



**British
Geological Survey**
NATURAL ENVIRONMENT RESEARCH COUNCIL

UNIVERSITY OF
EXETER



 **leominex**



Late-stage apatite: a potential HREE-enriched co-product of LREE minerals in carbonatites

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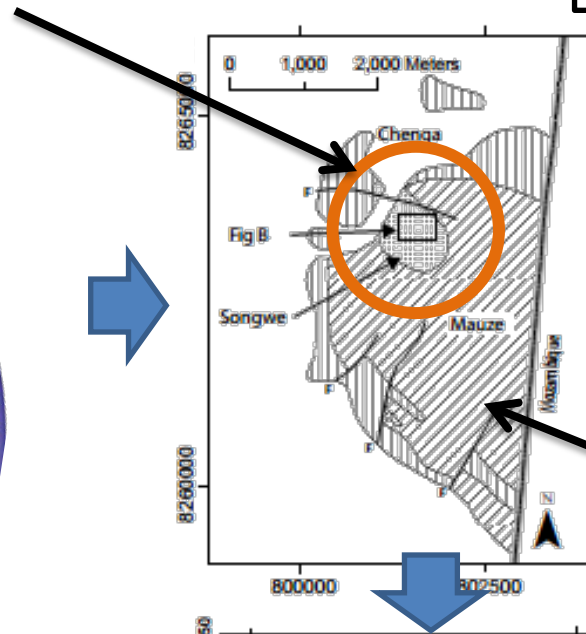
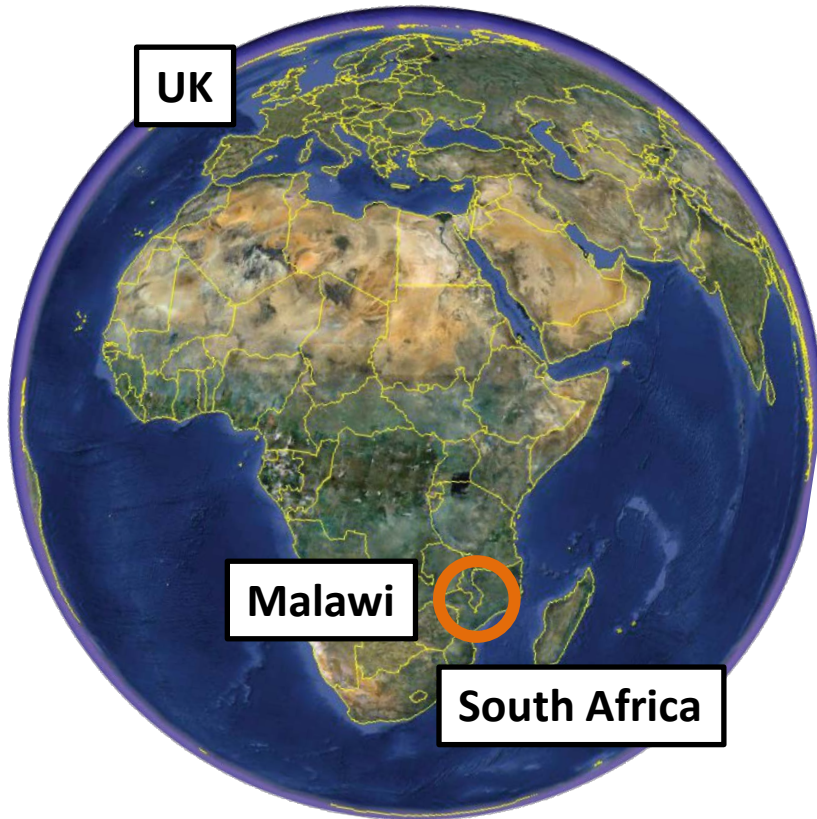
Aoife Brady

Will Dawes

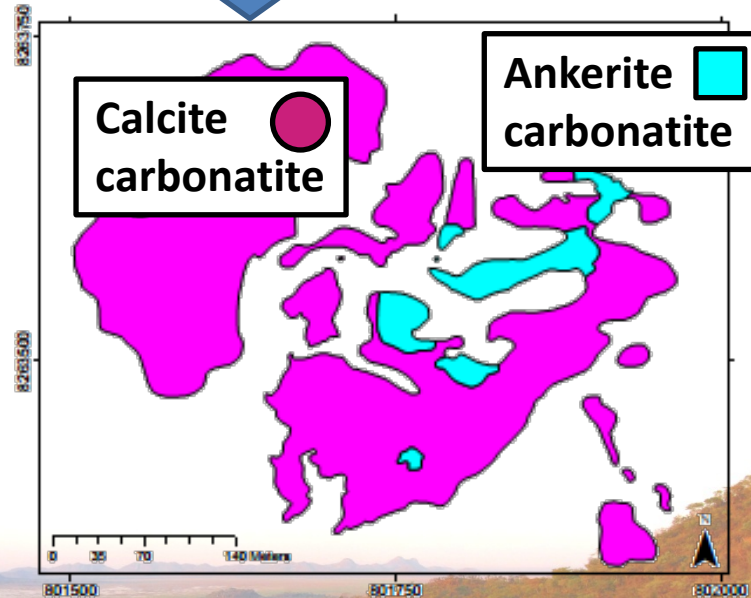
Jens Andersen

Songwe, Malawi

Also see poster GP1-D

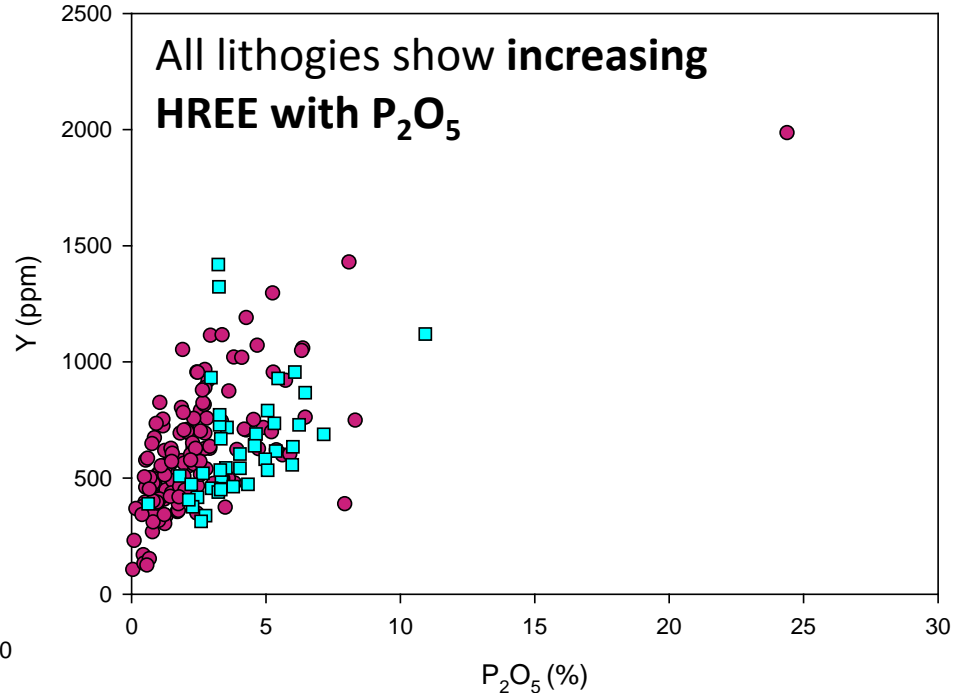
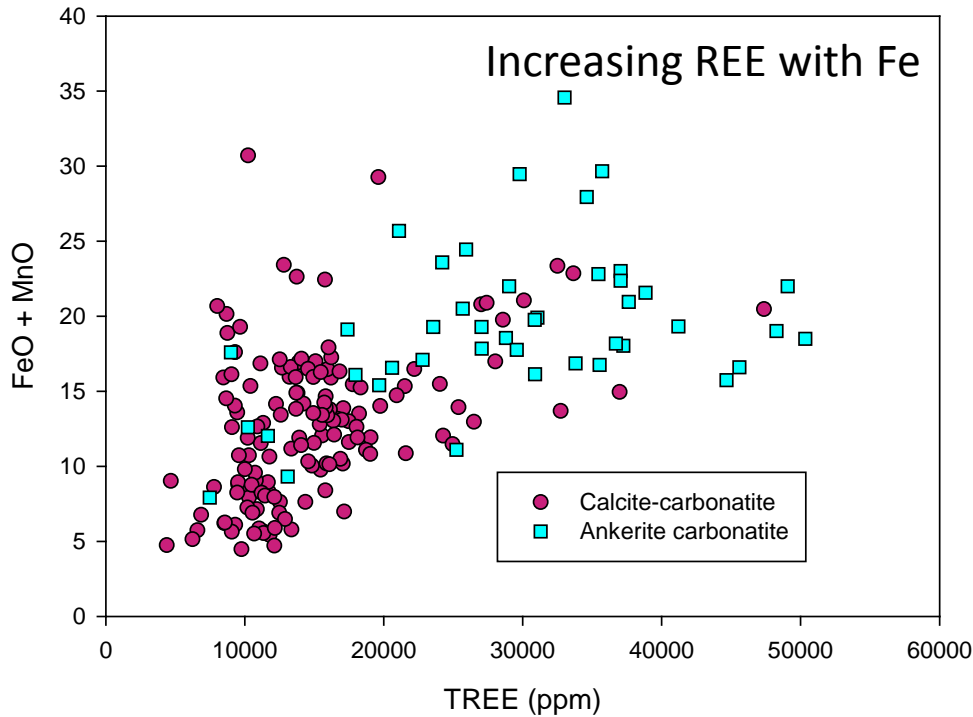


