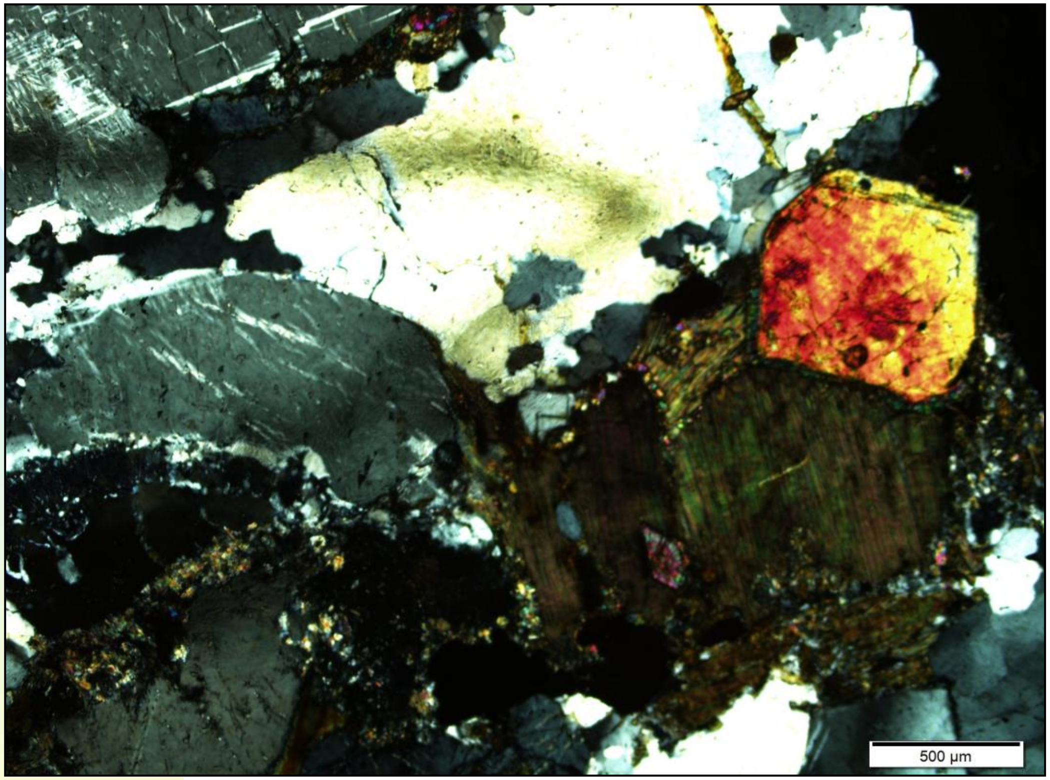
Magmatic and magmatic-hydrothermal transition evolution of the Razi & Chilimanzi granite suites: Insights from the mineralogical & petrographic record



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ENESIA RESOURCES

Talk format

1. Introduction
2. Current understanding on granitoid-hosted deposits.
3. Regional geology overview along the southern margin of the Zim Craton.
4. Normative Ab-An-Or classification plot of the granites.
5. Mineralogical & petrographic record of the younger granite suites.
6. Paragenesis of the Razi and Chilimanzi suites.
7. Do we have (economic) rare-metal granite deposits in Zim?
8. Conclusions

Introduction

- Granitoid-hosted mineral deposits: constitutes one of the global sources of economically important (lithophile) metals e.g., Li, Rb, Ta, Nb, Sn, W & U.

- Petrogenetic processes in determining metal fertility: tectonic setting, nature of source rock & magma differentiation.

- Metallogenic studies of granite-pegmatite systems are increasingly recognizing magma differentiation as an important petrogenetic process (particularly in evolved systems) & is the focus of this talk.

- Previously unclear questions were:

  (a) the role of magmatic & magmatic-hydrothermal fractionation processes,

- (b) The origin of metasomatic fluids involved in magmatic-hydrothermal systems. Stable isotope (O, H) & fluid inclusions studies demonstrate a co-magmatic /self-generated origin (Johan et al., 2012; Michaud & Pichavant, 2020).

- Mineralogical & petrographic record of the Razi & Chilimanzi potassic granites to decipher the magmatic & magmatic-hydrothermal transition evolution of the granites.

- What are rare-metal granites = highly evolved intrusions, with elevated contents of fluxing components & (economic) rare-metal mineralization such as tin, Li-F granites.

Present knowledge on granitoid-hosted deposits

Granitoid-hosted mineral deposits

- Magma genesis & evolution has a fundamental control on the metal endowment of granitoids (Cerny et al., 2005).
- Source and fractionation are key factors controlling granite metallogeny.
- Source = imposes geochemical heredity including metal & flux contents onto the evolving magma.
- Degree of magma fractionation (measured by indices e.g., K/Rb, Rb/Sr) = can be used to establish thresholds that distinguish barren from metal granites.

Magmatic evolution of granitic magmas

- Fractionation & magma differentiation processes: enhance concentration of metals during progressive magma crystallization.
- Incompatible metals (e.g., Li, U, Ta, Nb, Sn): are concentrated in the residual melt & may rich a threshold to form ore minerals e.g., cassiterite, columbite-tantalite.
- The Zaaiplats tin deposit, SA, formed from fractionation of a granitic phase of the Bushveld Complex magma: concentrated from 5 to 35 ppm, resulting cassiterite saturation (Coetzee & Twist, 1989).

Note that ore forming magmas have gross chemical & mineralogical similarities to barren granites, however there are stuble petrogenetic differences….source & degree of fractionation.

In “barren granites”, Sn, Nb, Ta & Li saturation is not attained during crystallization due to insufficient initial metal contents in the melt; also crystallization temperatures are too elevated.

Present knowledge on granitoid-hosted deposits…cont.

Metasomatic alteration in granite systems

- The metasomatic agents (fluids responsible for sub-solidus hydrothermal alteration) are residual fluids exsolved during fractional crystallization of the magma. Stable isotope (O, H) data demonstrate a magmatic origin for the fluids (Michaud & Pichavant, 2020)

- The agents are transported as co-magmatic hydrothermal fluids upwards from the root zones of the plutons to their apical parts or roof zones (e.g., Johan et al., 2012).

- Furthermore, the high temp (~600 °C) residual fluids are acidic, extremely corrosive & reactive (Gorbaty and Bondarenko, 1998; Piranjo, 2013).

