Zoning in Archaean Li-Cs-Ta pegmatites from the Bikita field, Zimbabwe: Implications to rare-metals exploration

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On today's docket

1. What are granitic rare – metal pegmatites?

2. House keeping:
distinguish between rare earth elements (REEs) and rare – metals (RMs) & why interest in the latter.

3. Where does the pegmatite-forming magma come from?

4. Regional zonation: we explore spatial association of the Chilimanzi & Razi granite suites with the world – class Bikita Pegmatite Field (BPF).

2. We evaluate deposit scale (lateral & vertical) zonation patterns in the Main Bikita Pegmatite – Case study

4. Methodology:
(a) Local & deposit scale geological maps,
(b) Field relationships – traditional geological mapping, and
(c) Explore internal evolution of the MBP: geochemical vectoring based on lepidolite (K/Rb & K/Cs ratios vs selected lithophile & HFSE).

5. Implications to exploration: we propose hints on what should guide explorers of Li-Cs-Ta pegmatites?

6. Take – Aways.

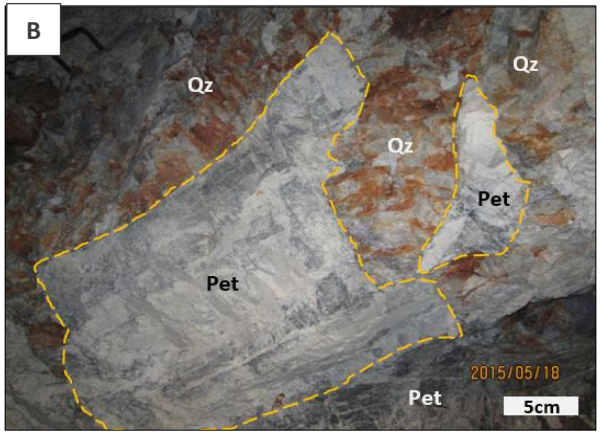
What are granitic rare – metal pegmatites?

- Granitic pegmatites are very coarse-grained, texturally, and mineralogically heterogeneous intrusions with variable size (London and Kontak, 2012).
- They are felsic rocks similar to granites, with feldspar constituting nearly two-thirds of their bulk chemical composition.
- In contrast to granites, pegmatites have lower contents of FeO, TiO_2, MgO, CaO and Al_2O_3.
- Complex-type pegmatites comprise common granite mineralogy, plus exotic minerals enriched in rare-metals (e.g., Li, Rb, Cs, Ta, Nb, Be, Ga, Th, U, Sn) & volatile components (e.g., Li, F, P, B & H_2O).

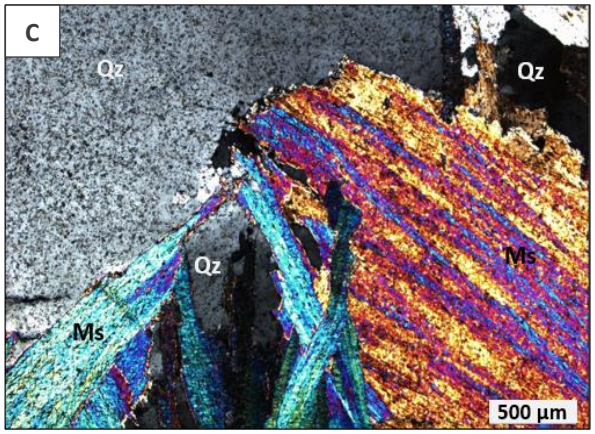
- Only a small proportion (<1 vol. %) of pegmatites in a given pegmatite district are enriched in exotic minerals (London and Morgan, 2012).

Field scale: beryl crystals from the Bumpus Mine in Maine, USA (Perham, 1987)

Hand specimen: Main Bikita Pegmatite



Photomicrograph: Main Bikita Pegmatite

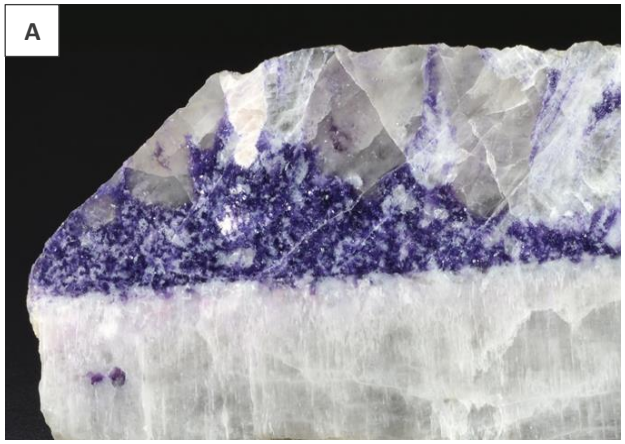


Why interest in Li-Cs-Ta pegmatites? : is the talk of the world at the moment

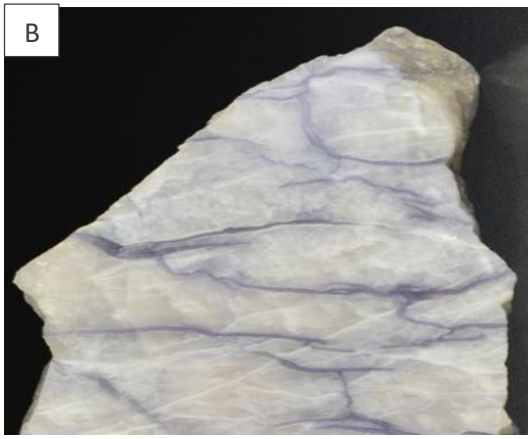
House keeping:

Rare Earth elements (REEs): **a group of 15 metallic elements in the periodic table known as the Lanthanide series, plus** scandium and yttrium. REEs are sub-divided into light elements (La, Ce, Pr, Nd & Sm) and heavy elements (Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb & Lu): hosted in monazite, xenotime & carbonatites. NOT discussing these in this presentation.

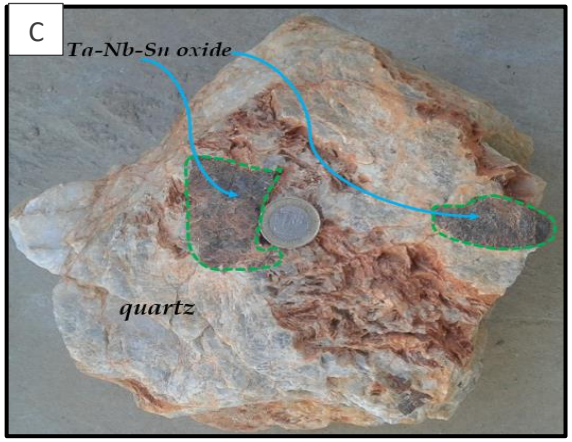
Rare Metals (RMs): Li, Cs, Ta, Nb, Rb, Sn, Be & Ga are physically and chemically dissimilar to REEs.



Li: lepidolite, spodumene & petalite



Cs: pollucite



Ta-Nb-Sn: columbite-tantalite

RMs are often referred to as "strategic elements" or "critical elements" (Linen et al., 2012).

