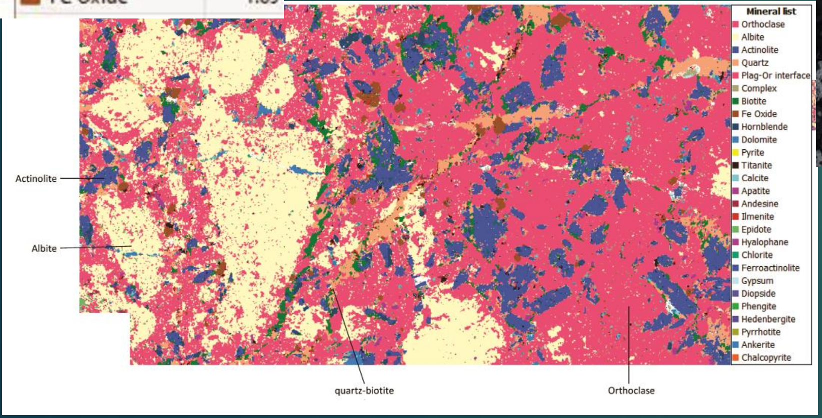
BURNS: CU-AU MINERALIZATION – **TYPE 2. INTRUSION-HOSTED K-FE ALTERATION**



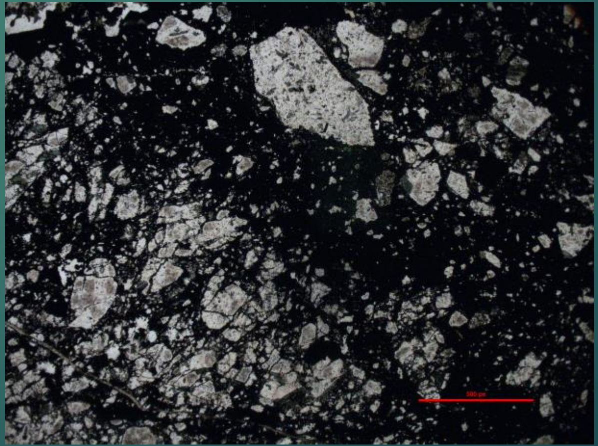


Ferruginous alteration on HMB/ porphyry contact

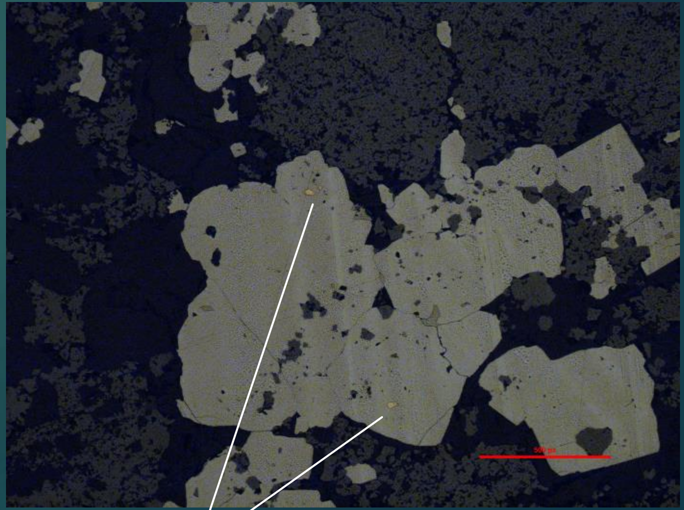
Magnetite veins in Kfeldspar-altered (bleached) porphyry