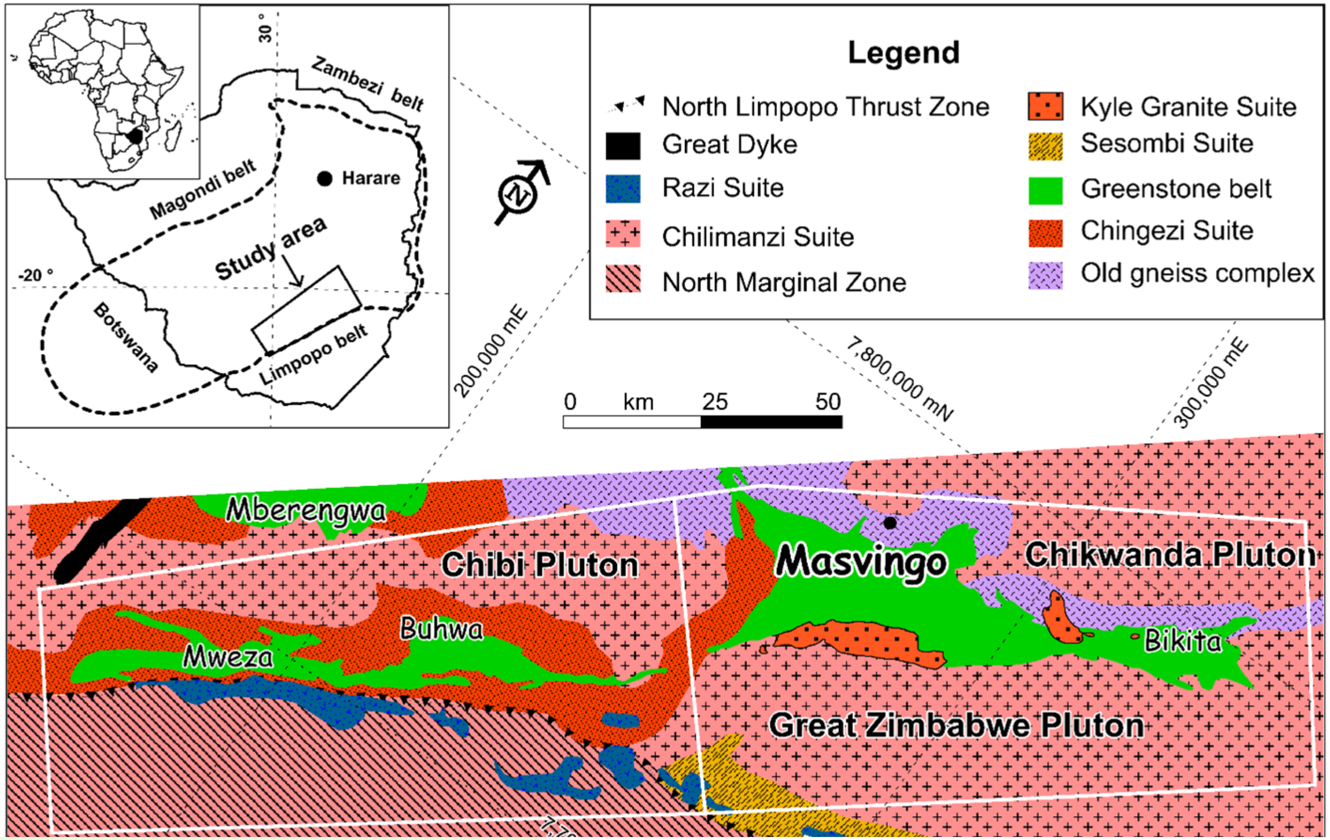
Thus metasomatic processes should not be confused with rock weathering.

- The accumulation of melt modifiers (e.g., Li, F, P, H_2O) lowers the solidus temp (London, 2008; London & Morgan, 2012), allowing for late-stage metasomatic alteration.

- The early evolution (magmatic fractionation) is overprinted by late subsolidus transformations (magmatic-hydrothermal transition).

- The late metasomatic/fluid-driven phase: controls extraction of elements & their redistribution out of crystallizing magmas (Ballouard et al., 2016; Hulsbosch and Muchez, 2020).

Geology map along the southern margin of the Zimbabwe Craton



Chilimanzi Suite- Chibi granite

Kyle Granite Suite

Razi Granite Suite

Razi & Chilimanzi granite suites (ca. 2630-2620 Ma)
Typical granite mineralogy

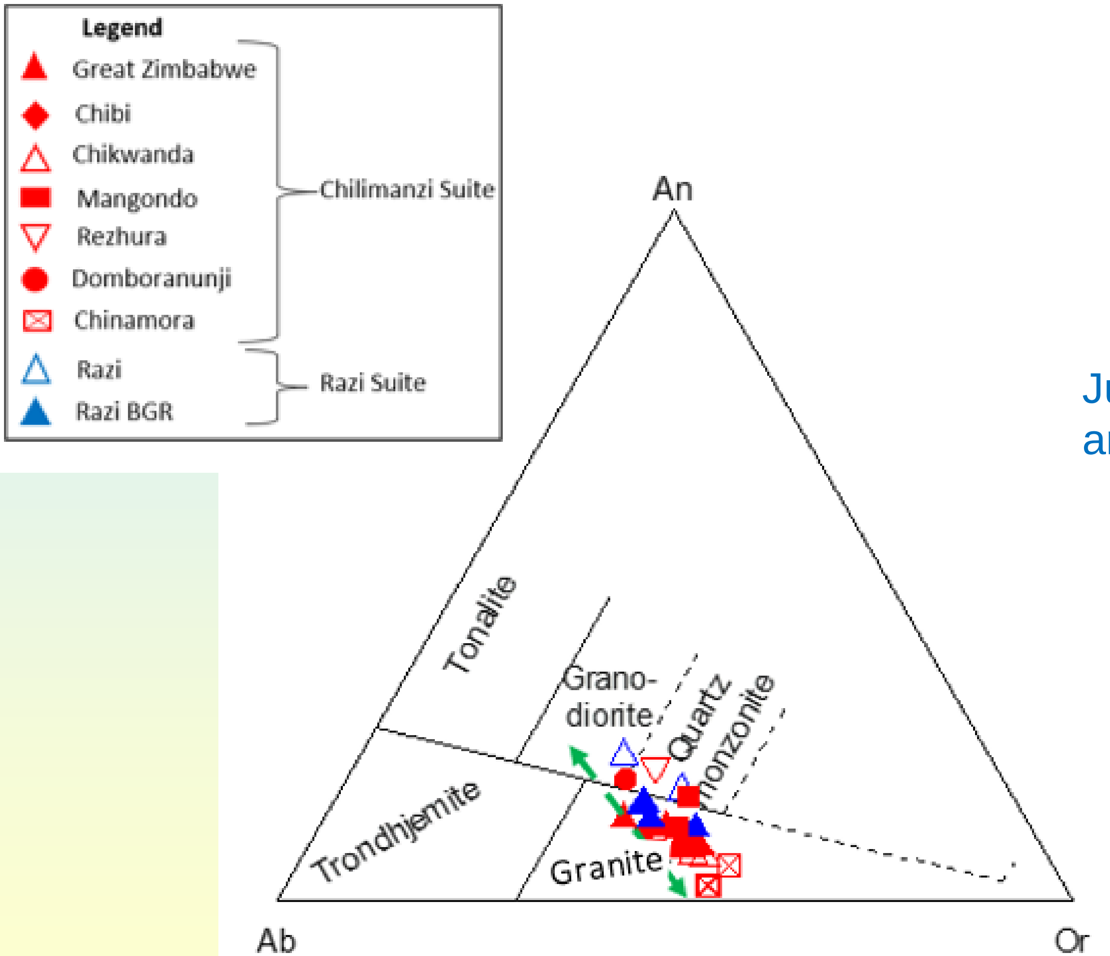
Potassic, evolved magmas, metaluminous, I-type: crustally derived from TTG protoliths.

Represent a good vertical section of the Zim craton:
Razi suite: lower crust.
: less evolved; emplaced close to melt source.

Chilimanzi Suite: high/shallow level intrusions: upper crust.
: typically more evolved than the Razi Suite.