- High-technology applications.
- Lithium-ion batteries, electric cars revolution, capacitor in electronics, caesium clocks for cell phones & GPS receivers.
- Advanced defense systems = special alloys for jet engines & rockets.

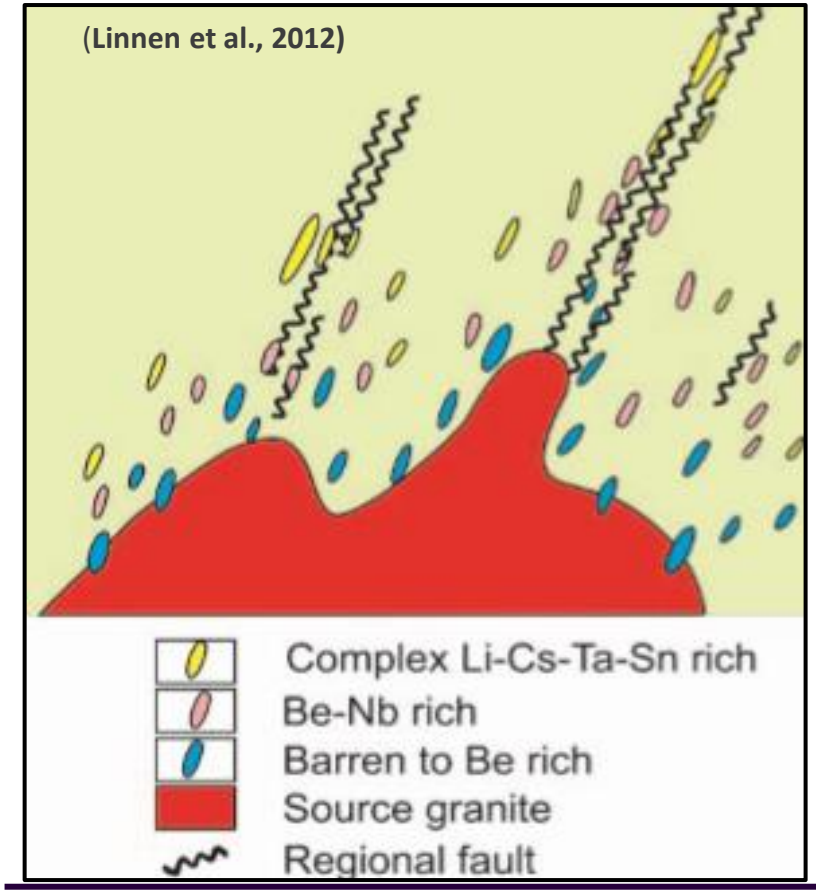
Where does the pegmatite-forming magma come from?

Anatectic melting of local crust

Li-Cs-Ta pegmatites (Černý & Ercit, 2005)

- syn- to late-post orogenic.
- Peraluminous to subaluminous S- or I-type granites.

Fractional crystallization of parental granite



(Pic. from northern Nyanga: Courtesy Gerald Kupeta)

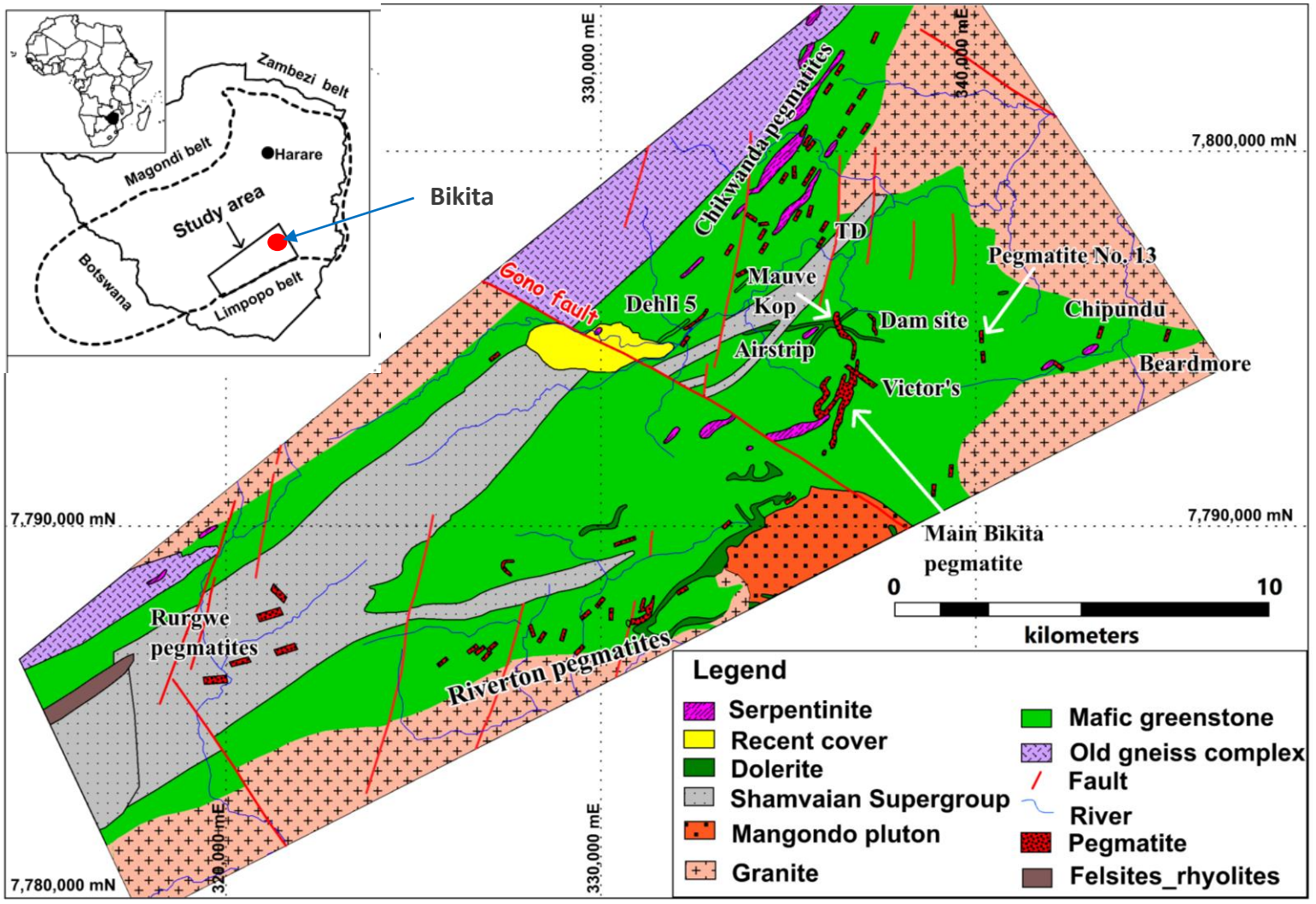
Regional zonation of rare-element pegmatites in the Mavis Lake pegmatite group peripheral to the Ghost Lake batholith, Canada (e.g., Selway et al., 2005).

Parent is assumed to be hidden:
Tanco pegmatite (Canada) & Greenbushes (WA).