Molybdenite

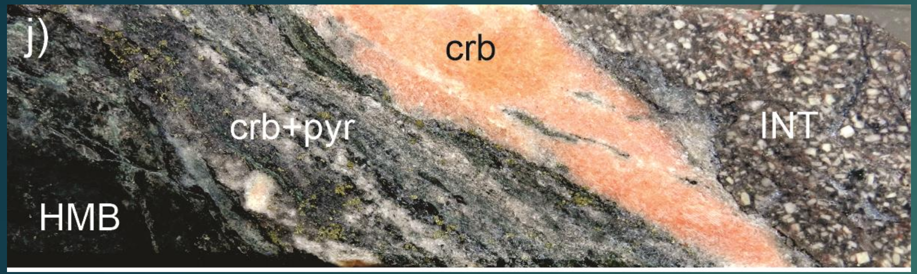


Breccia: Kfeldspar-altered clasts/magnetite infill



native gold

BURNS: CU-AU MINERALIZATION – **TYPE 3. CARBONATE ±SULFIDE VEINS**



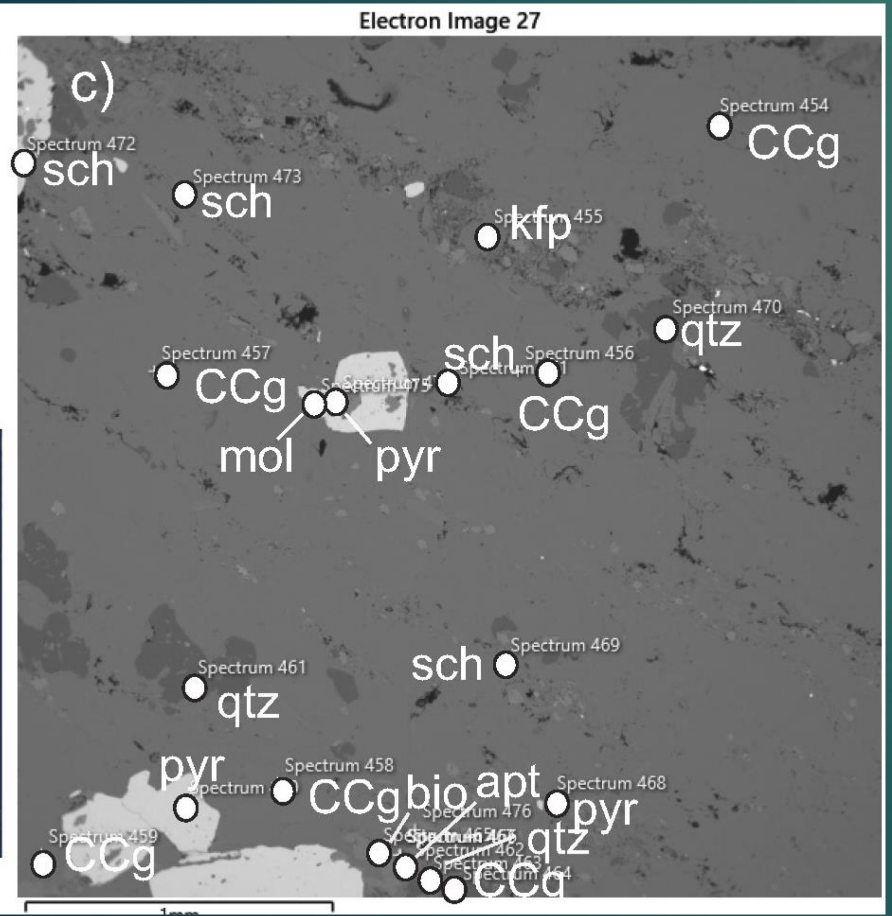
0.36 ppm Au, 0.36% Cu

0.032 ppm Au, 285 ppm Cu*

<0.01 ppm Au, 13 ppm Cu

4.95 ppm Au, 71 ppm Cu

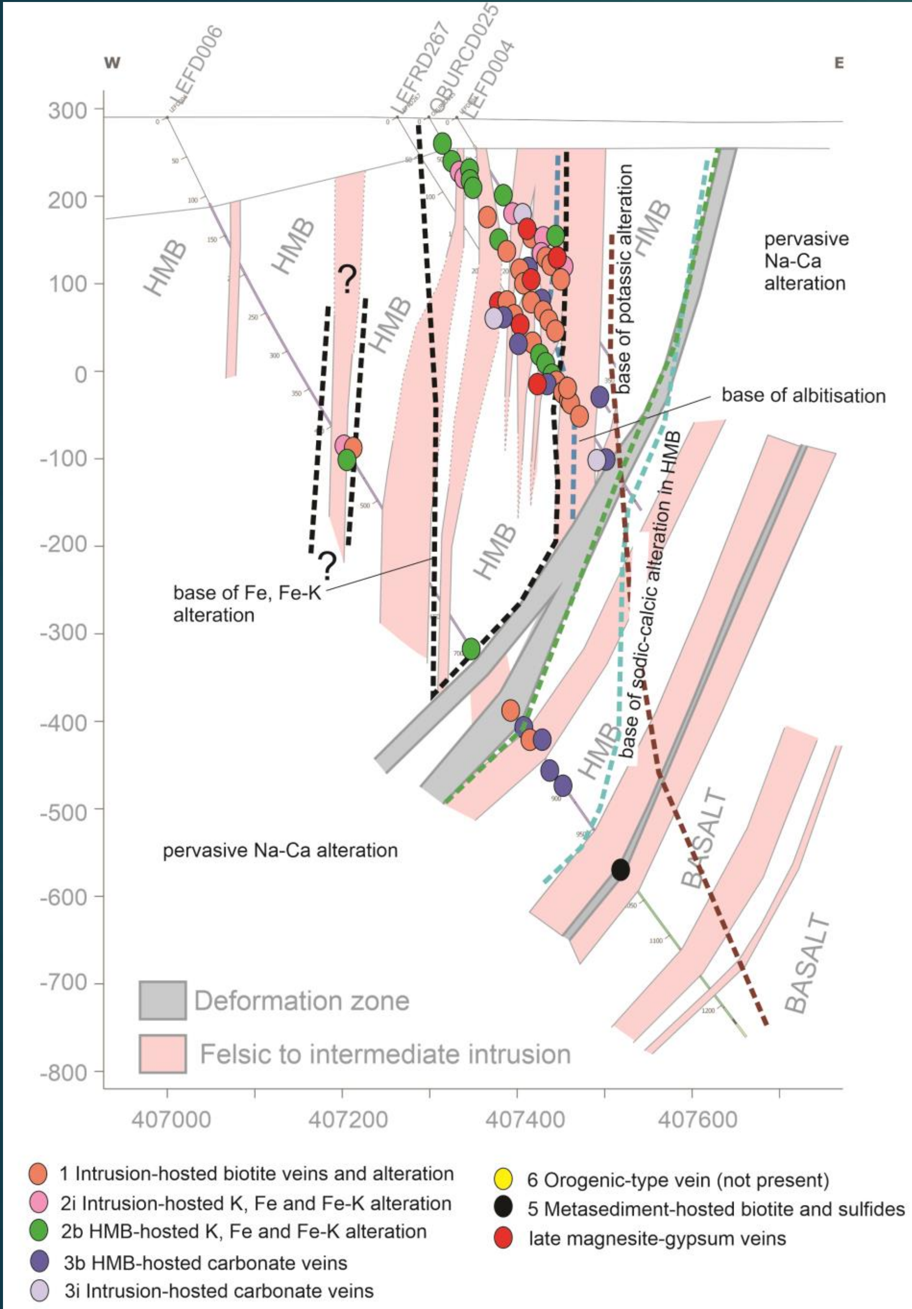
0.14 ppm Au, 119 ppm Cu



Carbonate-rich veins and alteration

- Lamellae veins (amphibole lamellae); locally breccia veins
- Two calcite varieties:
  - Orange calcite – barren, orange (minor Fe, Mn), in porphyry intrusions
  - Grey calcite – lamellar structure, amphibole lamellae, in HMB, associated with pyrite
- Calcite-biotite-epidote-pyrite association
- Minor scheelite and molybdenite