Mauze – Nepheline syenite



- Chilwa Alkaline Province, Malawi
- Late Jurassic/Early Cretaceous
- Mkango Resources Ltd.
- REE-resource, **13.2 Mt @ 1.62 % TREO, 18.6 Mt @ 1.38 % TREO.** (Cut-off, 1 %)

Drill core results show Y–P₂O₅ correlation

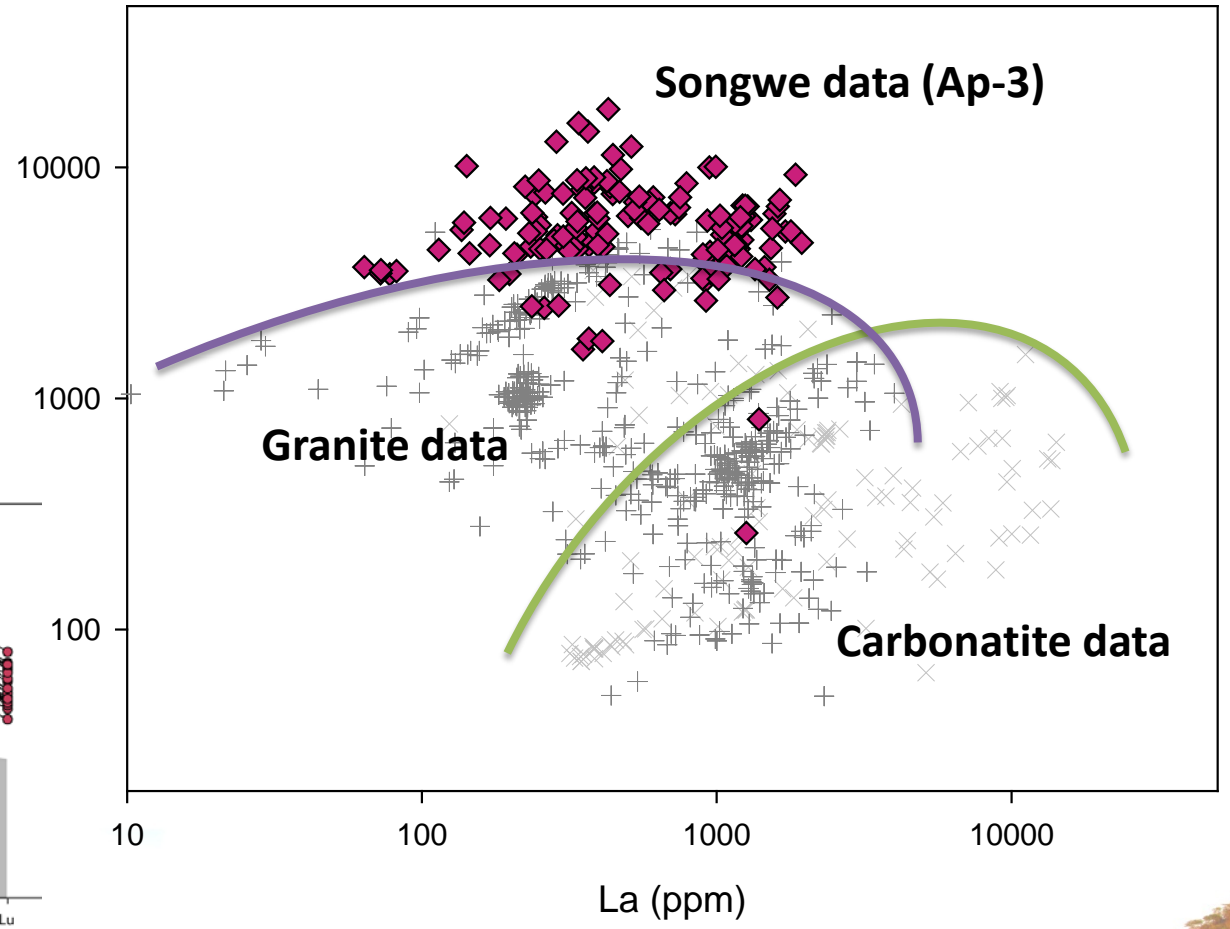
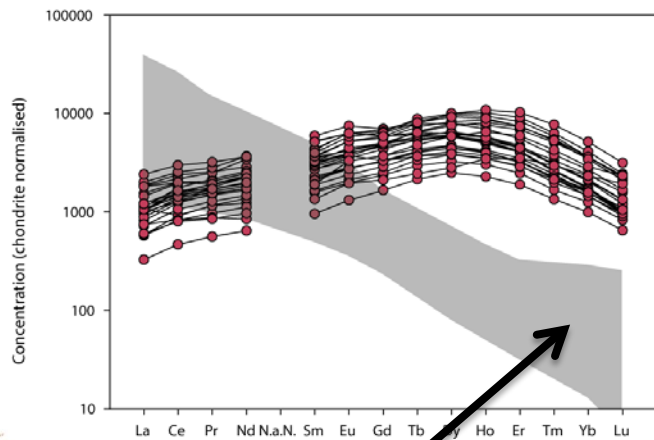


- Higher REE concentration in the later-stage ferruginous-calcite-carbonatite (as could be expected)

- Correlation between **P₂O₅** and **Y** in all lithologies
- Evidence apatite (Ca₅(PO₄)₃F) is the control on the HREE concentration

LA-ICPMS of apatite confirms M/HREE-enrichment

- Y concentration of **fluorapatite** from Songwe is higher than data from other carbonatites and granites



Typical carbonatite

Data compiled from 24 different published studies

Why is apatite M/HREE-enriched?

Questions:

- What is the **paragenesis** of the apatite at Songwe?
- At which **temperature** did crystallisation take place?
- What is the **source of the crystallising fluid**? Is it meteoric or magmatic?

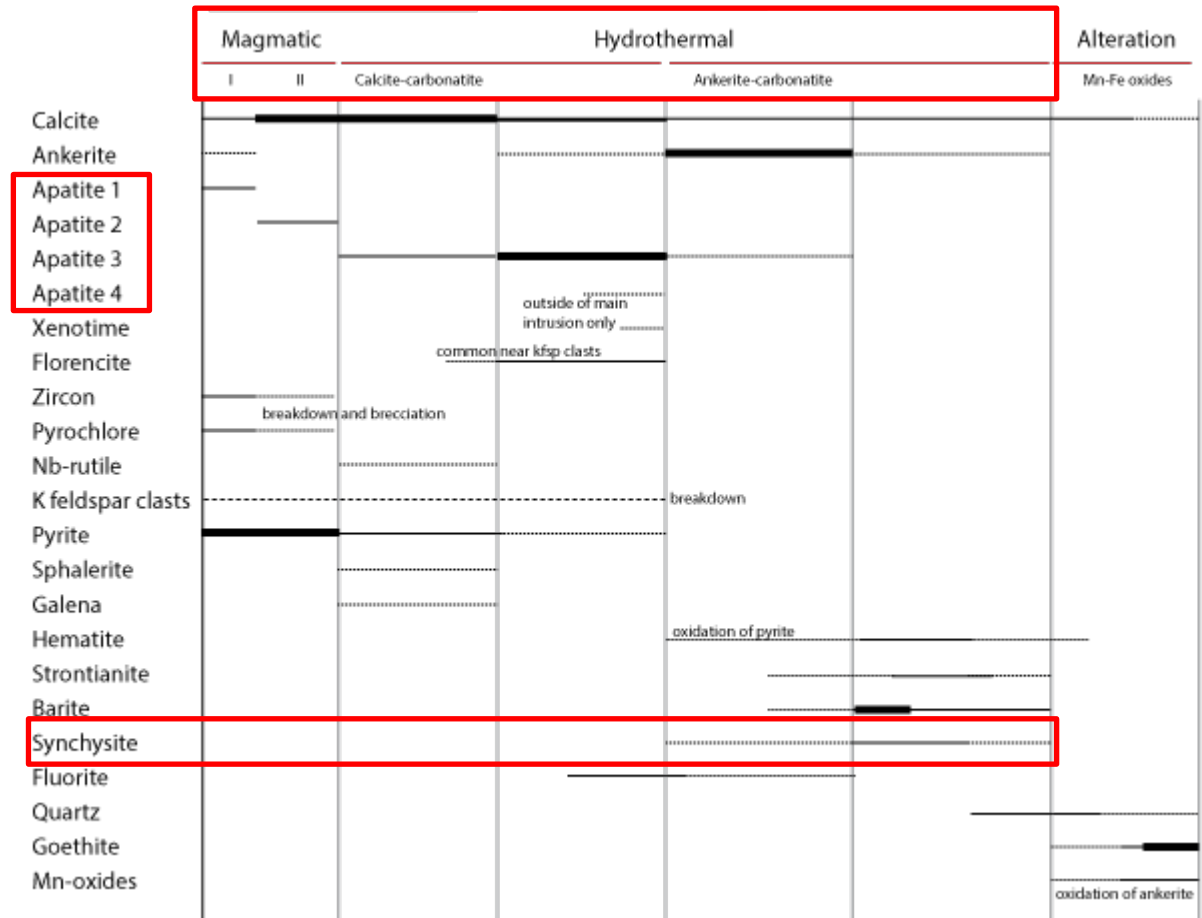
Techniques:

- Detailed **mineralogy**, coupled with laser ablation data
- Fluid inclusion analyses
- **O and C** isotope analyses of **carbonates** and **apatite**

Also see talk by Safaa Al-Ali, next...