Why are different regions endowed with different elements? = Source region metal budget & varying degrees of fractionation.

Associated granites: syn- to late-post orogenic

Location map of the LCT Bikita Pegmatite Field



(modified from Martin, 1964)

Field enveloped by Chilimanzi & Razi granite suites and OGC.

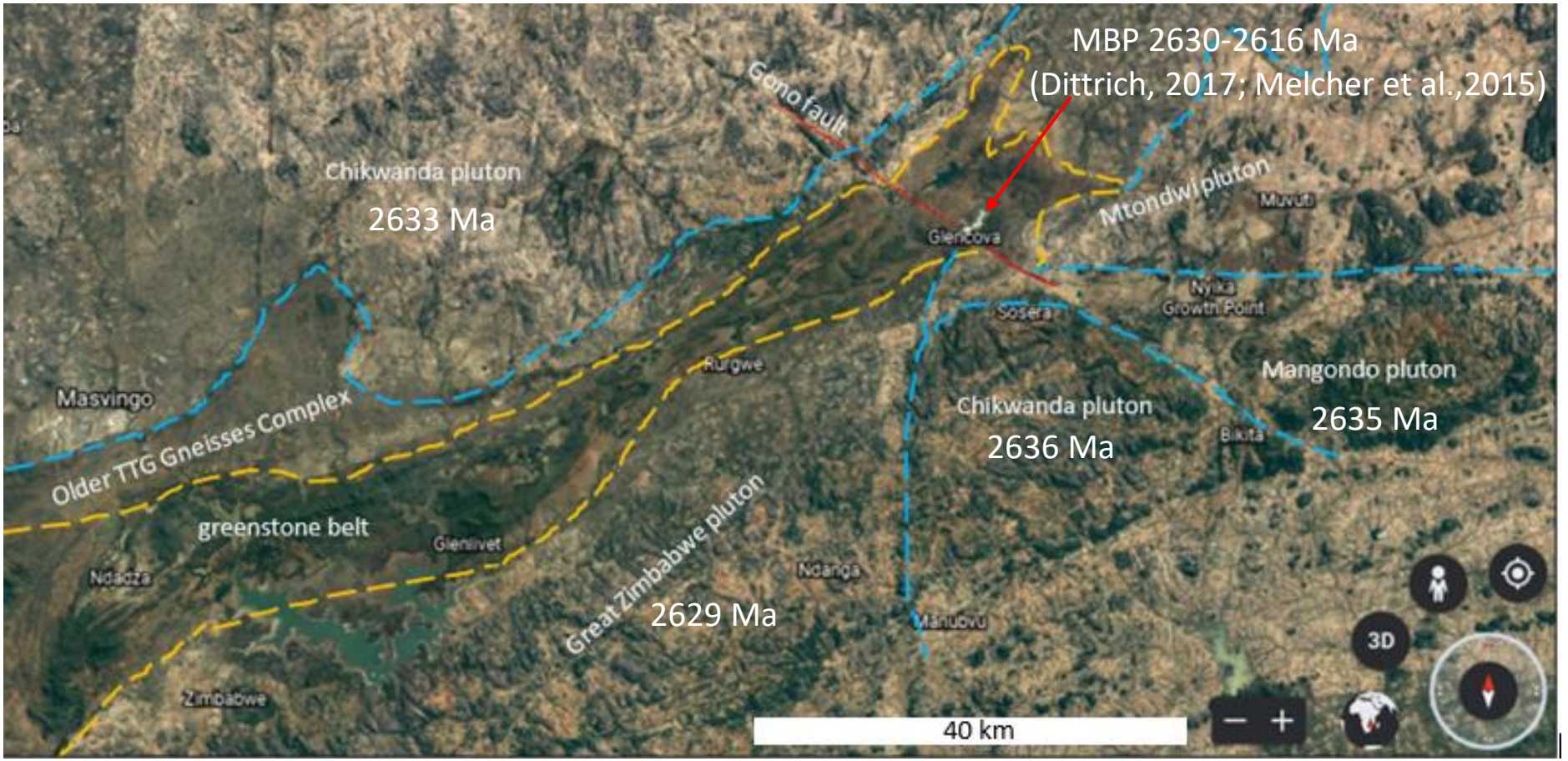
Post-tectonic & cross-cutting regional fractures: Gono & Bikita trends.

Emplacement: Gono & Bikita trends = pegmatite forming-magma chambers.

4 major groups: Rurgwe (Sn), Riverton (Be & Ta), Bikita (LCT & Ta-Nb-Sn oxides & Be) & Chikwanda (Be & Ta).

Note that regional zoning is not “classical” as proposed by Linnen et al. (2012) in the previous slide.