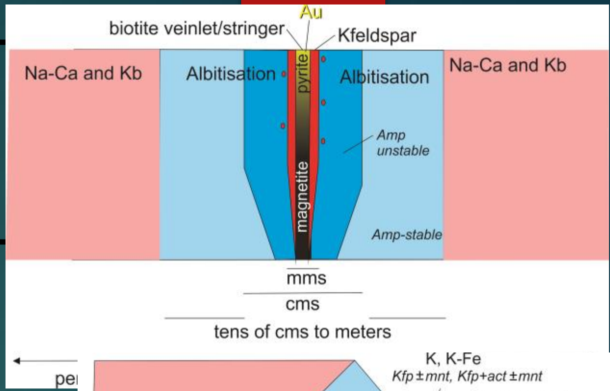
BURNS: CU-AU MINERALIZATION TYPES



Types 1 and 2 ore fluids focussed into subvertical zone of weakness – interleaved porphyry intrusions and HMB

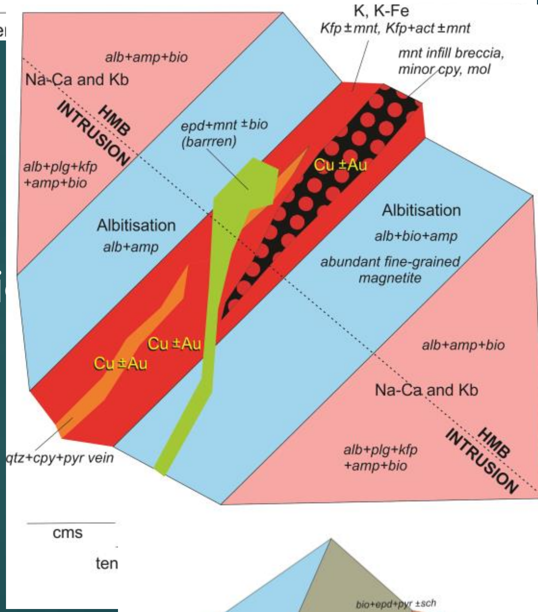
1. Intrusion-hosted biotite (-magnetite, -pyrite) veinlets, stockworks and fractures PORPHYRY-STYLE

High-temperature, oxidised, potassic (**porphyry-type**) magmatic-hydrothermal fluid derived from subjacent magma chamber



2. HMB & Intrusion-hosted shears and veins with K(Kfp), K-Fe, Fe alteration IOCG-STYLE

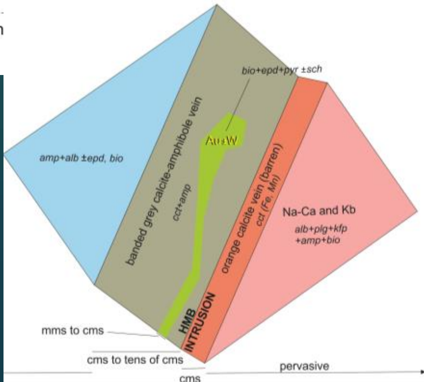
High-temperature, oxidised, K- and Fe- enriched flui
Resembles K-Fe-Ca alteration in **IOCG** deposits