Songwe Paragenesis

- 3 main carbonatite stages
 - Magmatic**
 - Hydrothermal**
 - Alteration
- Hydrothermal stage subdivided into
 - Calcite rich
 - apatite**
 - Ankerite rich
 - synchysite**
- Apatite occurs in 4 stages
 - Ap 1, 2 – magmatic**
 - Ap 3,4 hydrothermal**

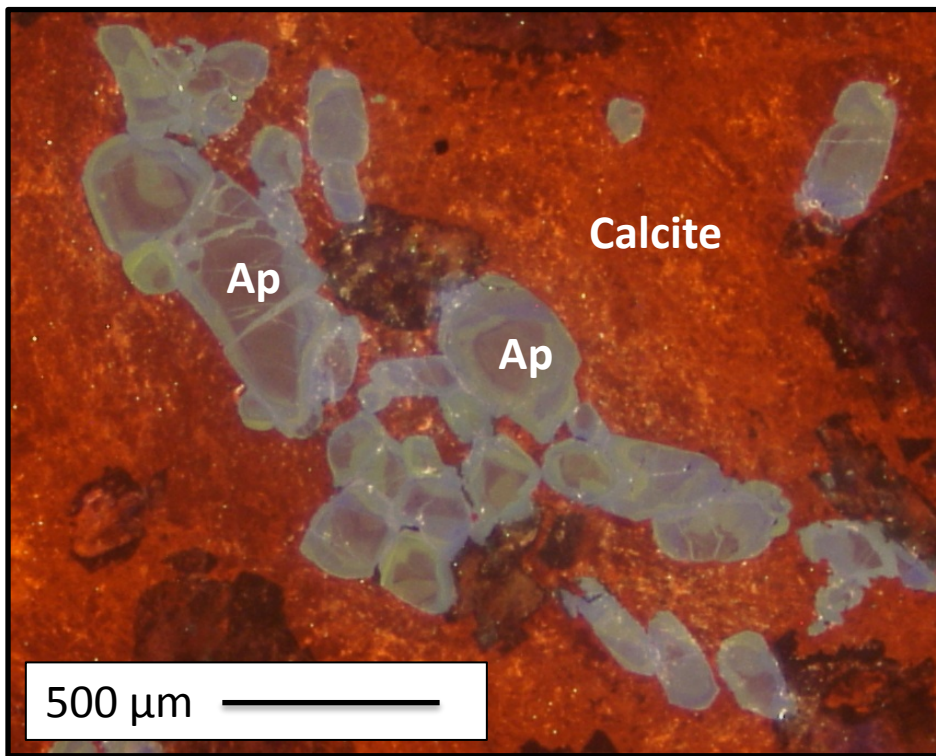


How does the apatite vary with the paragenesis?...

Earliest Songwe Apatite (Ap-1)

Medium-grained, calcite carbonatite

Isolated occurrences in breccia

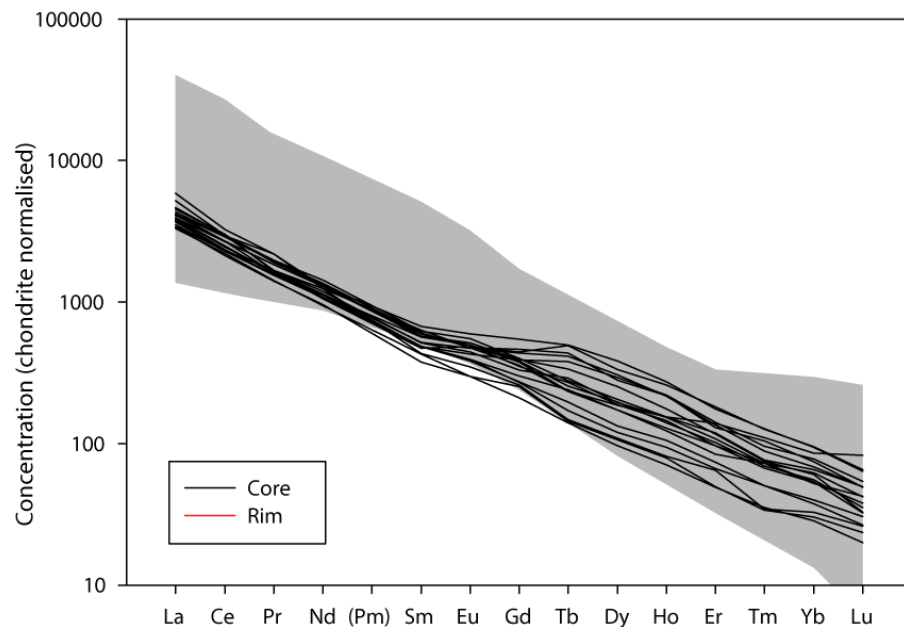


Apatite habit

lozenge shaped, **eu-subhedral**

Similar to typical carbonatite apatite

Laser ablation data, compared with data from other carbonatite-apatite



Apatite chemistry

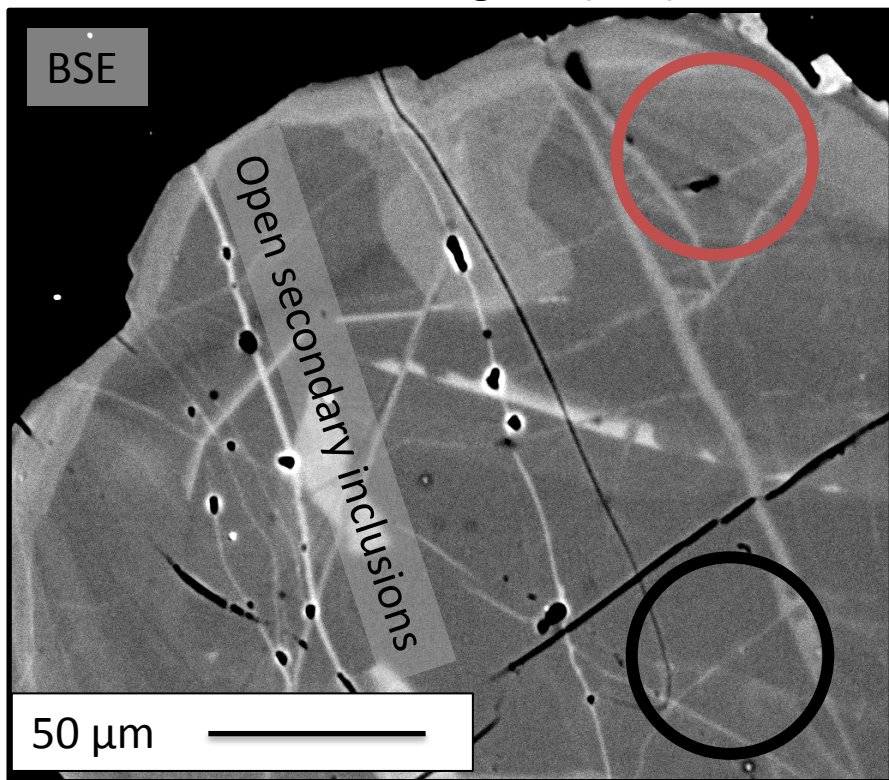
LREE Rich, around 3 % REO substituting

High Sr, low Mn

Normal for igneous apatite

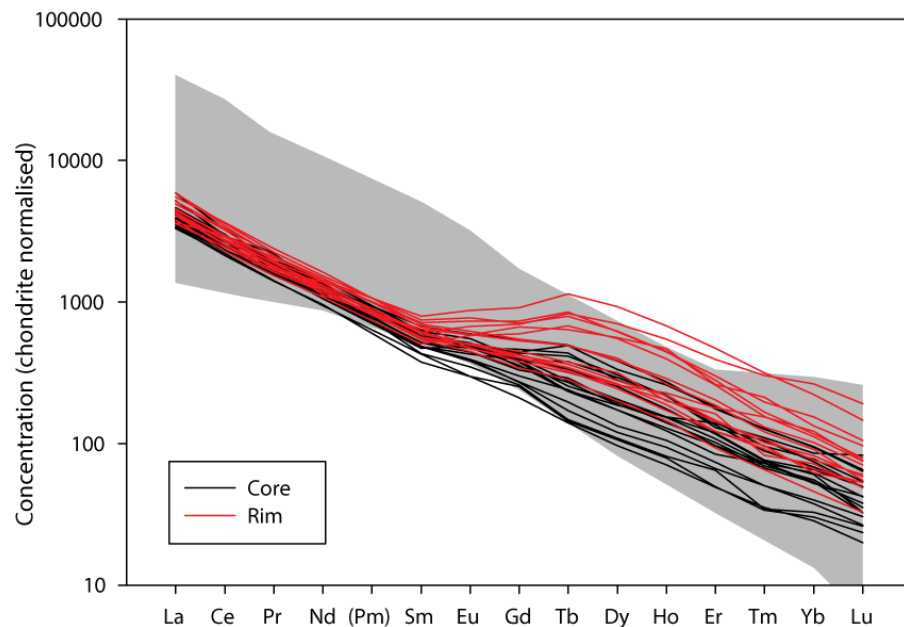
Earliest Songwe Apatite (Ap-2)