Granite-pegmatite spatial relationships & geochronology- Bikita field

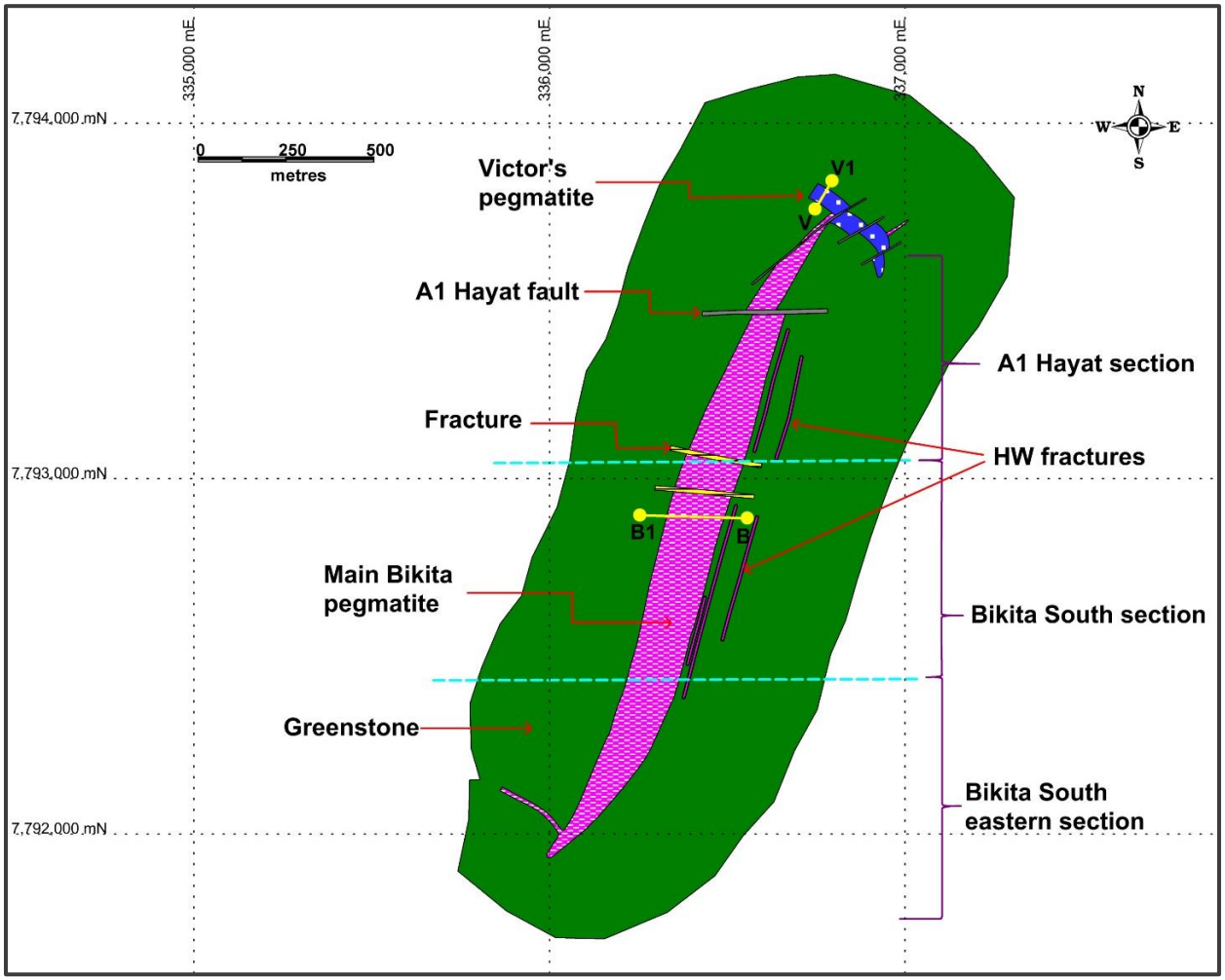


Zircon U-Pb ages from Chagondah et al., (under review)

Mother-daughter relationship: Pegs 5-15 Ma younger than associated plutons

Geochronological coherence suggests that enveloping granites are potentially source rocks for the pegmatite-forming magma in the BPF.

Plan view of the Main Bikita Pegmatite (MBP): our case study



from Chagondah et al., (in press)

A premier pegmatite by size, mineral diversity & grades.

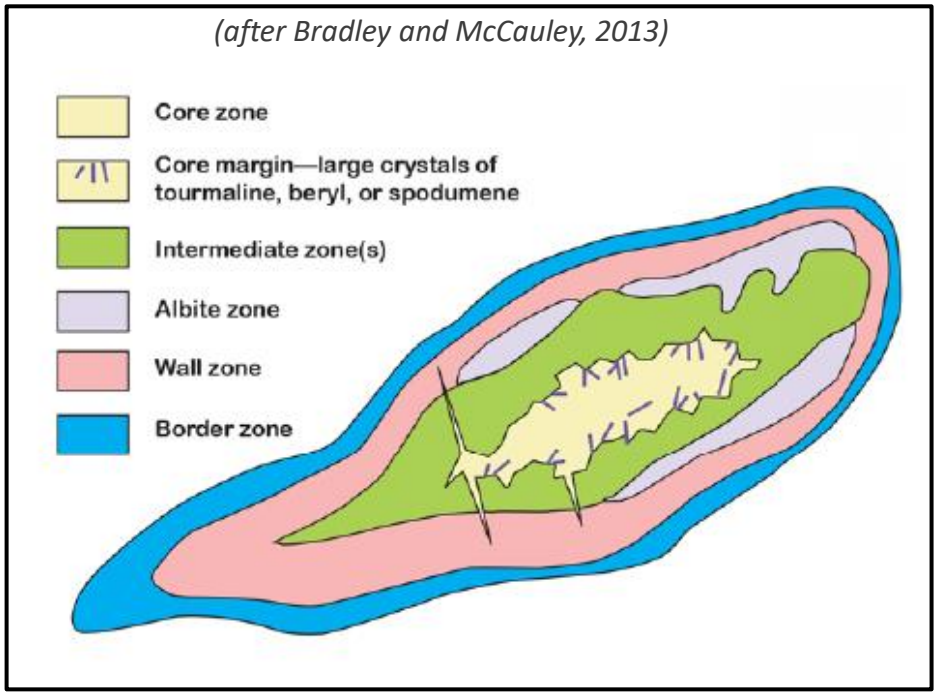
Intrusive into 2.7 Ga Amphibolite schist of the Masvingo greenstone belt.

Peg is discordant to NE trending foliation, it exploited NNE trending regional fractures.

- *2070 m strike length*
- *15-60 m thick*
- *15-35° dip south-east*

Exhibits both vertical & lateral zonation patterns.

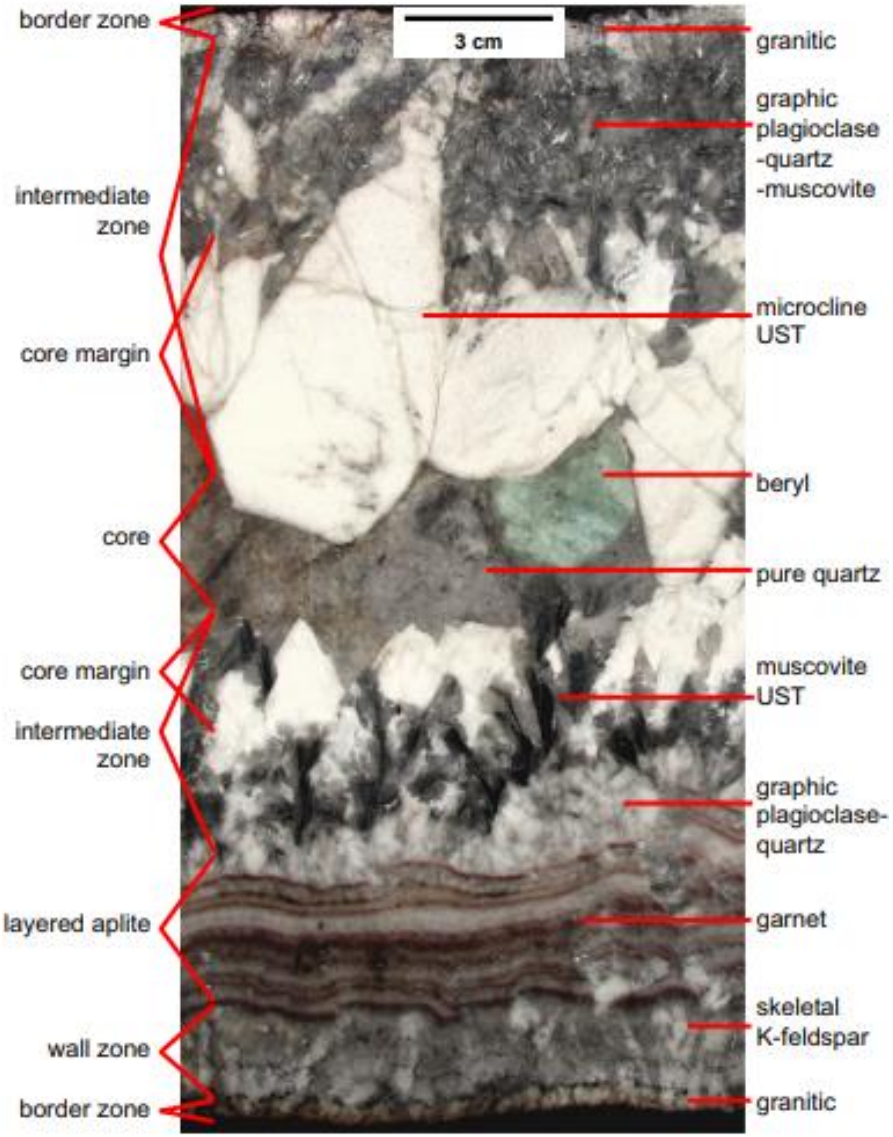
Internal zonation patterns in an idealized pegmatite



- Küster et al. (2009)
- Kenticha rare-element pegmatite, Ethiopia.