Chagondah et al. (2023)
Rollinson (2023)
Berger & Rollinson (1997)

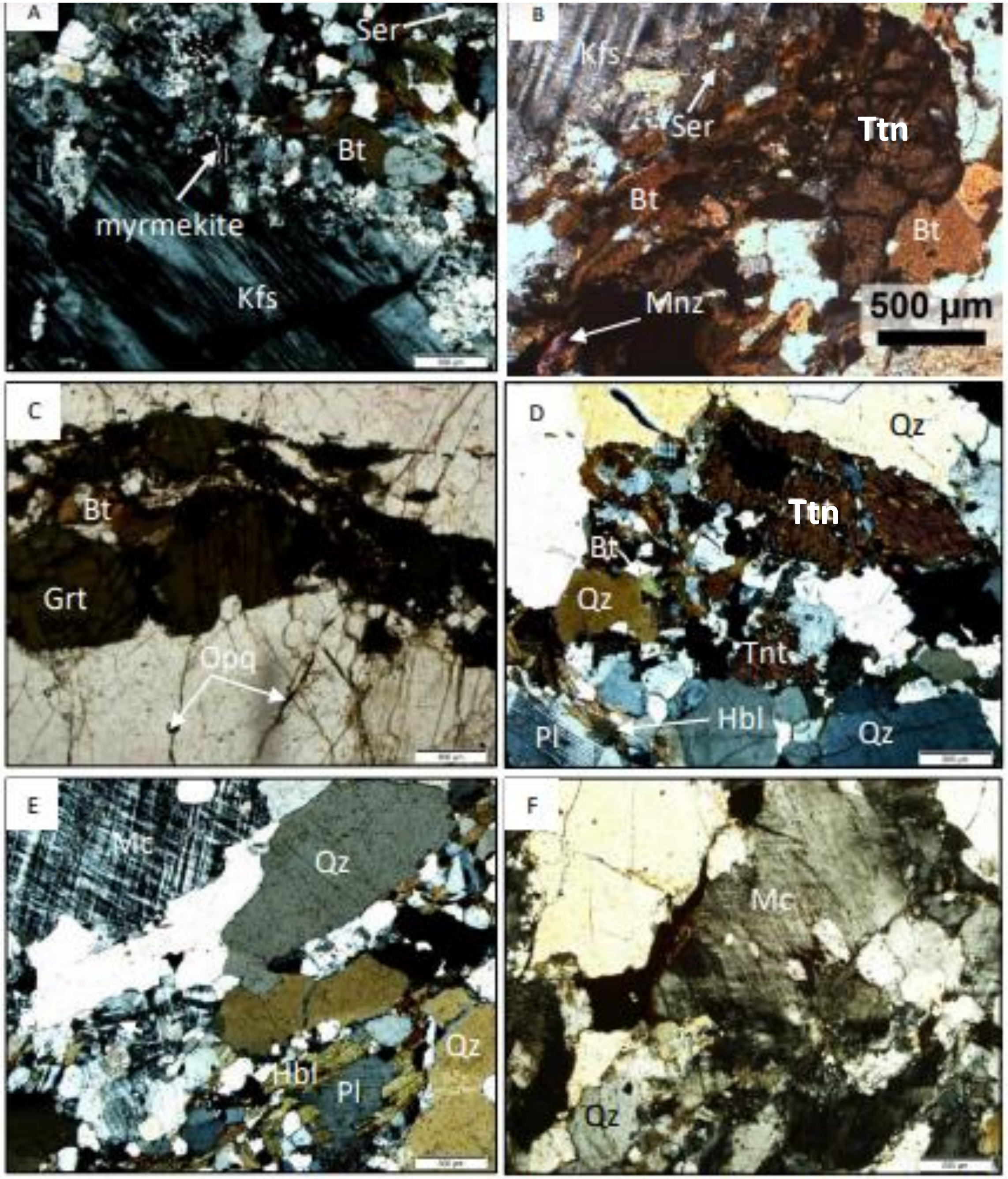
Normative An-Ab-Or classification diagram for the Chilimanzi & Razi suite samples (fields after O'Connor, 1965)



Just to confirm that we are talking of granites.

Chagondah et al. (2023)

Mineralogical & petrographic record: the Razi Suite



Dominated by magmatic Stage I… in accord with lower crustal level of emplacement.

Mineral abbreviations from Whitney & Evans (2010)

Ab = albite

Ap = apatite

Bt = biotite

Chl = chlorite

Grt = garnet

Hbl = hornblende

Pl = plagioclase

Kfs = K-feldspar

Or = orthoclase

Opq = opaque phases

Mc = microcline

Mnz = monazite

Ser = sericite

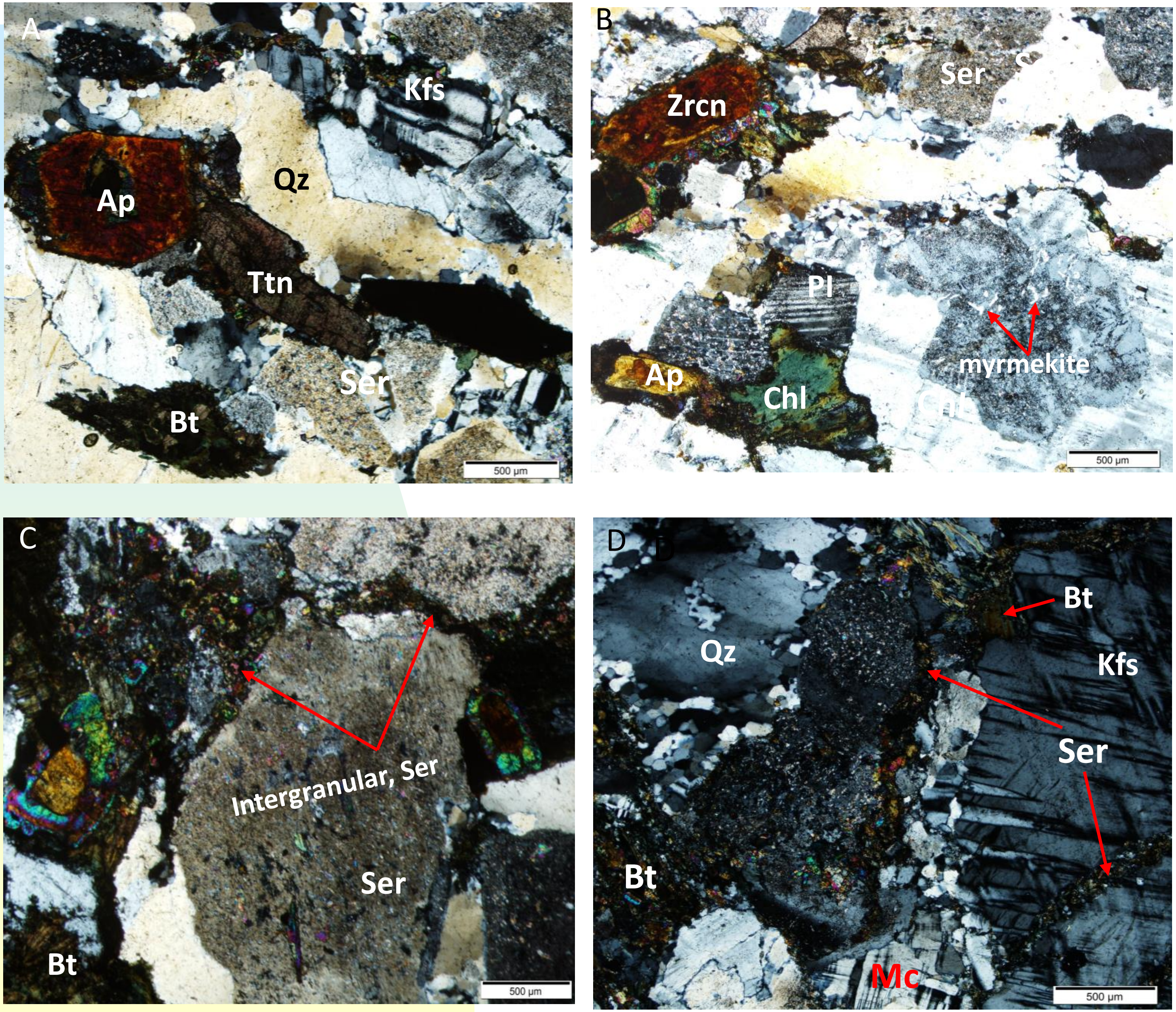
Ttn = titanite

Qz = quartz

Chagondah et al. (2023)