Closer look at an ovoid grain (BSE)



Apatite habit:
Zoned and fractured
Inclusions are rare

Laser ablation data, compared with data from other carbonatite-apatite



:REE distribution
Slight **Dy enrichment on rim**

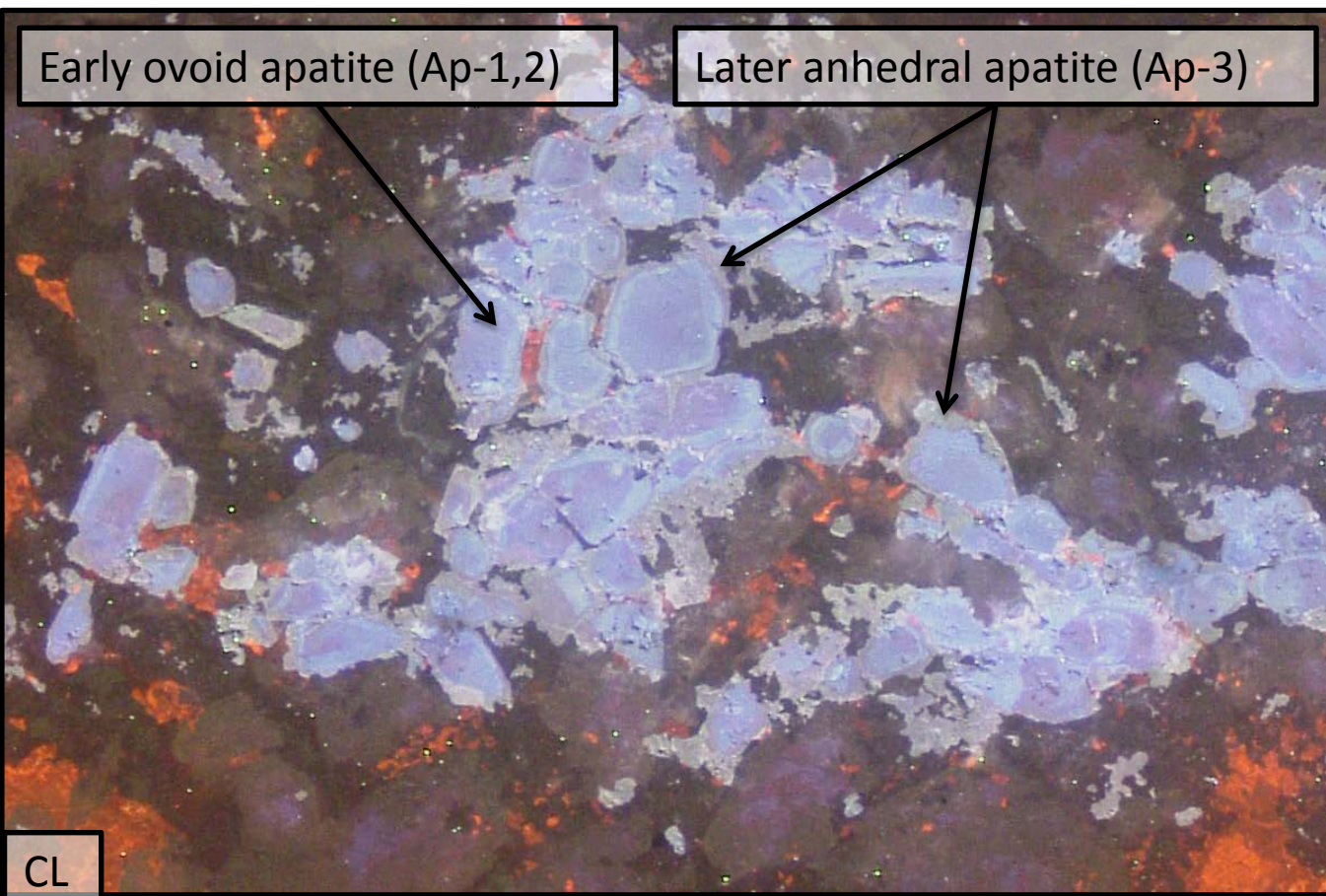
First signs of HREE enrichment at Songwe

Magmatic—Hydrothermal apatite (Ap1,2—Ap-3)

Early ovoid apatite (Ap-1,2)

Later anhedral apatite (Ap-3)

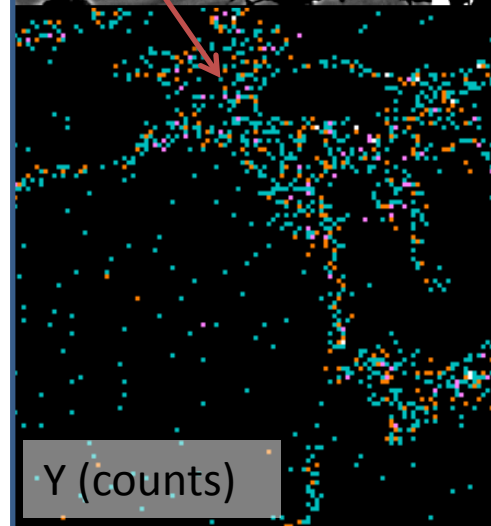
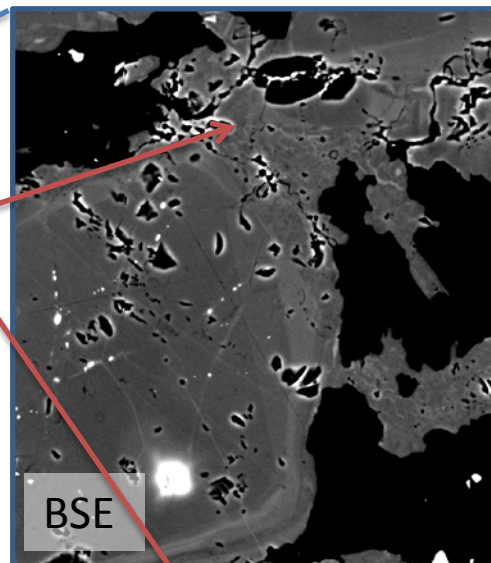
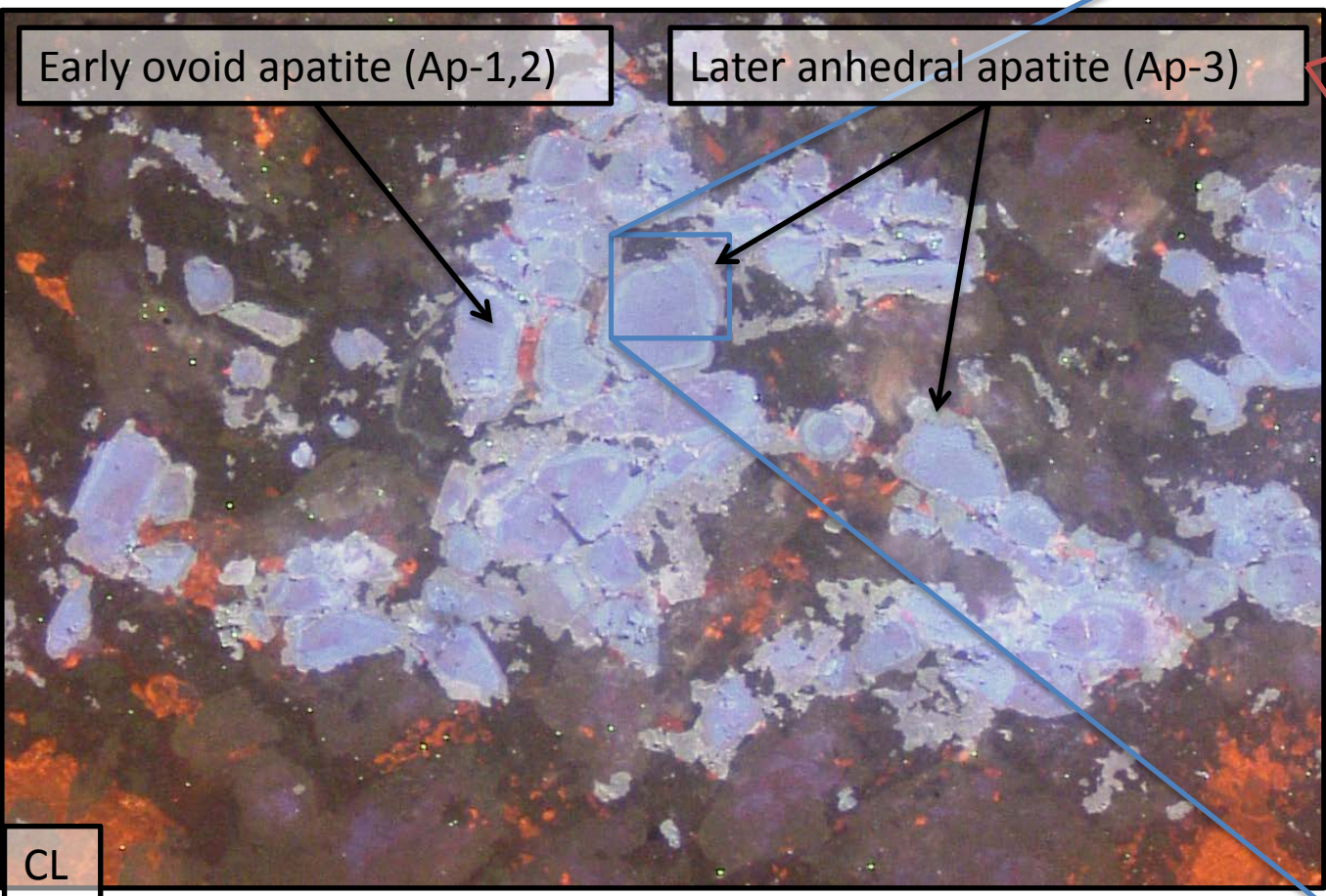
Transition to
non-magmatic
textures