- Internal differentiation within a magma chamber = layered, with bottom-up evolution/crystallization history.

29 cm thick peg. dyke near Palomar Mountain, San Diego County, California (USA) (London, 2021)

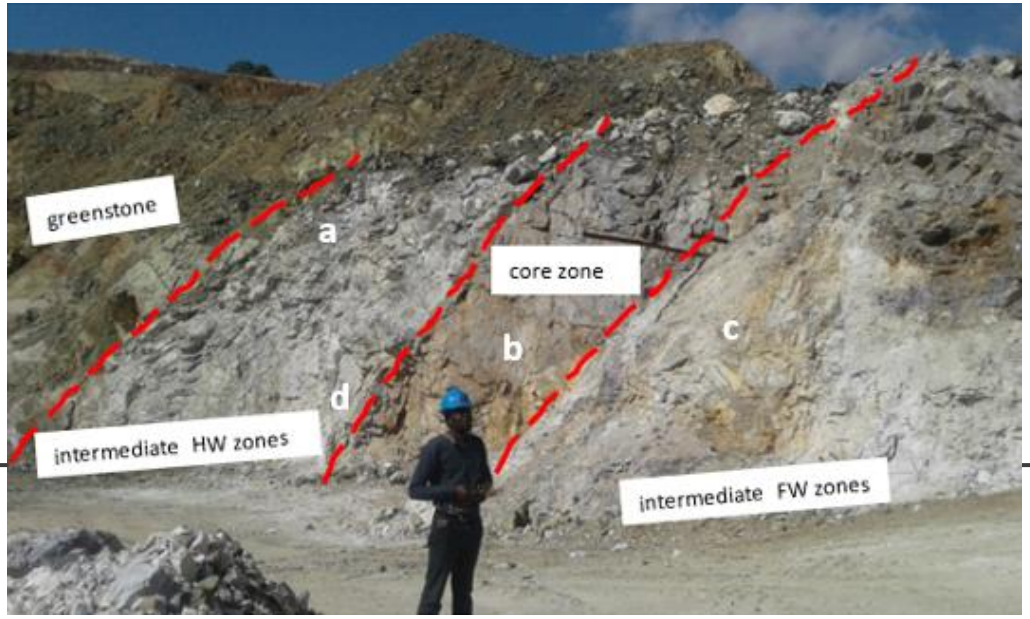


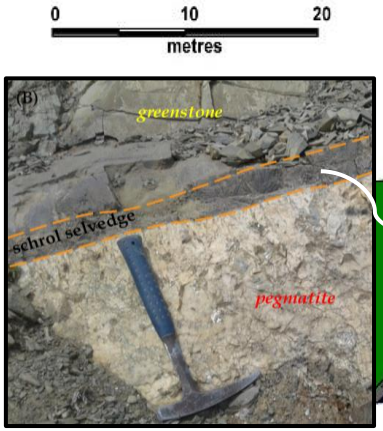
In practice = rare metal pegmatites are layered, with no or little symmetric zonation pattern

Schematic cross-section of the MBP: Bikita South section

Dittrich et al. (2019), albite predominant Pl in Archaean pegs from WA & Bikita.

Plagioclase poor carrier of metals: small ionic size = depleted proportion of FWIZ





from Chagondah et al., (in press)

magmatic layering a product of mechanical & geochemical processes

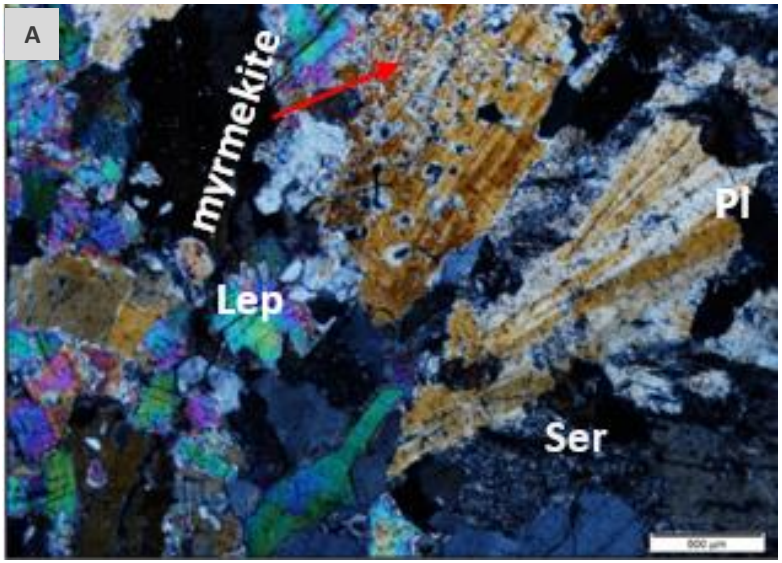
Selective mining for pollucite @ MBP

*Ore mineral for caesium,
*patchy distribution.

*structural position of pollucite: HW intermediate zone.

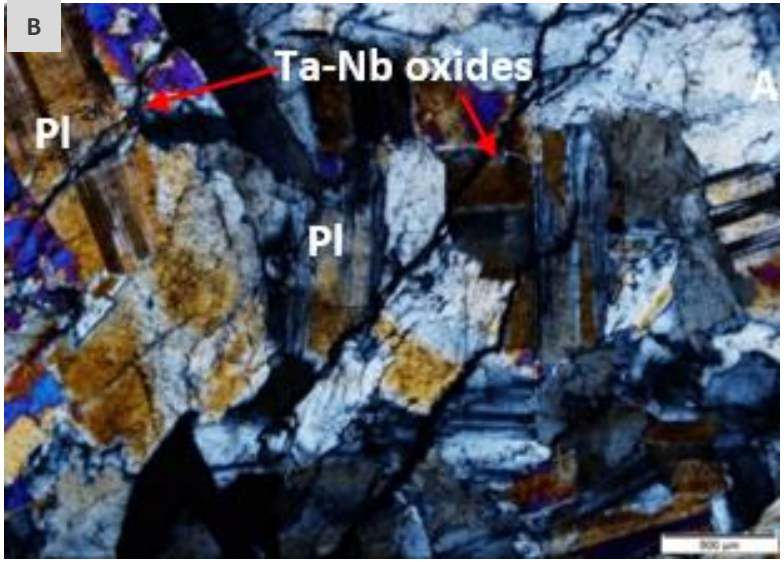
Polished pollucite slab (9 cm long)