Mineralogical & petrographic record: Chilimanzi Suite (Kyle granite, Mangondo)

(Chagondah, PhD thesis UJ, 2023)



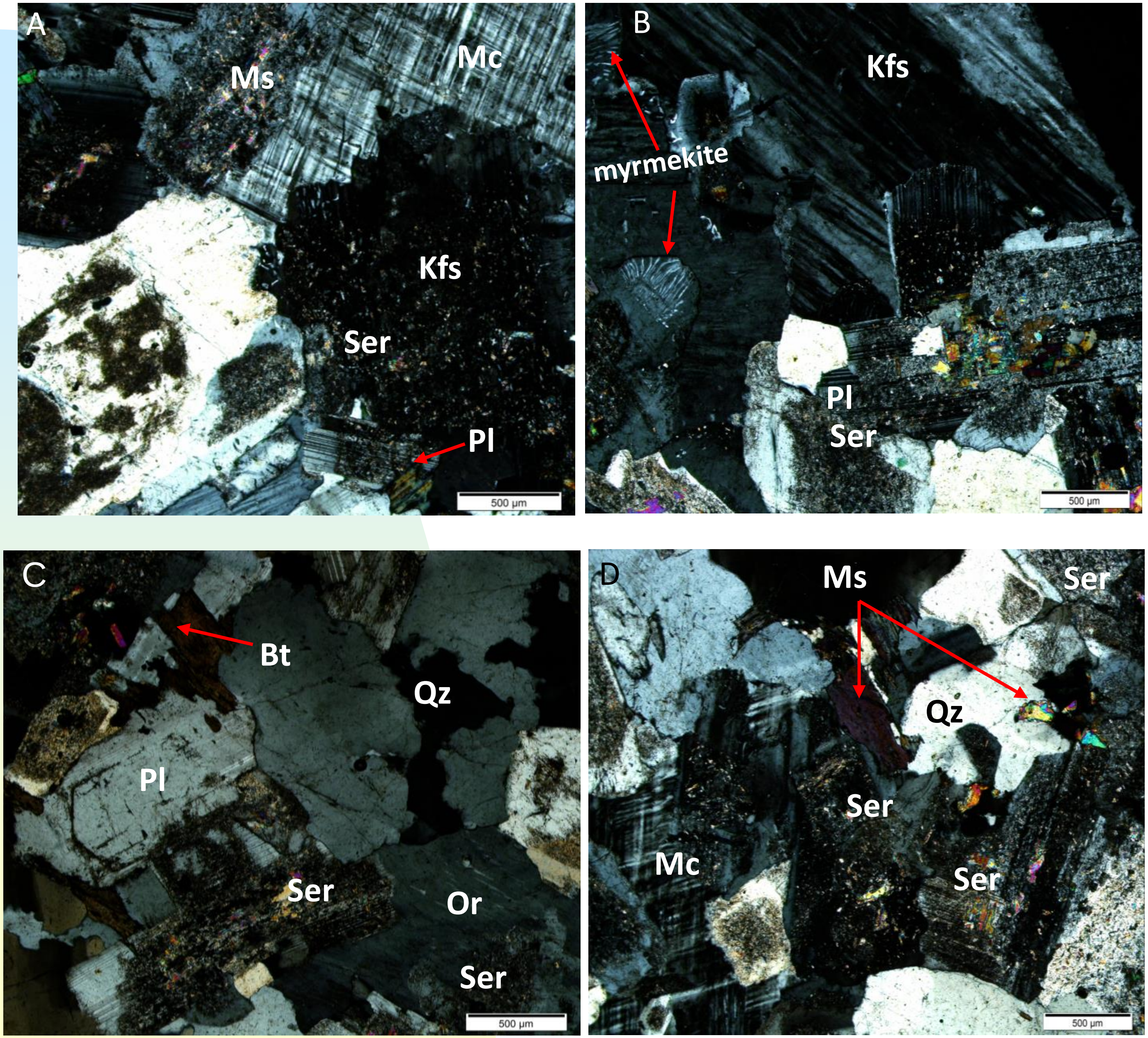
Metasomatic processes should not be confused with weathering, samples are fresh rock slabs.

Residual fluids, & volatiles: intergranular space.

Albitization (accompanied by albitites precipitation) is structurally-controlled: grain boundaries & fracture planes.

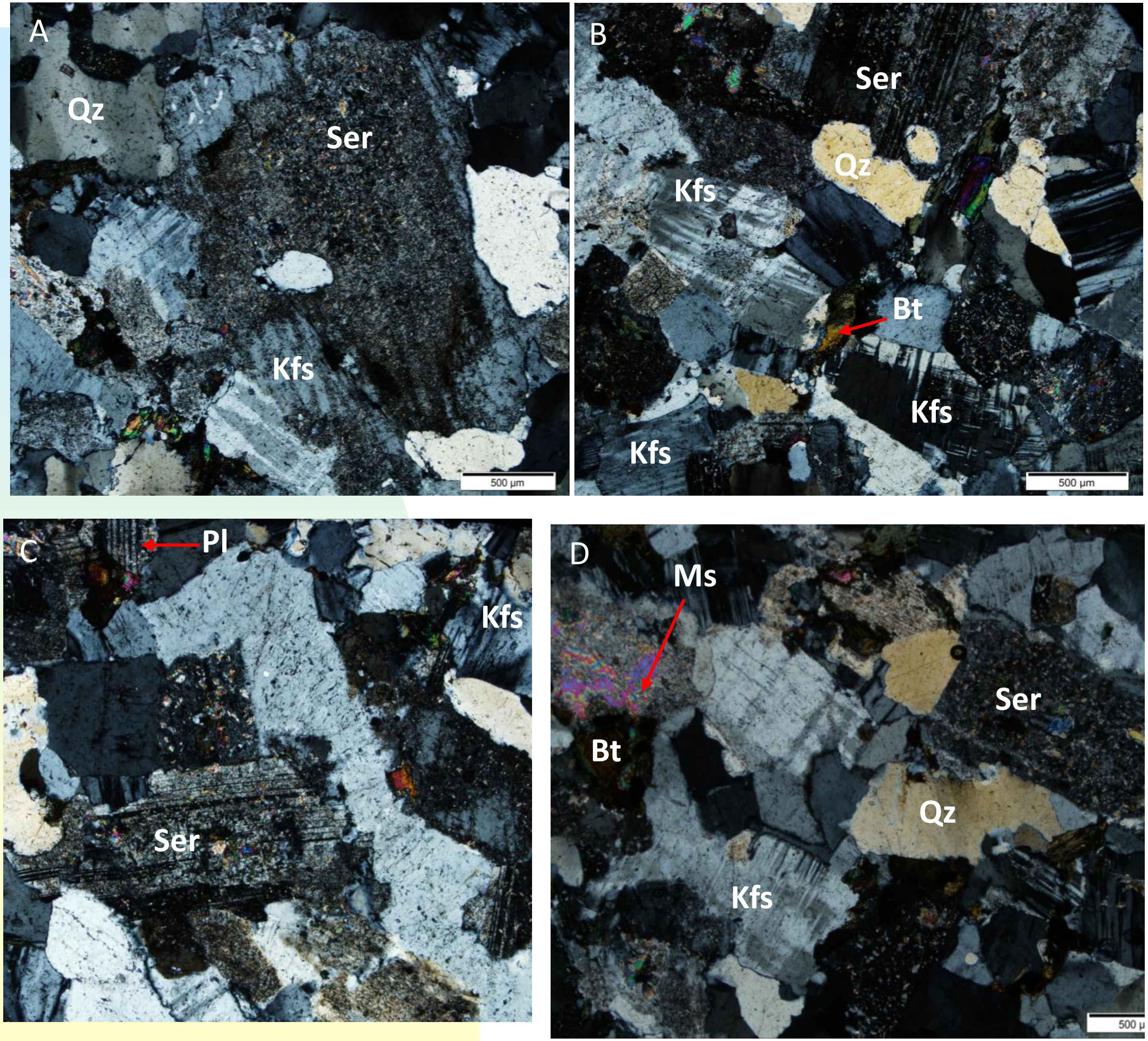
Mineralogical & petrographic record: Chilimanzi Suite (Chikwanda Pluton)

(Chagondah, PhD thesis, UJ, 2023)



Concentric mineral zoning in Zrcn, Pl (calcic cores & outer sodic zones); attests to magma fractionation process.

