



HOLLY ELLIOTT, SAM BROOM-FENDLEY, FRANCES WALL

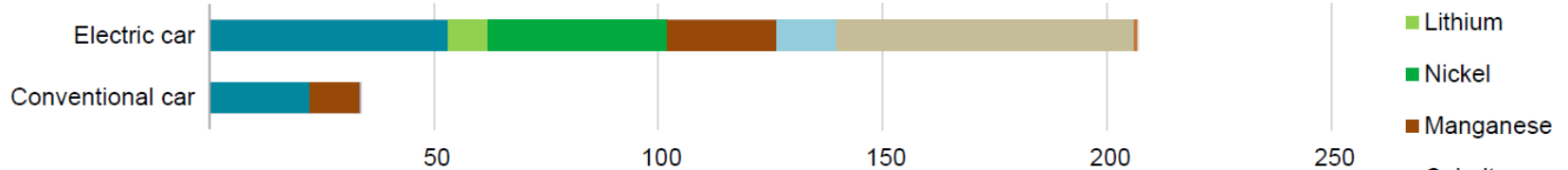
# Fertility indicators for carbonatite-hosted REE deposits



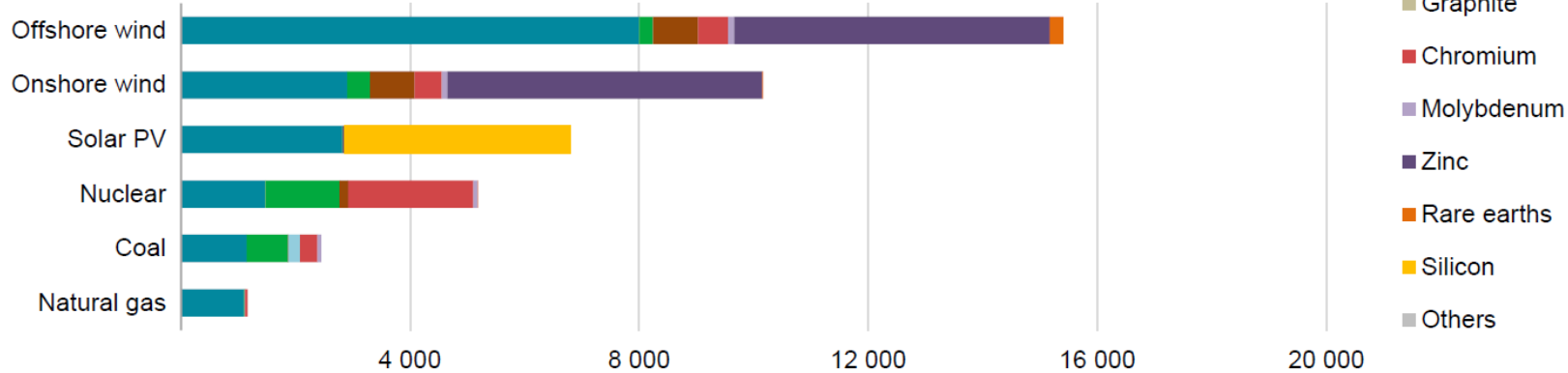
# CRM for the Energy Transition

Minerals used in selected clean energy technologies

## Transport (kg/vehicle)



## Power generation (kg/MW)



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# Rare earth elements