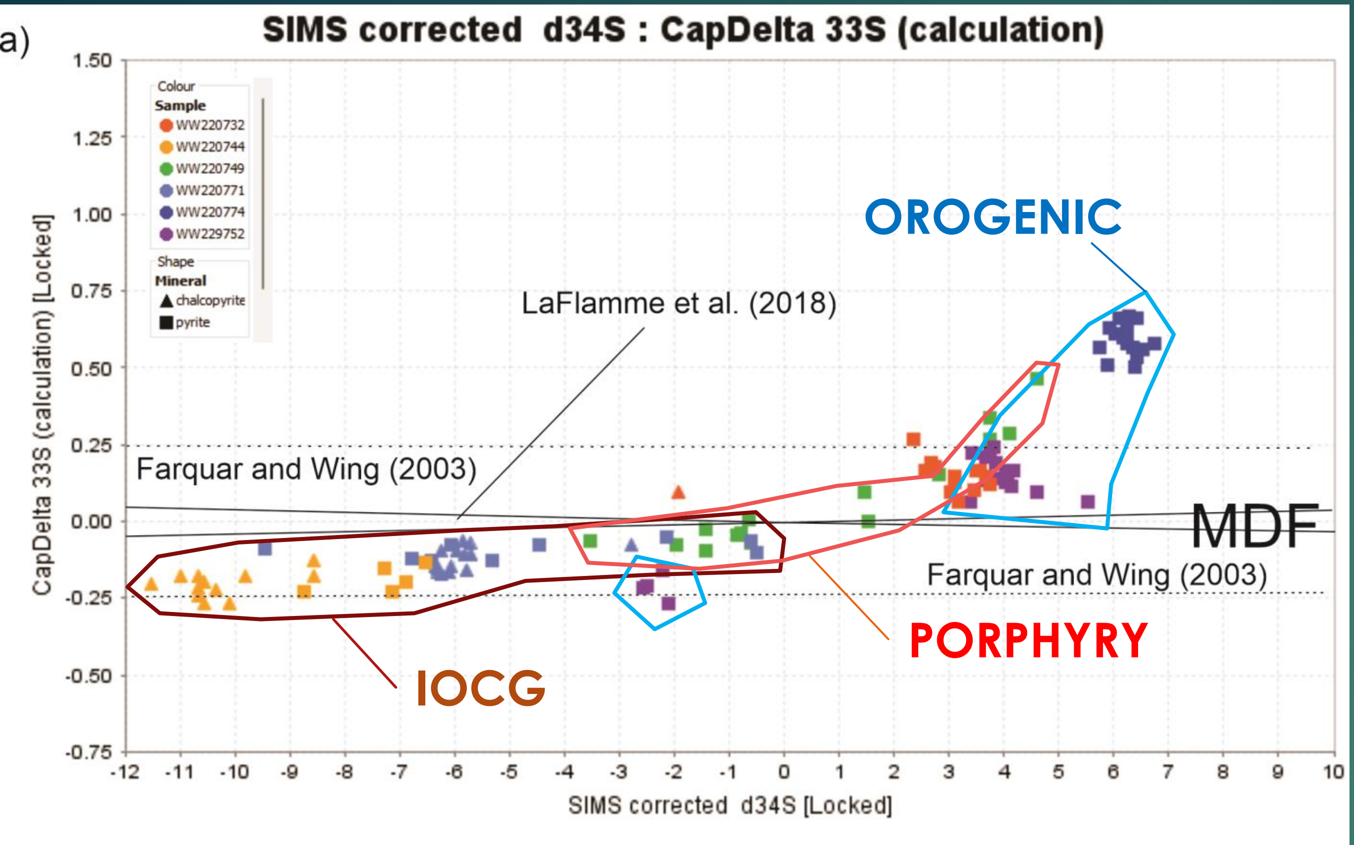
Type 3 ore fluids focussed into major deformation zone and splays