Petrography of pegmatites: photomicrographs of the MBP zonation and alteration



scale bar is 500 µm

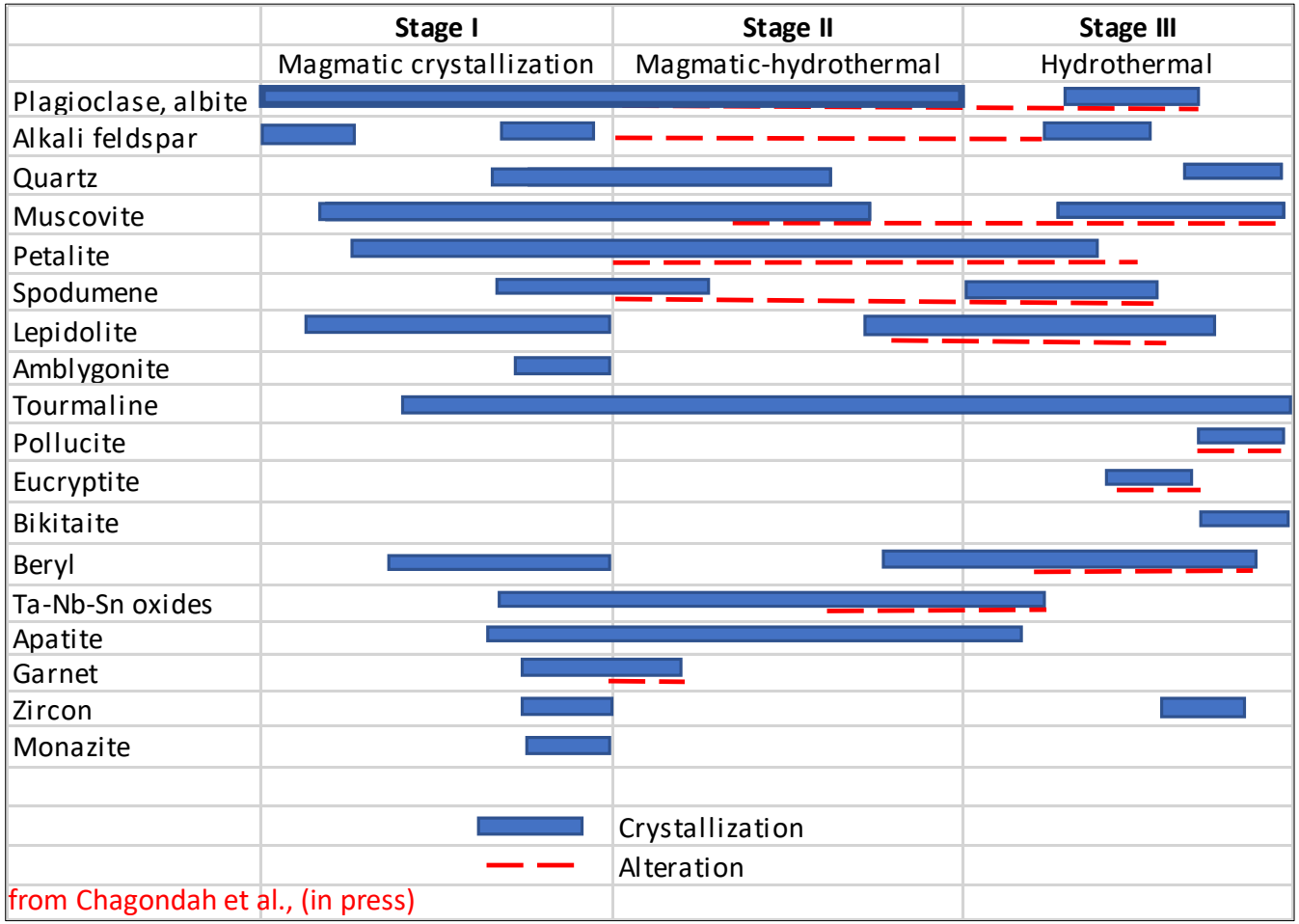
(A): HW intermediate zone exhibiting intergrowths of Lep, Pet, Pl & Qz and myrmekite in Pl.



(B): FWIZ = late-stage Qz vein filled fractures truncate early grains. Note that Ta-Nb-Sn oxides are associated with fracture fillings.

In-situ petrochemical study on a thin section

Proposed paragenetic sequence of the MBP



from Chagondah et al., (in press)

Stage I: affects entire peg. Occurs in potential relation with undercooling and constitutional zone refining processes (see London, 2008).

Coarse-grained sub to euhedral primary mineral intergrowths from the melt. Anhedral to irregular Qz, Ms Grt = interstitial.

Stages II & III: metasomatic & involve melt-fluid & fluid phase environments. Replacement & dissolution textures. Stages predominate in the HWIZ relative to FWIZ.

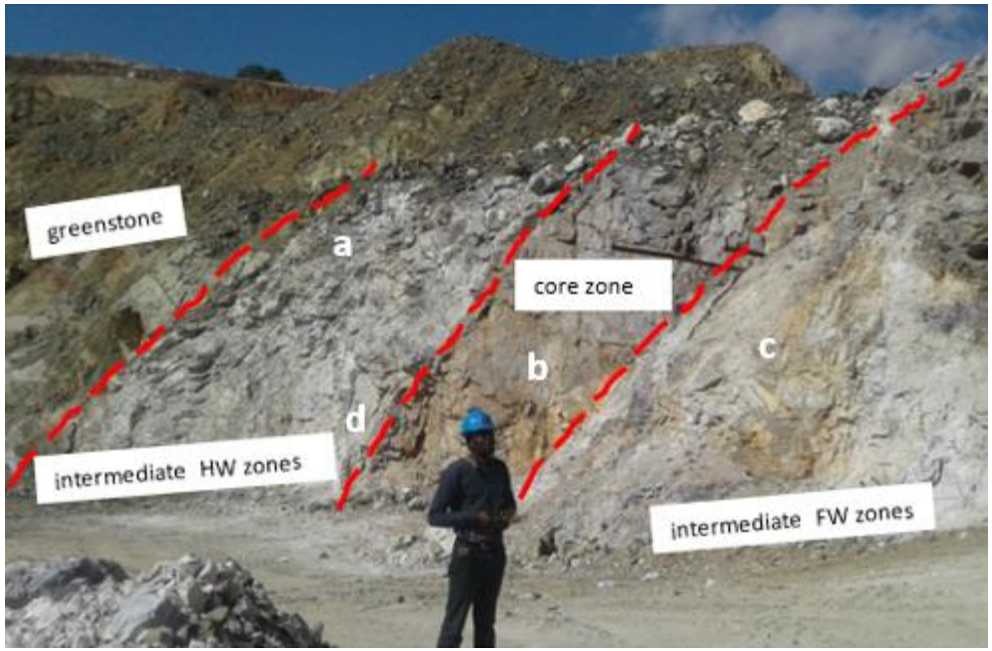
Sub-solidus metasomatic alteration is accompanied by redistribution of metals & fluxes causing their enrichment in residual fluids.