CL

500 μm

Magmatic—Hydrothermal apatite (Ap1,2—Ap-3)



500 μm

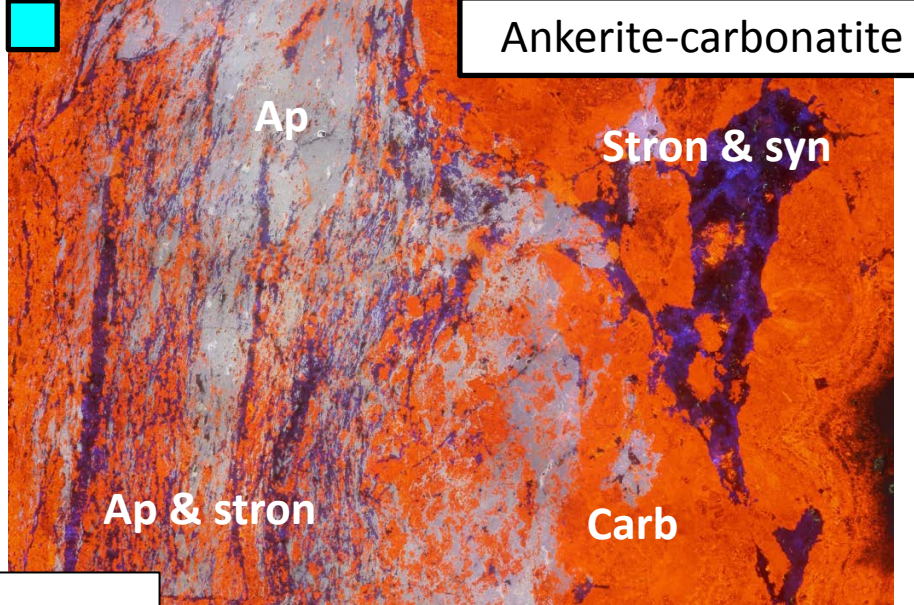
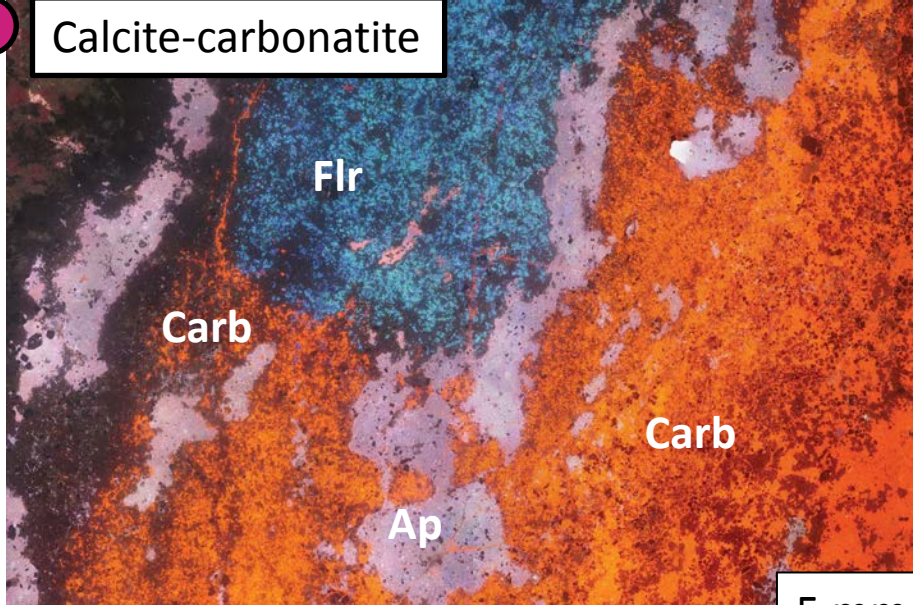
Later apatite is more Y-rich

50 μm

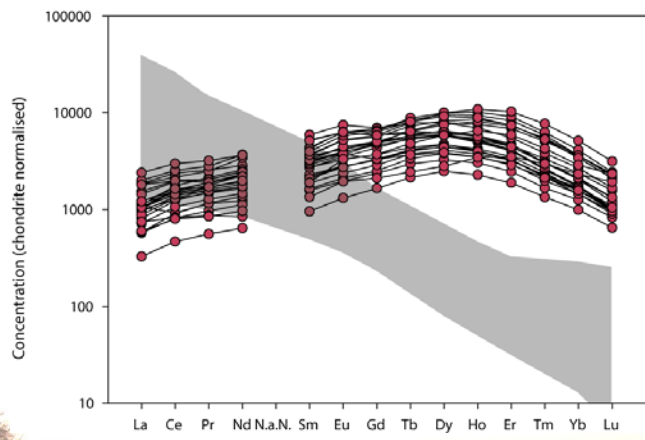
Hydrothermal apatite (Ap-3)