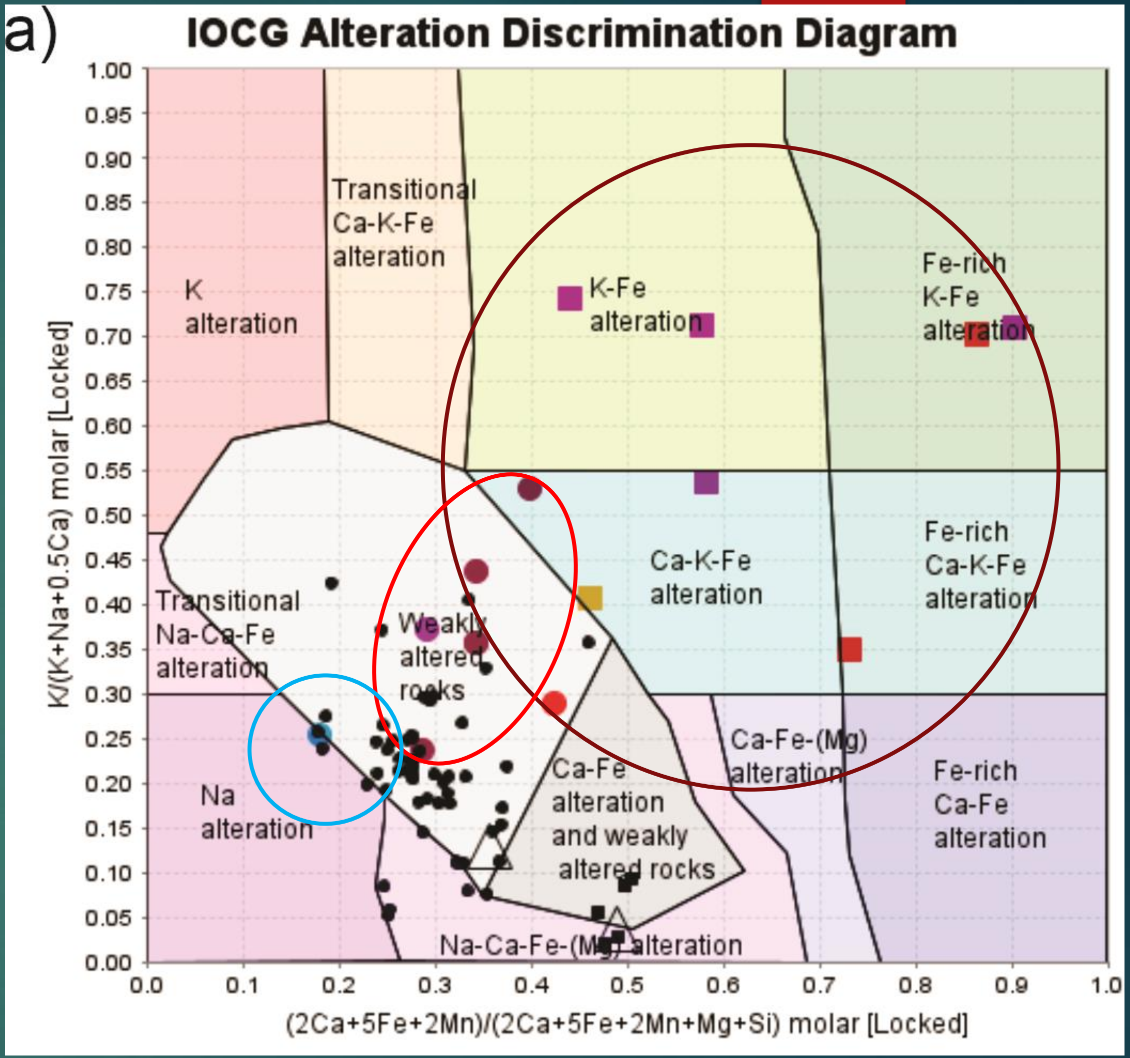
3. Carbonate-sulfide veins in shear zones; quartz veins in intrusion; carbonate alteration OROGENIC

Moderate-temperature, reduced?, CO_2-enriched fluid resembles deeply-sourced orogenic fluid



Burns: SULFUR ISOTOPES (Pyrite, chalcopyrite), Alteration





Type 2 mineralization extends over a range of -12 to 0 per mil (redox reaction between oxidised ore fluid and reduced wallrocks)