## Technological Advancements



## Green Technologies





# REE Sources: Carbonatites

Nkalonje, Malawi



Songwe Hill, Malawi



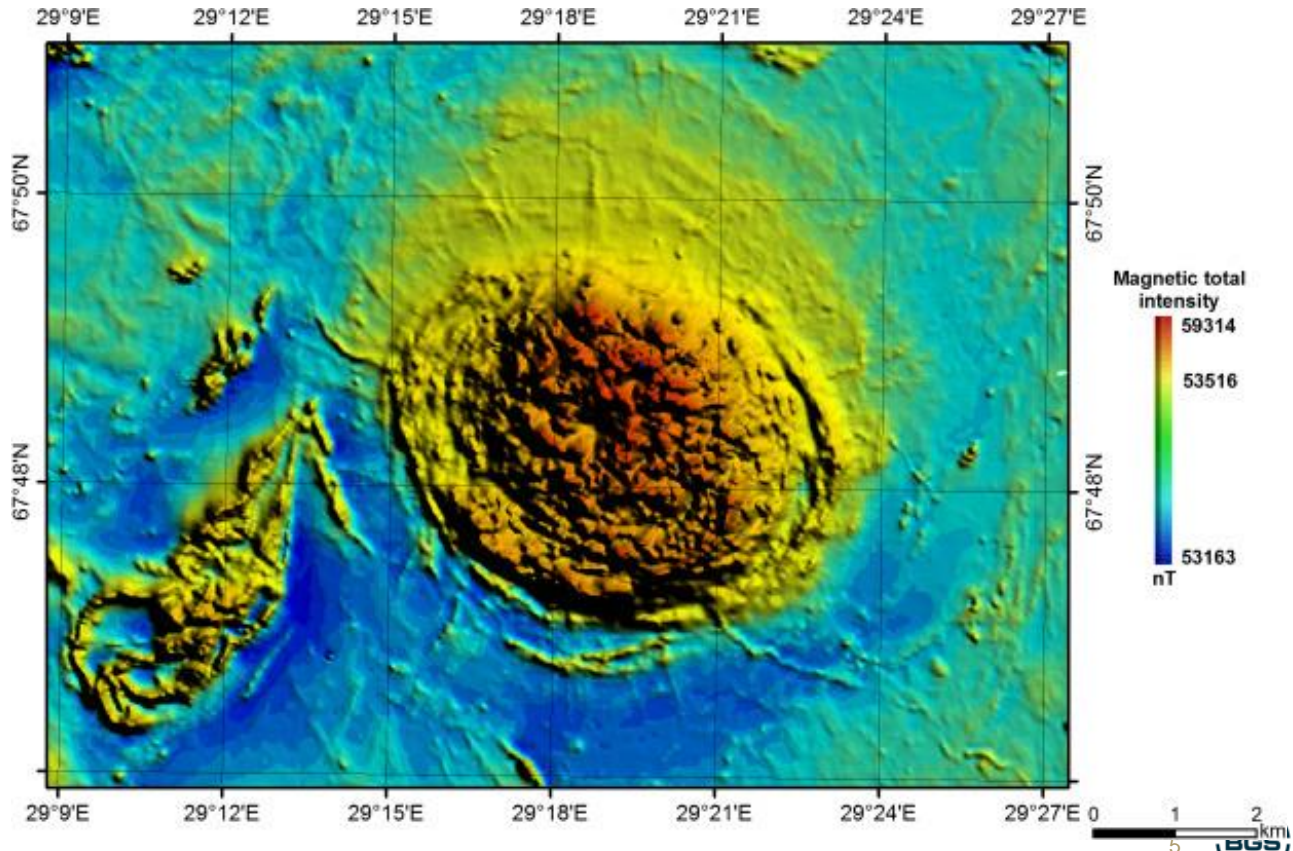
Tundulu, Malawi



Oldoinyo Lengai, Tanzania

# Exploration: magnetic surveys

- Carbonatites rich in magnetite
- Create positive magnetic anomaly
- Release oxidising fluids
- Magnetite -> hematite
- Fenite forms negative magnetic anomaly



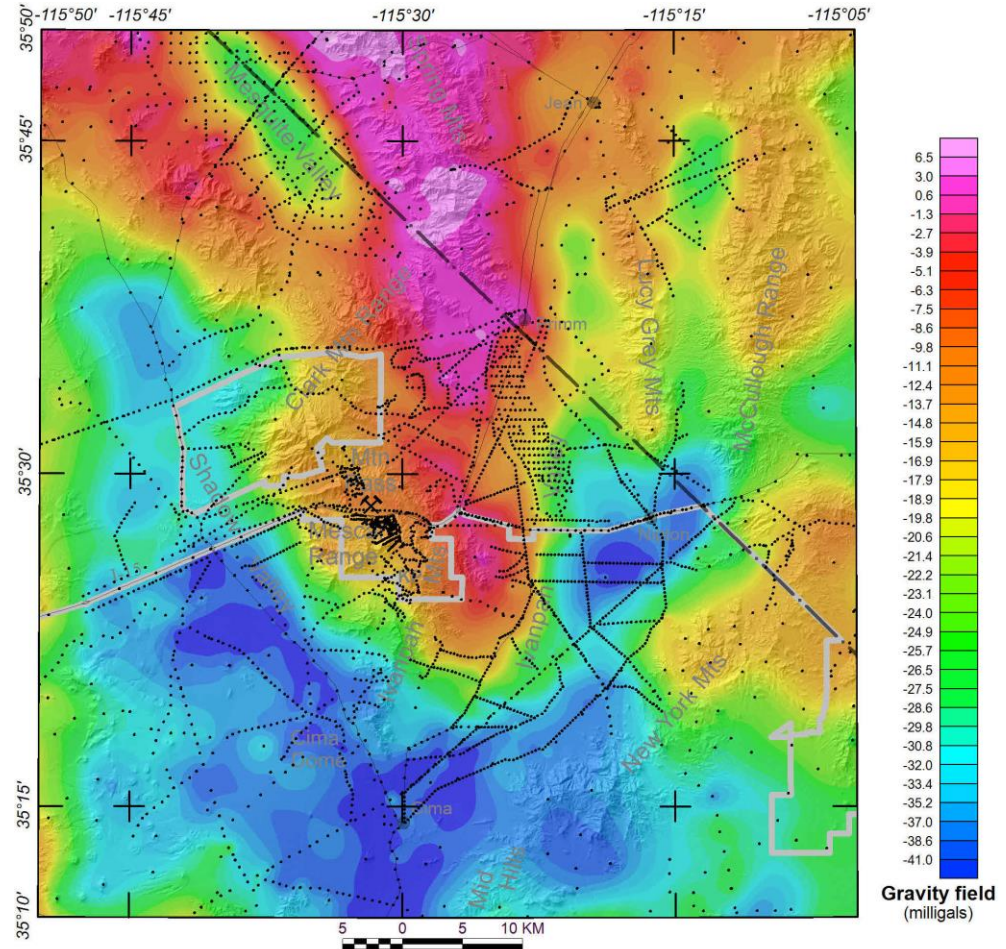
Source: Geological Survey of Finland – Sokli, Finland