Volatile component in magma: which derive stages II & III

Li & F = lepidolite; P = amblygonite; B = tourmaline, hydrous phases (H_2O) = muscovite.

Advocates for paragenetic sequence (e.g., Ballouard et al., 2016; 2020; Kaeter et al., 2020; Barros et al., 2020; Wilde et al., 2021).

Geochemical evolution & crystallization history of the MBP using lepidolite chemistry



Legend

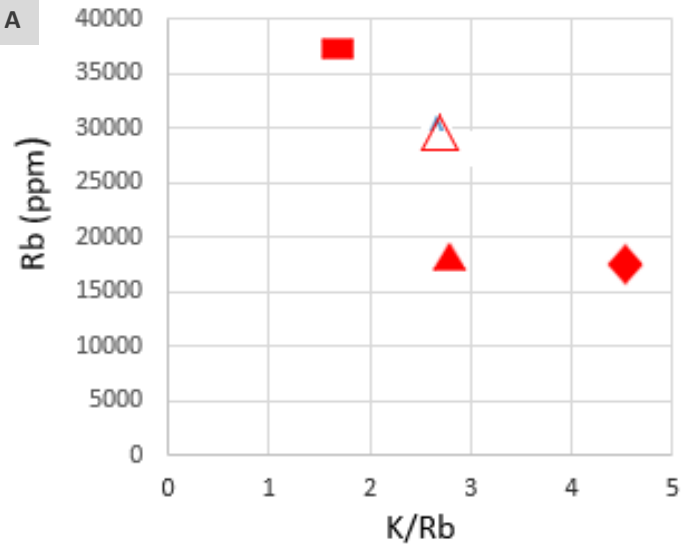
- Footwall intermediate zone (c)
- Core zone (b)
- Pollucite lense (d)
- Hangingwall intermediate zone (a)

Fluid-mobile elements: HWIZ enriched relative to FWIZ

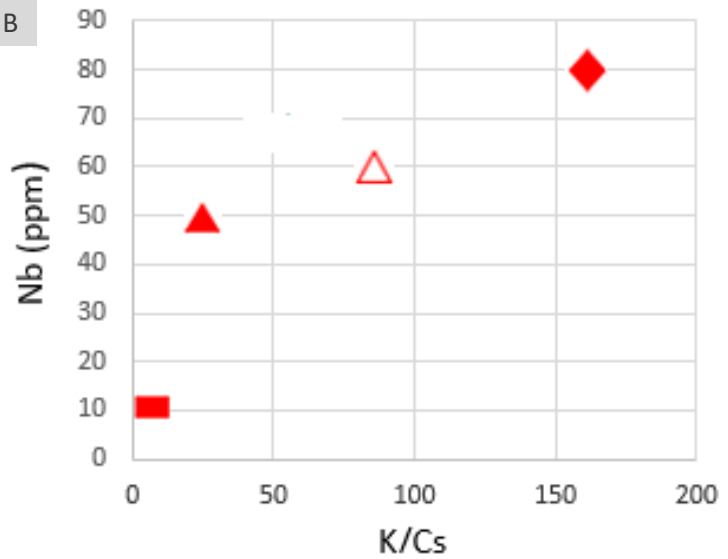
Černý et al. (2003): inwards increase in Rb, Li & Cs in beryl away from FW towards interior.

All data is consistent with ***bottom-up (i.e., FW to HW) crystallization & resembles*** Küster et al. (2009)'s Kenticha peg in Ethiopia.

A

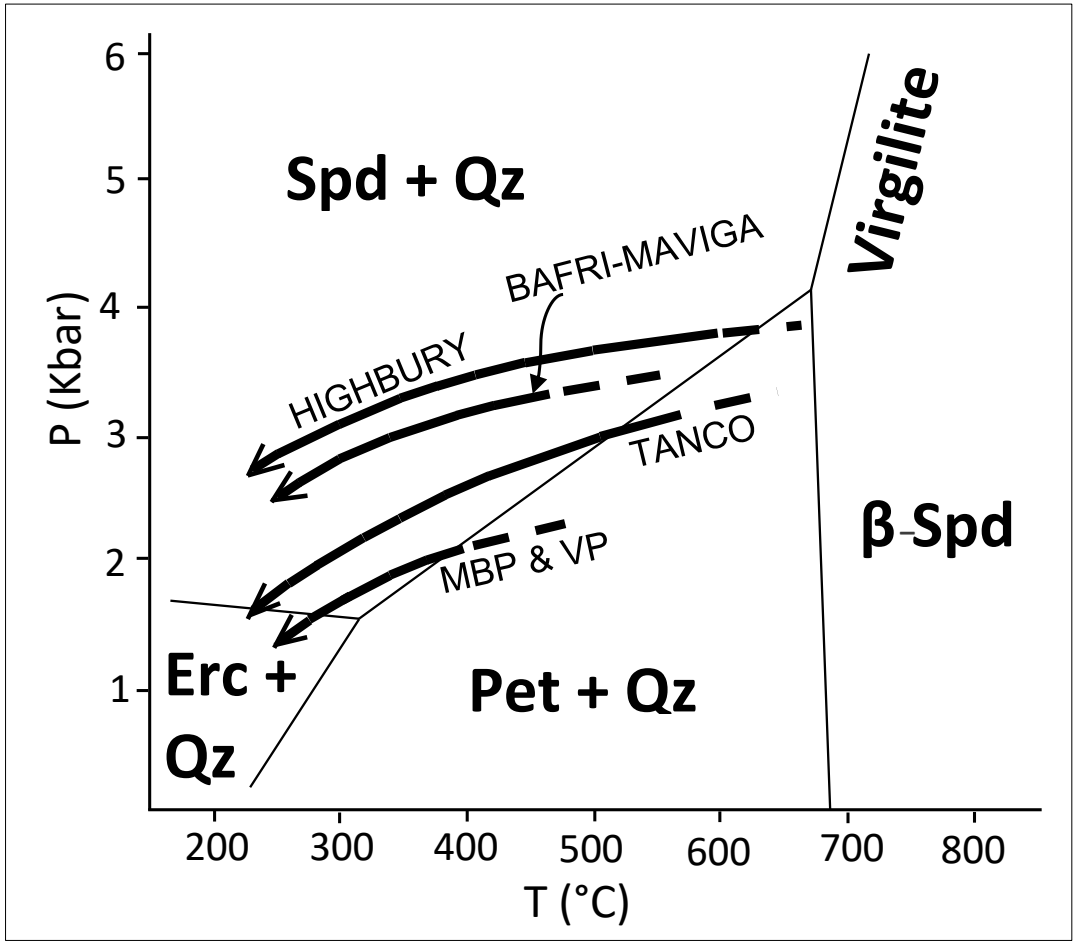


B



HFSE (e.g., Nb, Ta, W & Th): preferentially partitioned into the melt phase – due to their low fluid-melt partition coefficients (e.g., Linnen & Cuney, 2005).

Inferred P-T crystallization paths for the MBP and Victor's Pegmatite (VP)



from Chagondah et al., (in press)

Based on Li aluminosilicates + Qz assemblages.