Mineralogical & petrographic record: Chilimanzi Suite (Great Zim Pluton)



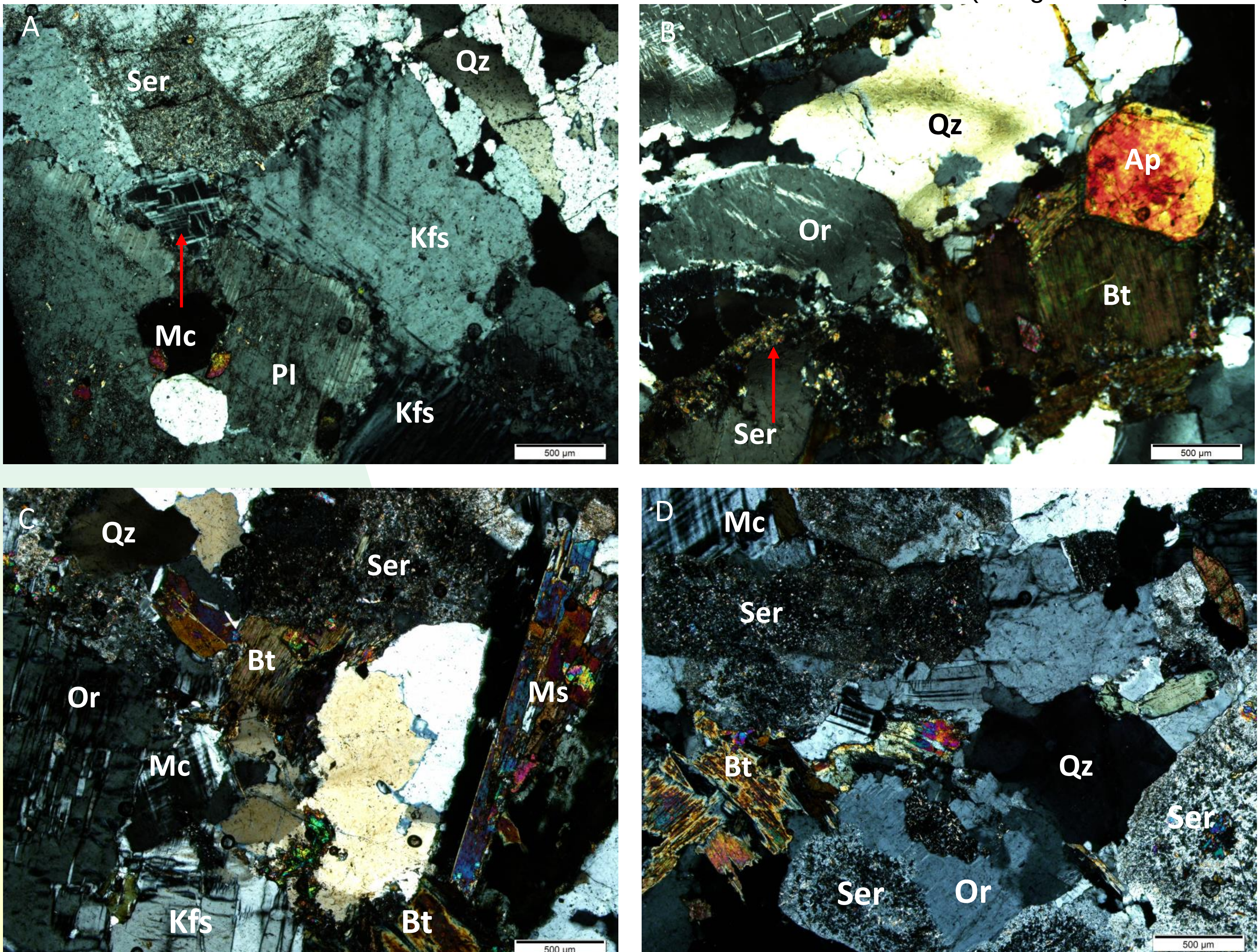
Fsp phenocrysts metaso. = Ab + Ser + Qz

Ms phenocrysts metasomatism = Ser + Qz

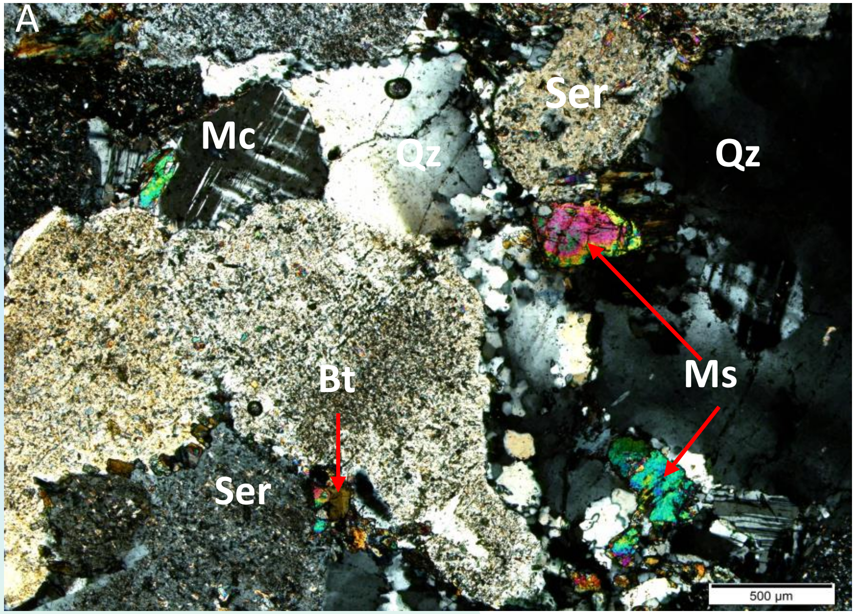
(Chagondah, PhD thesis, UJ, 2023)