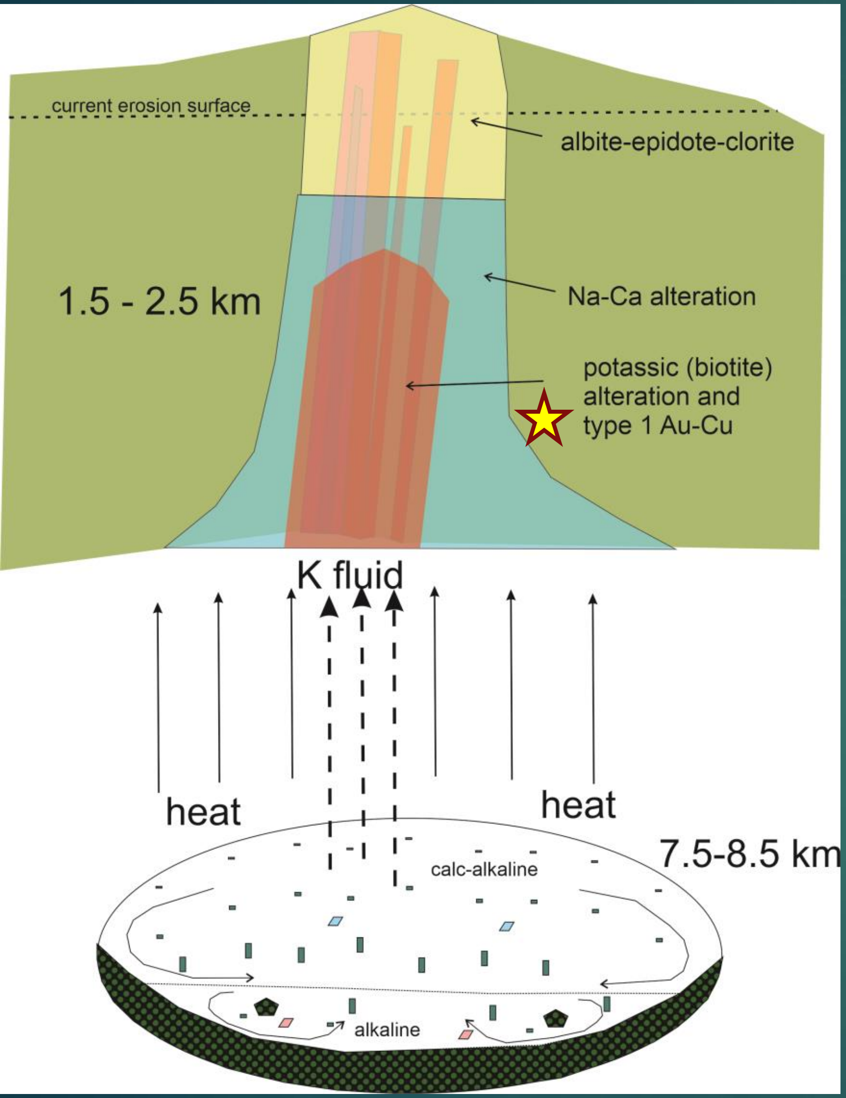
(Montreuil et al 2016)

Type 3 mineralization main population from +2 to +6 per mil
Coincident with data from Mt Charlotte orogenic gold deposit

Type 1 mineralization range of -4 to +4.5 per mil (?mixing between type 2 and 3 ore fluids or overprinting?

Errors on all analyses fall within the MDF field of LaFlamme et al. (2018), except highest type 3 cluster

Burns: A genetic model



Na-Ca alteration

Repeated pulses of magma from the subjacent magma chamber maintains high geothermal gradient in shallow crustal setting (porphyritic textures, local flow banding)

External fluids drawn up-temperature towards the BPIC
Albite-zoisite-actinolite (c.f. western U.S. porphyry districts, Runyon et al., 2019)

Albite-epidote-chlorite alteration at shallower crustal levels removed by erosion