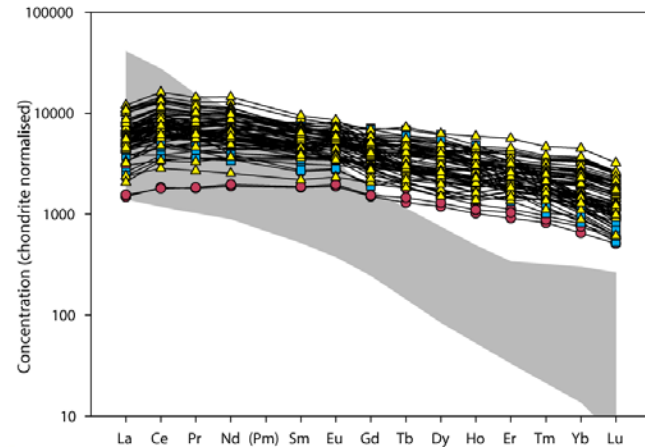
Calcite-carbonatite



5 mm ———

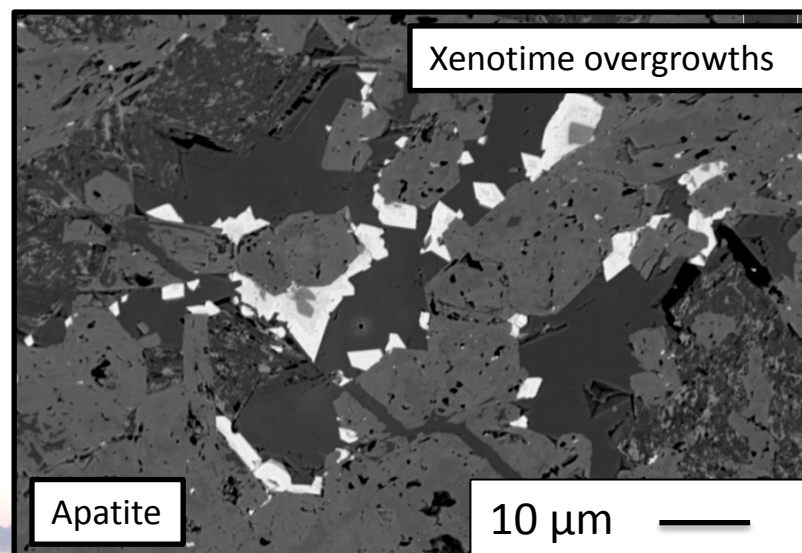
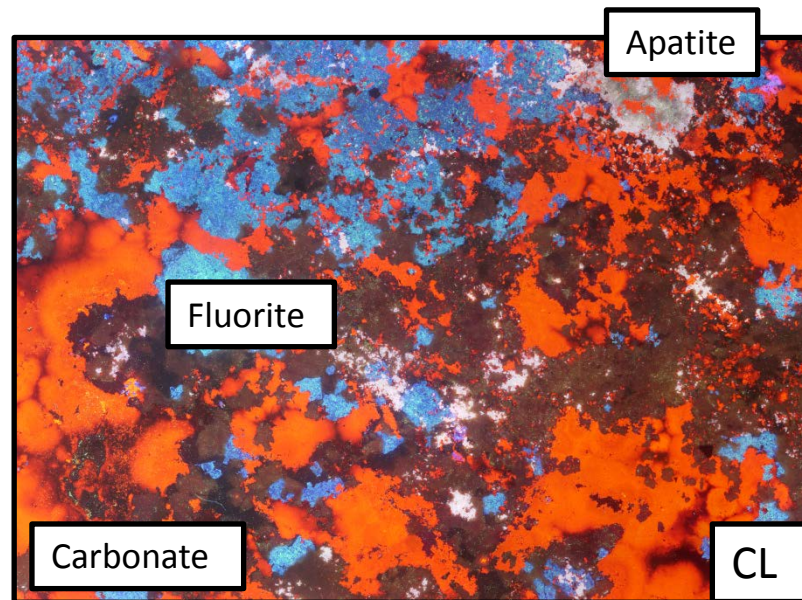
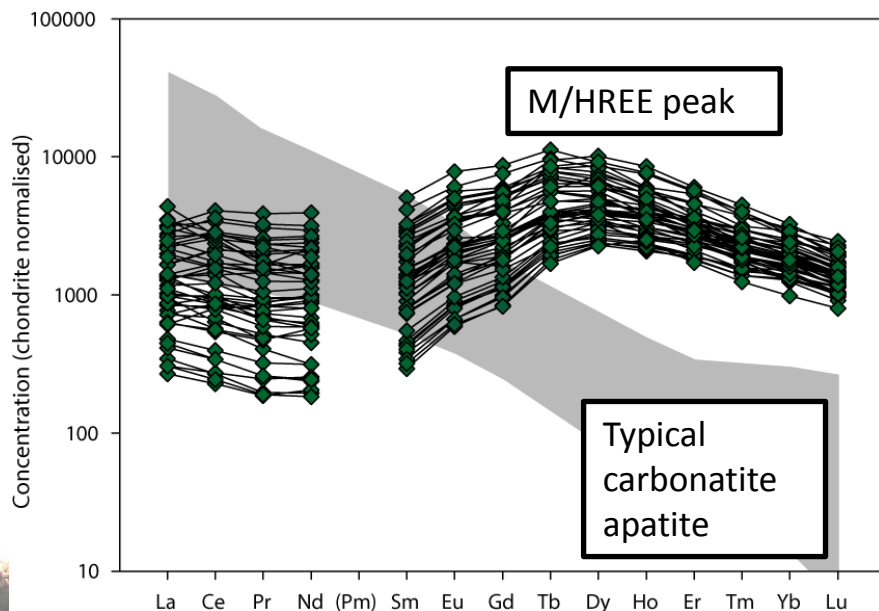


- Most common apatite type at Songwe
- Stringers, anhedral, banded
- Same apatite habit in all carbonatite types
- Different REE distributions

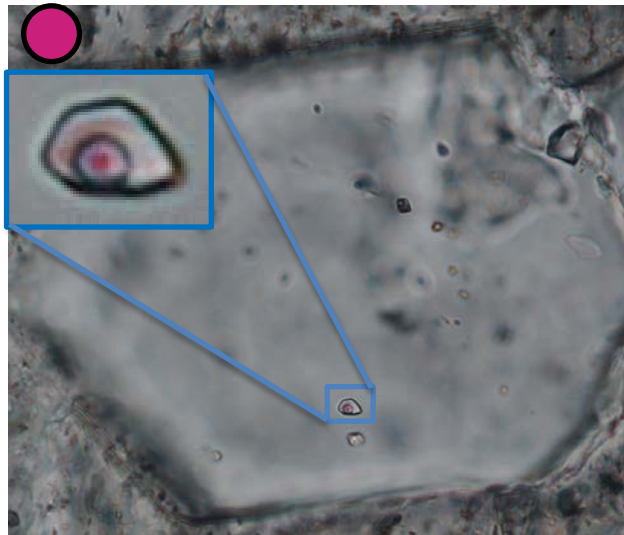


Hydrothermal apatite Ap-4

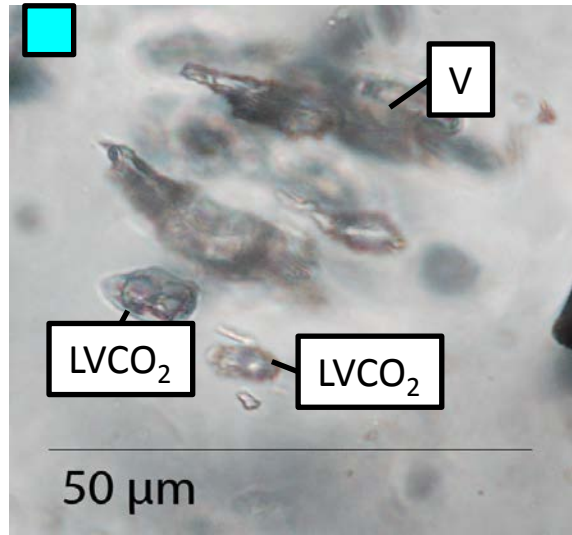
- Found outside the main carbonatite body
- Abundant fluorite
- Very HREE-rich
- Xenotime overgrowths