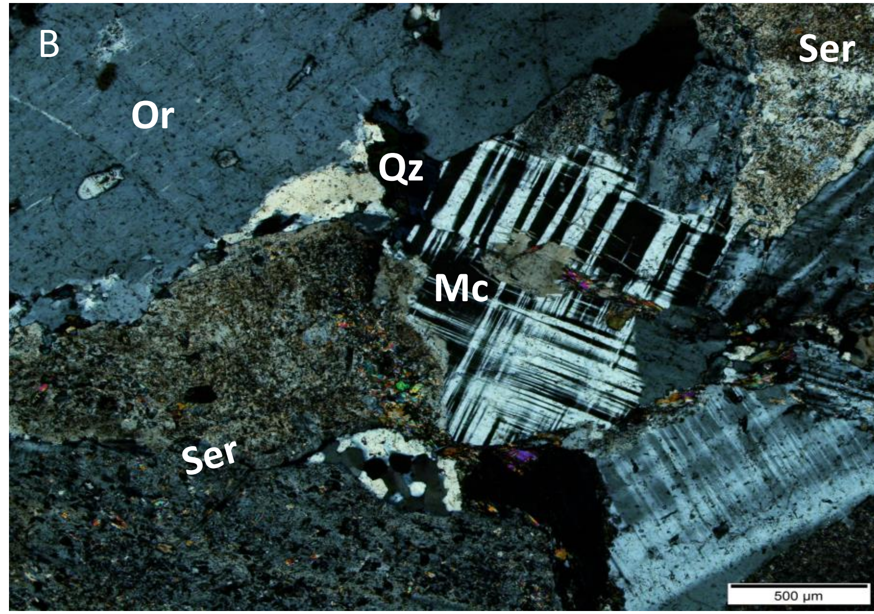
Mineralogical & petrographic record: Chilimanzi (GTZ Pluton)

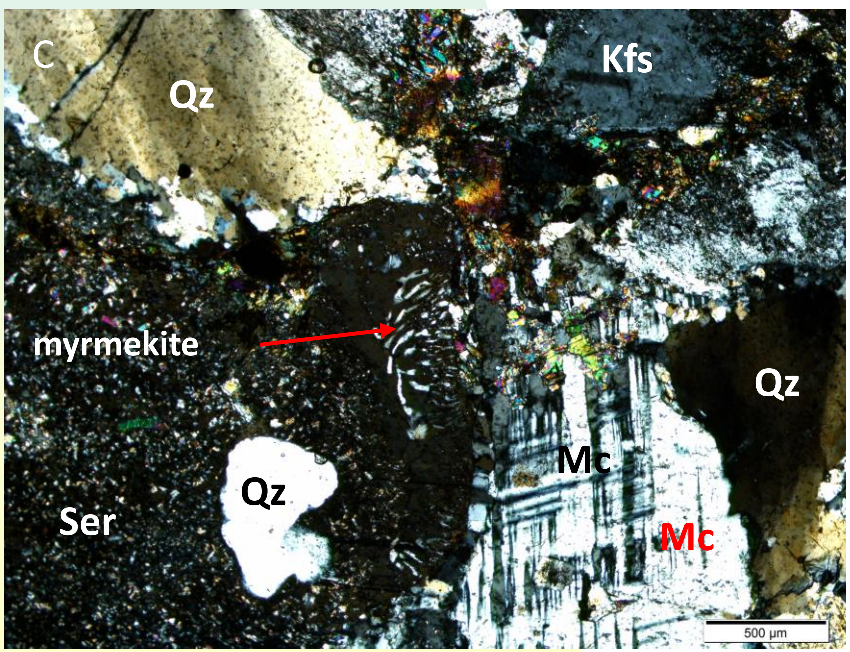
(Chagondah, PhD thesis UJ, 2023)



Mineralogical & petrographic record: Chilimanzi Suite (Chibi Pluton)





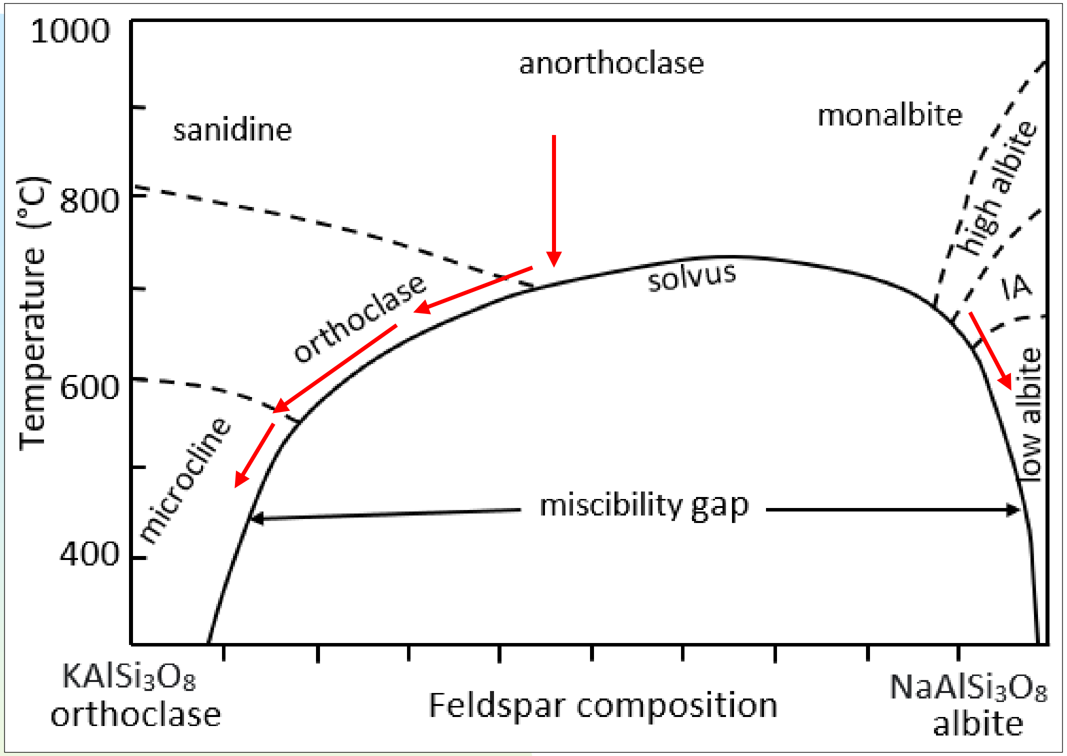


Exsolution textures: perthites and micro-perthites (unmixing) in Or & Mc crystals indicate low-temp phase separation during cooling of a high-temp intermediate alkali composition….anorthoclase.

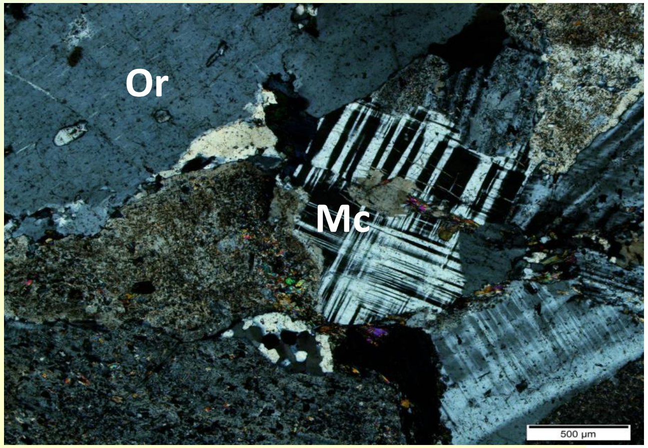
Both granites exhibit myrmekite texture: low temp microstructures formed in fluid-enriched sub-solidus alteration.

(Chagondah, PhD thesis, UJ, 2023)

Phase diagram & solvus for K-Na feldspar at 1 atm pressure showing inferred crystallization of the granite suites



Red arrows: inferred crystallization of the granite suites.



Based on the mineralogical & petrographic record of the granite suites:

K-Na feldspar system: spread in the crystallization temp gradients in the granite suites.

Early crystallization of anorthoclase at high temps; followed by stabilization of orthoclase then microcline on the solidus, & development of perthitic unmixing (albite) at lower temps.