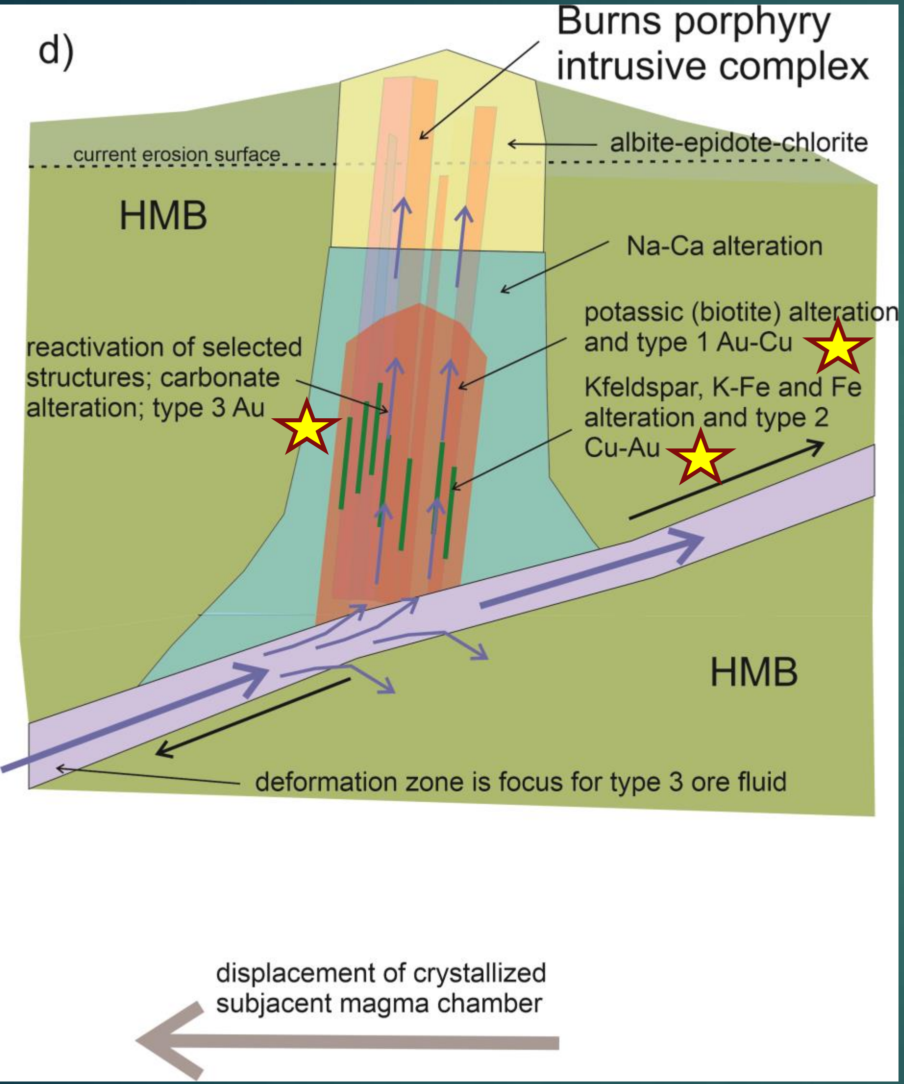
K (biotite) alteration

Upward, down-temperature flow of magmatic-hydrothermal fluid from subjacent magma chamber

Higher fluid:rock ratios in larger brittle fractures produces porphyry Au (-Cu) mineralization

Probably some uplift associated with change from up-T to down-T flow

Burns: A genetic model



Kfp, K-Fe, Fe alteration

On-going crystallization in the subjacent magma chamber maintains a thermal anomaly

External fluids drawn up-T towards the heat anomaly and ascends down-T

Possible contribution from magmatic-hydrothermal fluid

IOCG Cu (±Au) mineralization forms on sheared porphyry/HMB contacts.

Carbonate alteration

After solidification of the subjacent magma chamber is displaced westwards due to reverse movement on major deformation zone

Distal source orogenic gold deposited in selected reactivated contacts

BURNS: IMPLICATIONS

Multiple mineralizing events superimposed at Burns: porphyry type, IOCG and orogenic but absolute ages are not known

IOCG model favoured by

- spatial association with a shallow, intermediate (andesitic) intrusion
- widespread (district-scale) Na-Ca metasomatism
- structurally-controlled lodes and breccias common
- Cu-Au lodes associated with K-Fe-Ca metasomatism
- Multi-metallic signature (Fe-Cu-Au-Mo-W)

First recognition of IOCG Cu-Au mineralization in the Yilgarn; but other Archean examples are known in Carajas Province, Brazil

Are there other IOCG systems in the Yilgarn Craton?

- Crusader
- Hannans South
- Admiral Hill

Sites of multiple mineralization events tend to be big (Golden Mile)