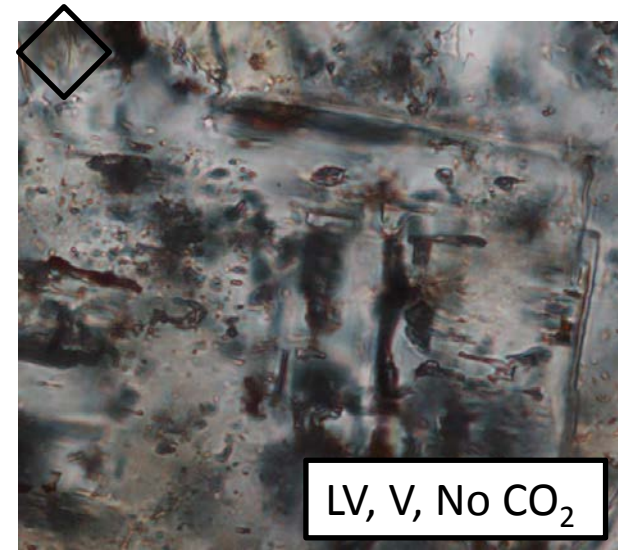
Apatite crystallisation temperature



Ap-1



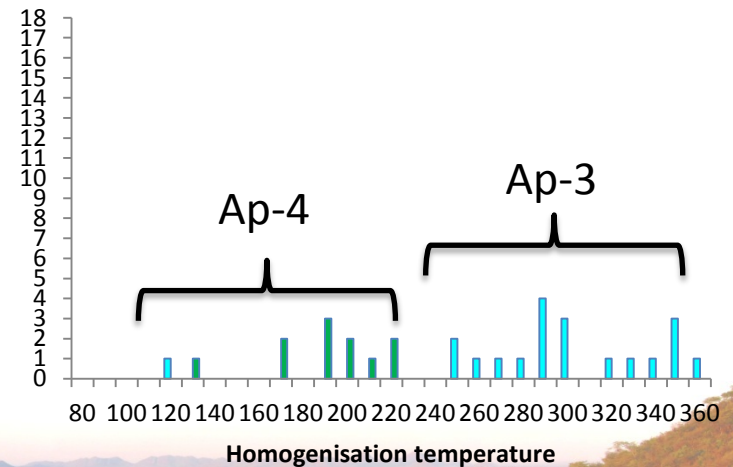
Ap-3



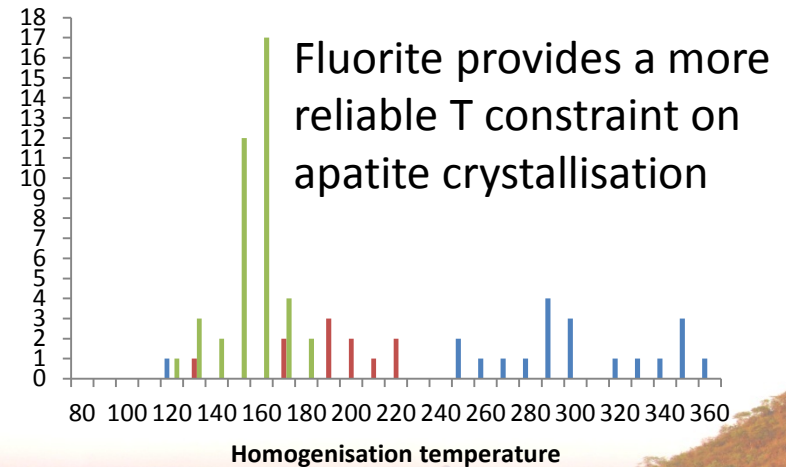
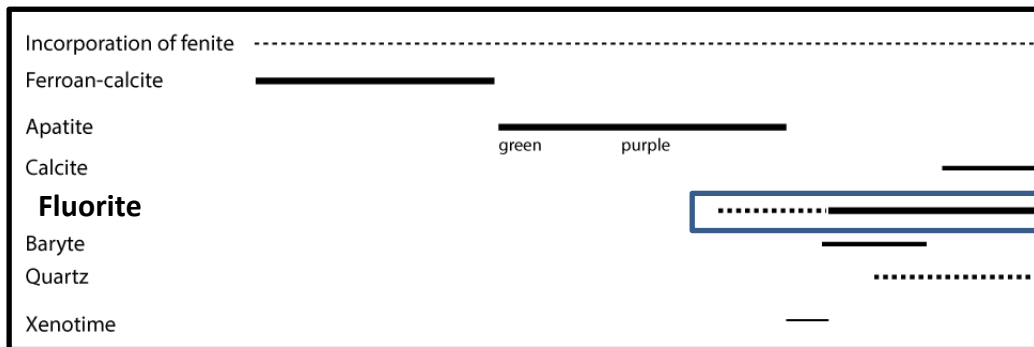
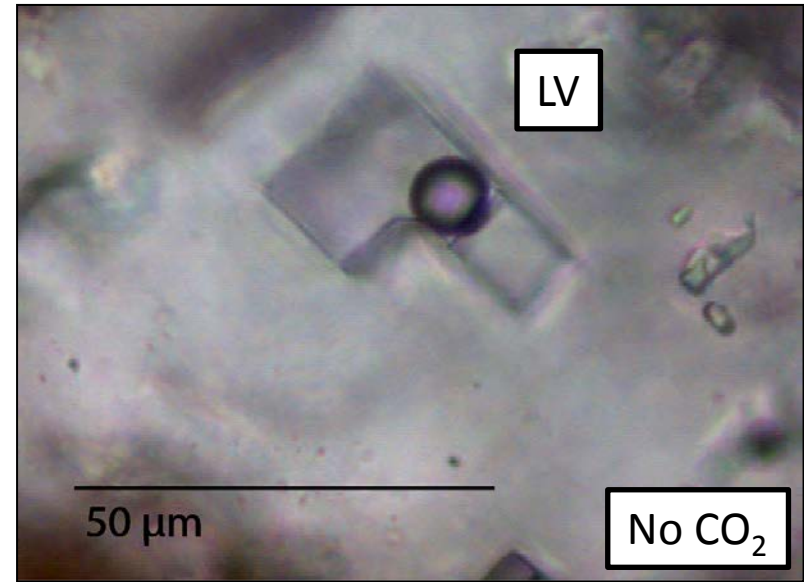
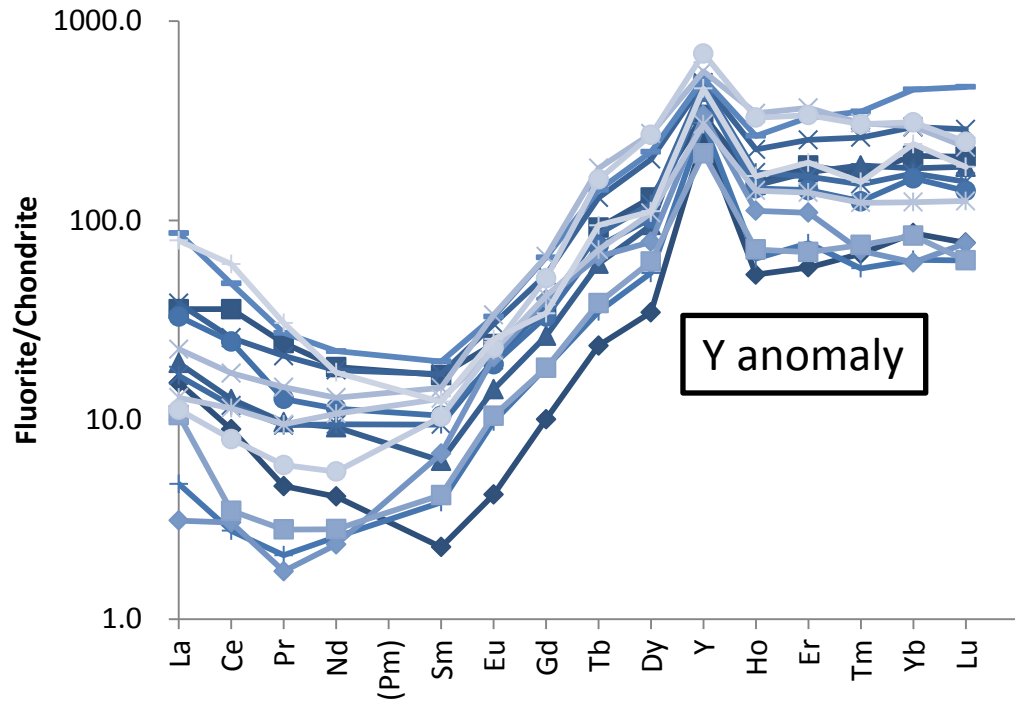
Ap-4

Increasing inclusion abundance
 Decreasing T
 Decreasing CO₂ (?)

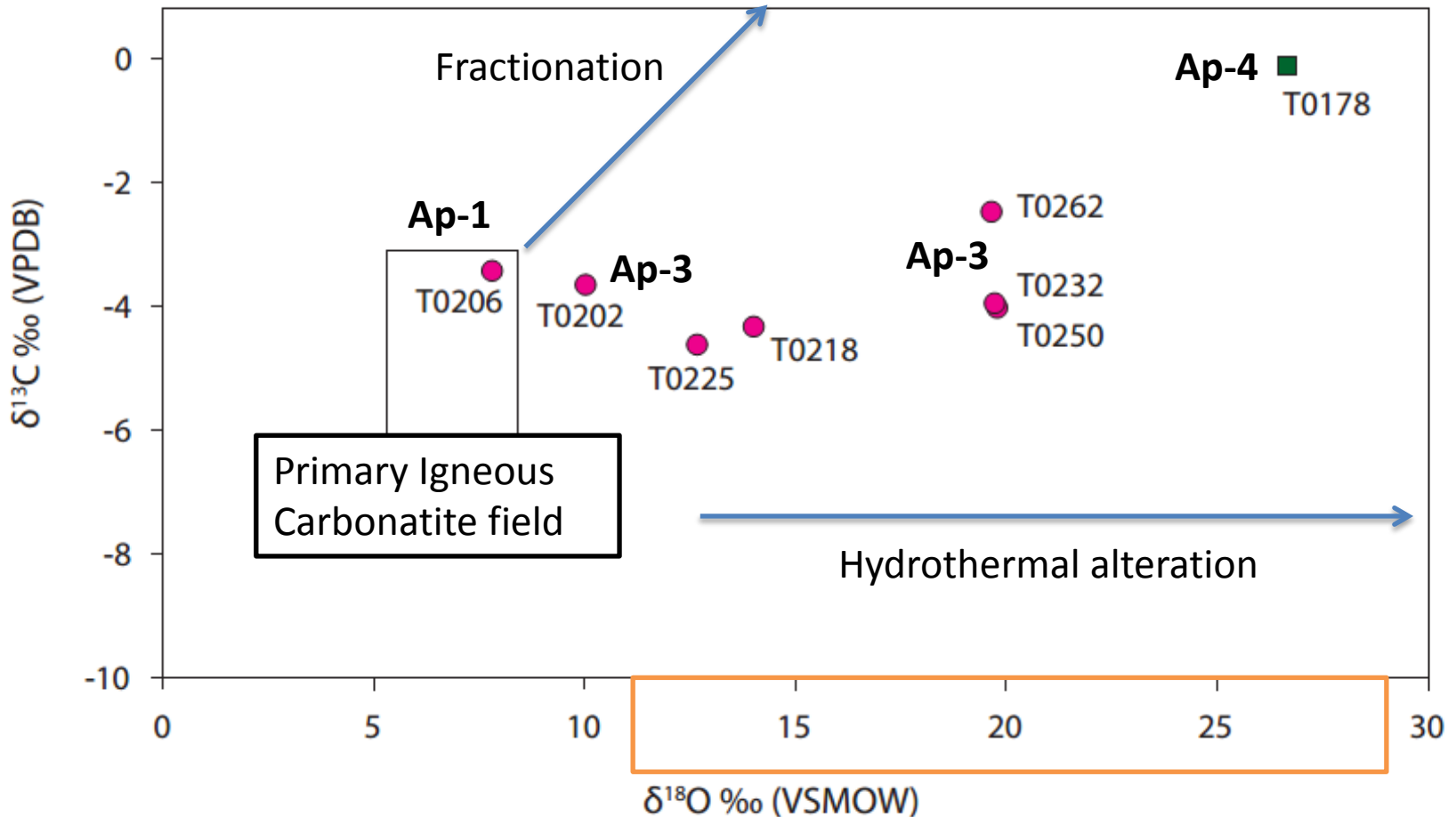
- Mostly LV inclusions
- Lower T
- Many open, hard to analyse
- Small data set, wide spread of Th



Fluorite – post apatite



Stable isotope evidence for hydrothermal alteration - carbonates



Carbonate isotope data indicates a hydrothermal influence --- meteoric or deuteric?