Ubiquitous perthitic structures in the Chilimanzi Suite relative to the Razi Suite is consistent with higher degree of metasomatism in the former & its emplacement at higher crustal levels.

Paragenesis of the Razi and Chilimanzi granite suites

Three main stages are recognized for the paragenesis of the granite suites:

Stage I: = Magmatic crystallization (melt-driven)

- Igneous crystallization of rock-forming minerals from melt; minerals in a planar textural relations.
- Eu- to subhedral intergrowths as Pl, Kfs, Mica (Bt & Ms) & Opq phases.
- Qz & Ms are typically anhedral to irregular = interstitial.

Stages II = Magmatic-hydrothermal transition/early metasomatic

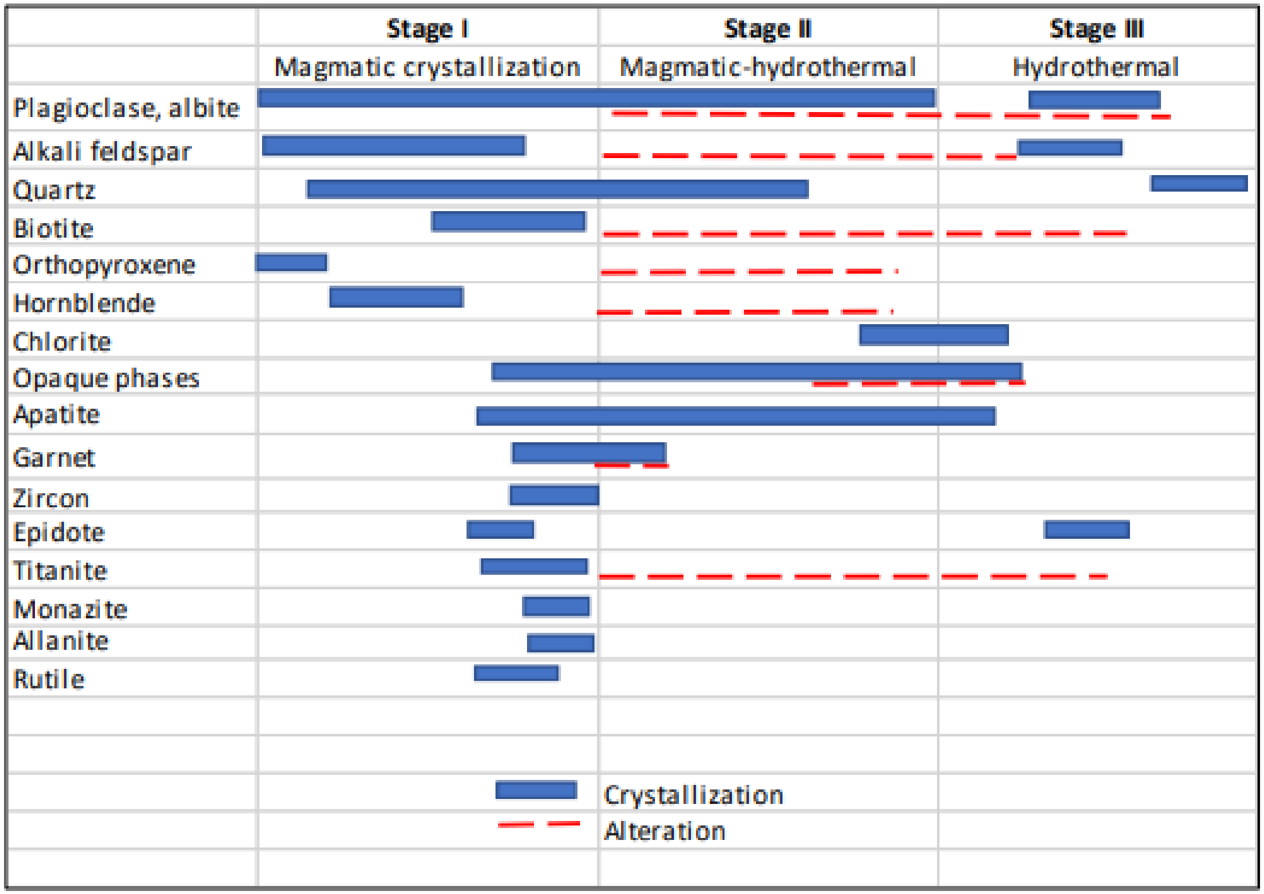
- Transition from a melt- to a fluid-driven crystallization regime.
- Hydrosaline melt coexisting with an aqueous fluid (e.g., Kaeter et al., 2018; 2020; Barros et al. 2020).
- Replacement & overprinting of early evolution processes by late subsolidus transformations.
- Hydraulic fracturing; suggest micro-faulting on earlier crystals prior to late-magmatic (stage III) hydrothermal activity.

Stage III = Hydrothermal/late metasomatic (fluid-driven)

- Metasomatism occurs in aqueous fluid & volatile components (e.g., Li, B, F, P & H2O) enriched conditions.
- Metasomatic agents exsolved from the hydrosaline melt (e.g., Ballouard et al. 2020).
- Similarly to albitization, Ser growth is structurally-controlled in earlier stage minerals.
- Qz vein fracture-fillings truncates earlier formed crystals suggesting hydrothermal activity.