Mineral name	Chemical formula	Lithium content (Li %)
Spodumene	$LiAlSi_2O_6$	3.7
Lepidolite	$K_2(Li,Al)_{5-6}\{Si_{6-7}Al_{2-1}O_{20}\}(OH,F)_4$	1.39–3.6
Petalite	$LiAlSi_4O_{10}$	1.6–2.27
Eucryptite	$LiAlSiO_4$	2.1–5.53
Amblygonite	$LiAl[PO_4][F,OH]$	3.4–4.7

Fields experimentally established by London (1984).

Dittrich et al. (2019): SQI = alter. Pet to Spd due to changing physiochemical conditions.

Primary crystallization of Spd = orogen centre.

So what is the geological significance of Spd occurrences in Zim Craton interior = Un-identified geodynamic conditions??

Phase diagrams used for inferring magmatic crystallization, magmatic - hydrothermal transition & hydrothermal evolution in Li pegmatites (e.g., Stewart, 1978; London, 1984; Thomas et al., 1994; Kaeter et al., 2020; London, 2021).

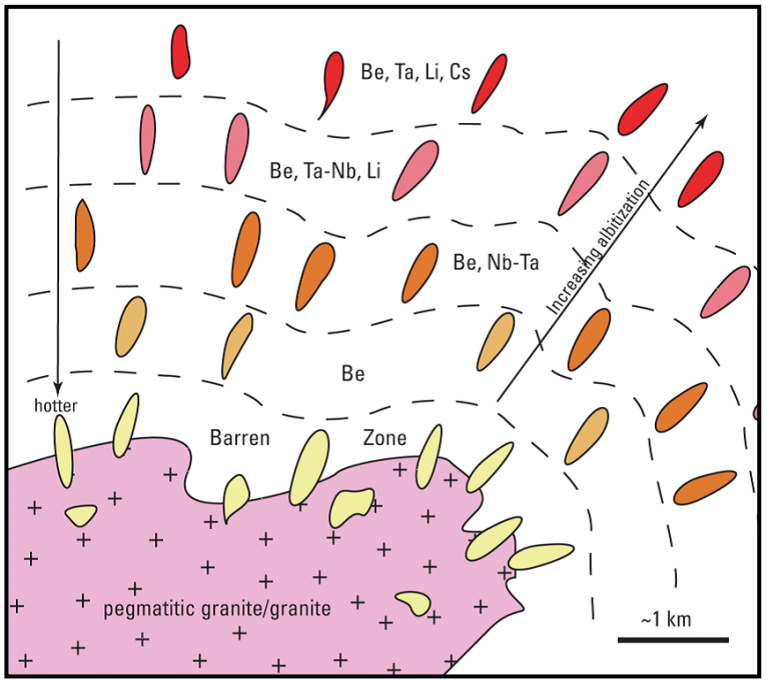
Implications to rare-metals exploration

Regional & internal zonation patterns = endowed with different suites of rare-metals.

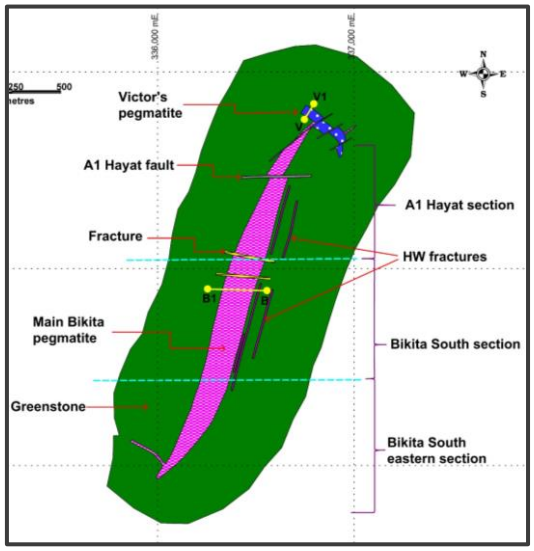
- Contrasting mineralogical and geochemical zones in the MBP
- MBP internal structure resembles other world-class complex-type pegmatites e.g.,

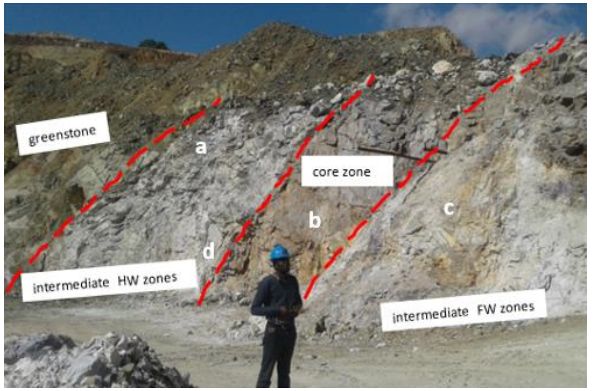
Tanco, Canada (Stilling et al., 2006), Greenbushes, Australia (Partington et al., 1995), Kenticha, Ethiopia (e.g., Küster et al., 2009).

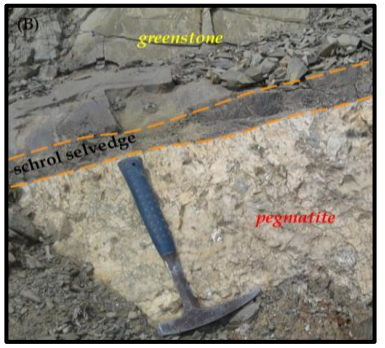
Regional zonation



Deposit scale lateral and vertical zonation: MBP







Metasomatic selvedge chemistry: useful insights into suite & relative enrichment of Li-Cs-Ta pegmatites in a field/district.

Take – Aways

1. There is geochronological coherence evidence for the Bikita field pegmatites to be late-stage differentiates of the spatially associated Chilimanzi & Razi suite plutons.

2. Thus, pegmatites were likely derived from extremely fractionated, fluxed (Li, F, P, B & H_2O), I-type, metaluminous granites.

3. The presence of Cs in the MBP indicates that extreme levels of fractionation were attained by the pegmatite-forming magma. Fractionation efficiency promoted by presence of fluxing agents.

4. Mineralogical & geochemical evolution evidence suggests bottom-up (FW to HW) crystallization history for the MBP.

5. Implications to exploration:

(a) Regional zonation pattern in the BFP (i.e., Rurgwe, Riverton, Bikita & Chikwanda groups) suggests multi-pegmatite magma sources.

(b) Lateral zonation demonstrated in the MBP (i.e., Al Hayat, Bikita South & Bikita South extension) indicate unique suites of rare-metals along the strike length of the pegmatite, with vertical zonation/efficient fractionation pronounced in widest parts of the pegmatite.

(c) Vertical zonation across the MBP demonstrates varying degrees of rare-metals enrichment:
HFSE (Ta, Nb, W, Sn, U): melt phase = FW intermediate zone.
Lithophile (mobile) elements (Li, Rb, Cs): fluid dominated phase = HW intermediate zone.

(d) Metasomatic selvedges hints on suite & relative enrichment of Li-Cs-Ta pegmatites across a field/district/belt.

Acknowledgements