Stable isotope evidence for hydrothermal alteration - apatite

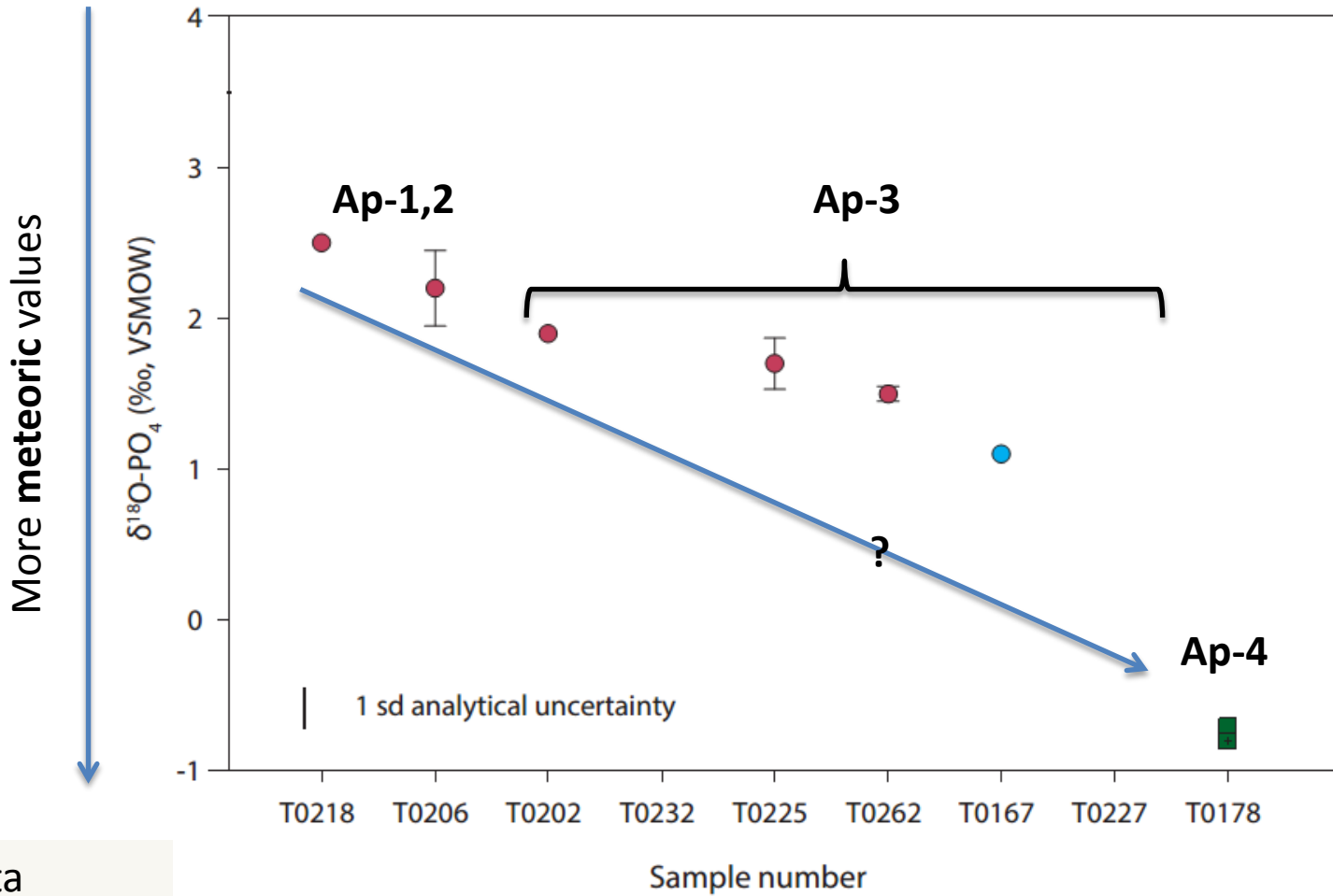
New isotope data – in collaboration with NIGL, UK

Apatite:

Not influenced by diffusion

Records conditions during REE mineralisation

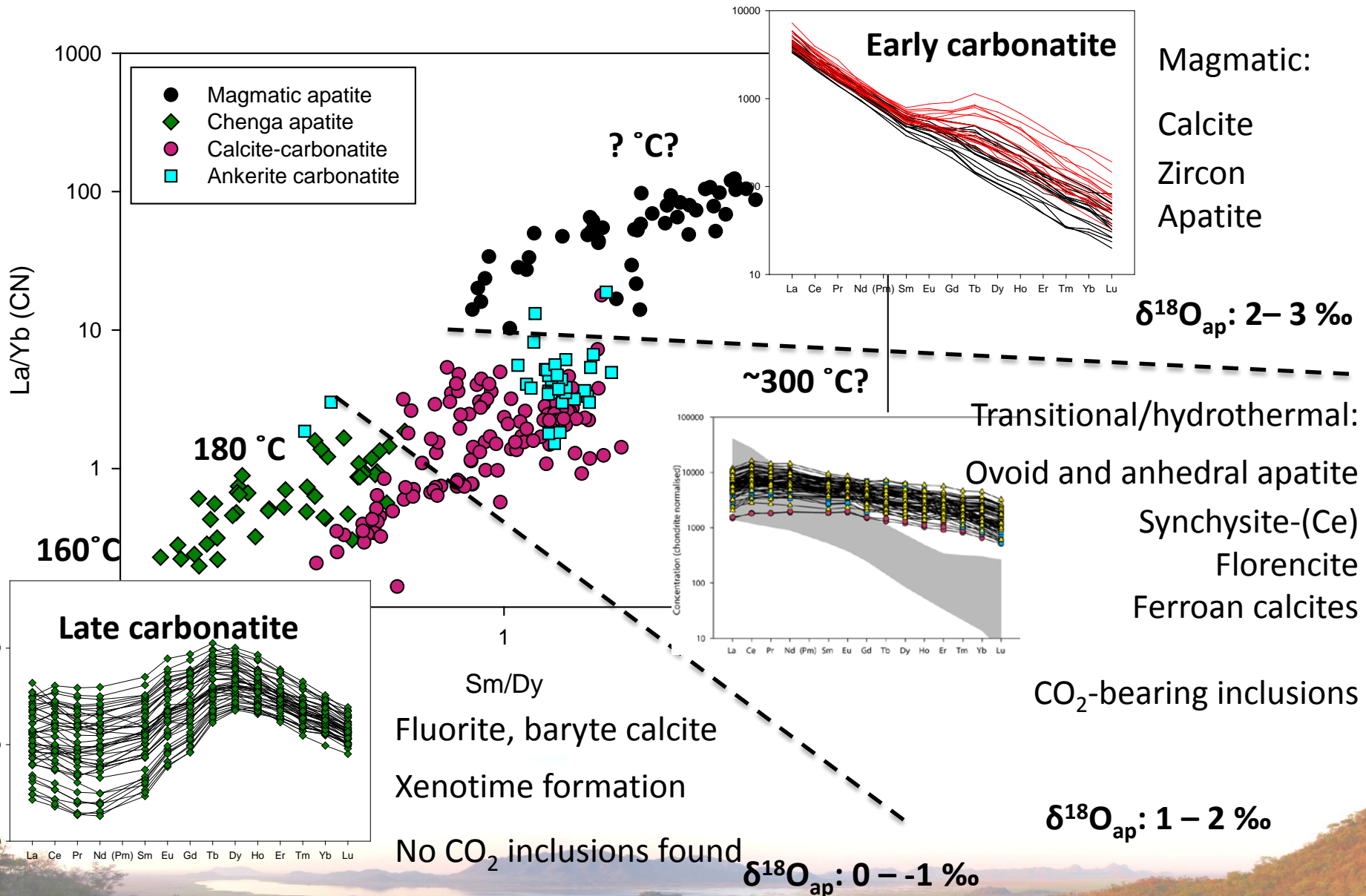
Apatite isotope data suggests a **meteoric influence**



Sample number

Paragenesis

Trends in REE concentration



Conclusions

Questions:

- What is the **paragenesis** of the apatite at Songwe?
- At which **temperature** did crystallisation take place?
- What is the **source of the crystallising fluid**? Is it meteoric or magmatic?

Answers:

- Complicated! But dominantly **anhedral and hydrothermal**. Varied REE distribution
- Uncertain, but limited FI data suggests low-T, but **above 160 °C**
- Isotope data suggest interaction with **meteoric water** caused crystallisation