Paragenesis of the Razi Suite

Magmatic and magmatic-hydrothermal transition evolution: Razi Suite

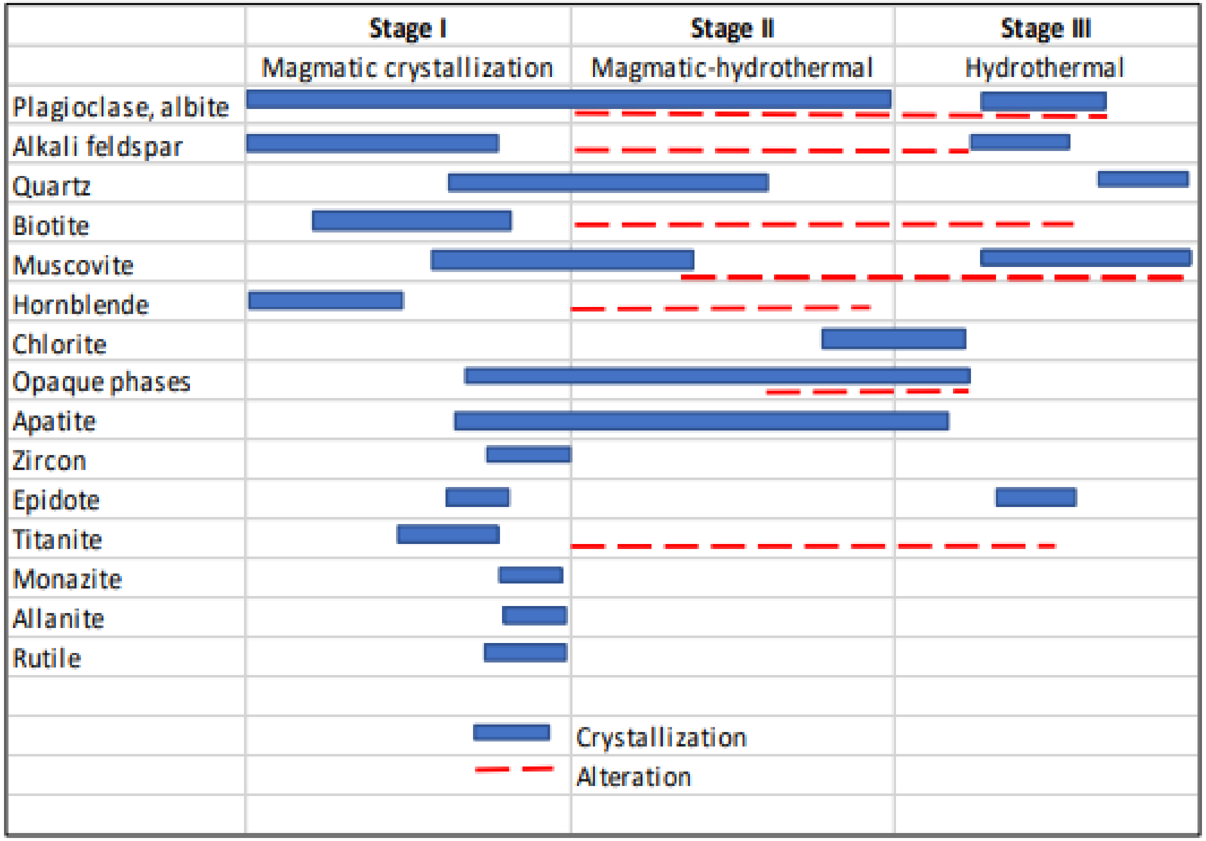


Razi magma: lower crustal anatexis of charnoenderbite (TTG) suite.

Razi Suite = dry mineralogy (Opx presence & absence of Ms), suggests genesis in water unsaturated conditions.

Paragenesis of the Chilimanzi Suite

Magmatic and magmatic-hydrothermal transition evolution: Chilimanzi Suite

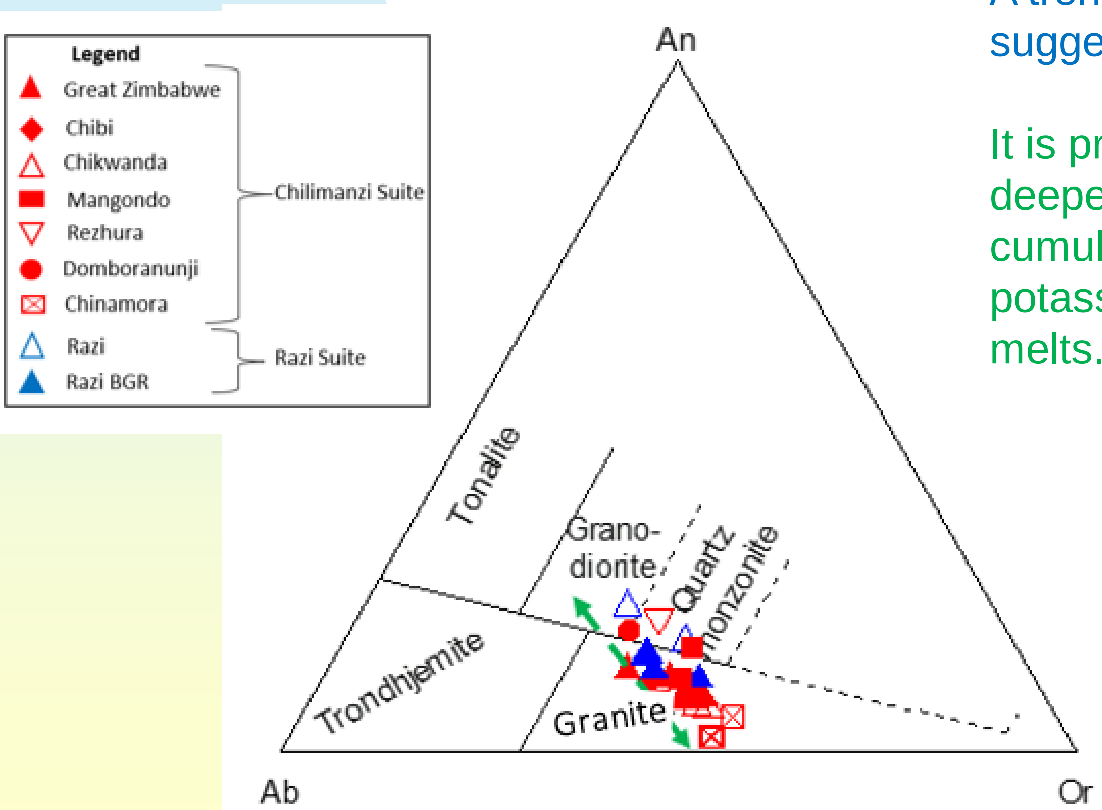


Primary Ms crystallization: suggests the initial melt was H_2O rich.

K-feldspar & micas: important repositories of rare elements.

- Partial to complete albitization of Fsp leading to growth of secondary Ab.
- Melt-fluid element partitioning.
- Dissolution of Kfs, Mica…..release of Li, K, Rb, Cs….reprecipitation.
- Localized development of aplitic Ab-Qz units which are spatially associated with Ta-Nb-Sn oxides.

Normative An-Ab-Or classification diagram for the Chilimanzi & Razi suite samples (fields after O'Connor, 1965)



Broken double arrow represents plagioclase fractionation control line.

Intra-crustal fractionation as the melts evolve to higher crustal levels.

A trend sub-parallel to the An-Or boundary suggestive of plagioclase fractionation.

It is probable that the Razi Suite, which is deeper and less silicic, is dominated by cumulus mineralogy, whereas the more potassic Chilimanzi Suite are the residual melts.

Residual melts of high-level granites are enriched in incompatible elements.

Chagondah et al. (2023)

Do we have (economically important) rare-metal granites in Zim?

Table 1						Economically relevant grades	
	Ave. L. Crust	Razi (n=2)		Ave. UCC	Chilimanzi (n=15)	Rare-metal granites	Pegmatites
ppm							
Li	13	10		24	48		>2000
Ga	13	26		18	20		
Rb	11	96		84	243		
Nb	5	17		27	14		
Sn	1.7	5		2.1	7		
Ta	0.6	0.8		0.9	1.3	110 - 210	20 to >2000
W	0.6	0.2		1.9	0.8		
U	0.2	2		2.7	9.7		

Lower Crust Comp (LCC) & Upper Continental Crust (UCC) values: Rudnick & Gao, 2014

Economically relevant grades: S & P Global (2021)

The Chilimanzi Suite is anomalous relative to the UCC but is far from hosting economically relevant rare-metal ore grades.

- S-type granites: Tin belt granites, peraluminous, S-type magmas, metased. precursors.
- RMGs deposits: are generally found in the uppermost parts of peraluminous & hydrothermally altered late-stage granitic plutons for example in China, Egypt, Russia & Nigeria.
- I-type granites: perhaps from cupolas/greisens of moderately-extremely fractionated magma….have since been eroded in Zimbabwe??.
- Perhaps the record of mineralization…. in residual melts = LCT-type pegmatites?

The Bikita & Mweza field LCT pegmatites & enveloping Chilimanzi Suite share common petrography & evolution, age & geochemical coherence (Chagondah et al., in prep).

Conclusions

1. Reading the mineralogical & petrographic record of multistage minerals is a key to documenting complex crystallisation history & processes: magmatic, magmatic-hydrothermal and hydrothermal.

2. The Razi Suite, is less altered relative to the Chilimanzi Suite….which is in accord with its lower level of emplacement relative to the latter.

3. Magmatic, and MHT processes occurred in both granite suites and could have set the stage for rare element pre-concentrations, which were later redistributed to form LCT pegmatites.

4. World-class LCT pegmatites along the southern margin of the Zim Craton are products of extended crystallization of the spatially & temporarily associated Chilimanzi (and Razi???) granites (Chagondah et al., in prep).

5.The Chilimanzi Suite is anomalous relative to the UCC but is far from hosting economically relevant rare-metal ore grades.

Acknowledgements

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