# Exploration: gravity surveys

- Carbonatite average density:  $2.6 \text{ gcm}^{-3}$
- Granite average density:  $2.64 \text{ gcm}^{-3}$
- Requires density contrast
- Dependent on host rock
- Many intrude metamorphic terrains with average density of  $2.77 \text{ gcm}^{-3}$

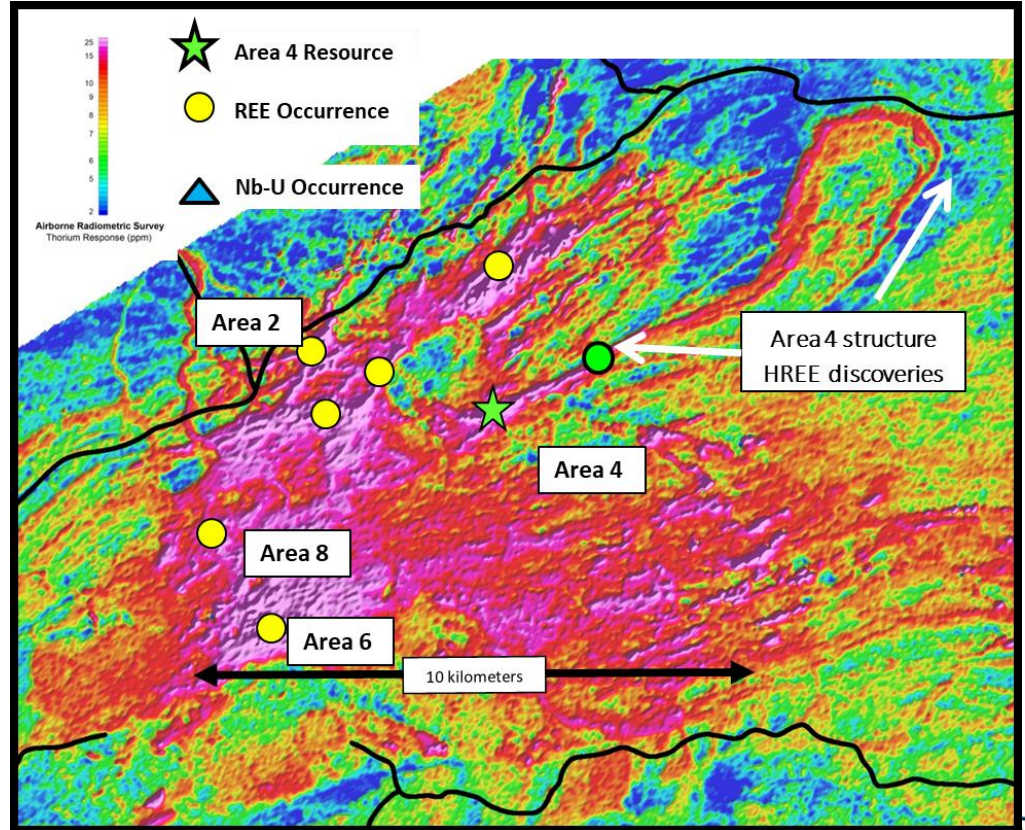
Source: Denton and Ponce (2016) –  
Mountain Pass, USA



# Exploration: radiometric surveys

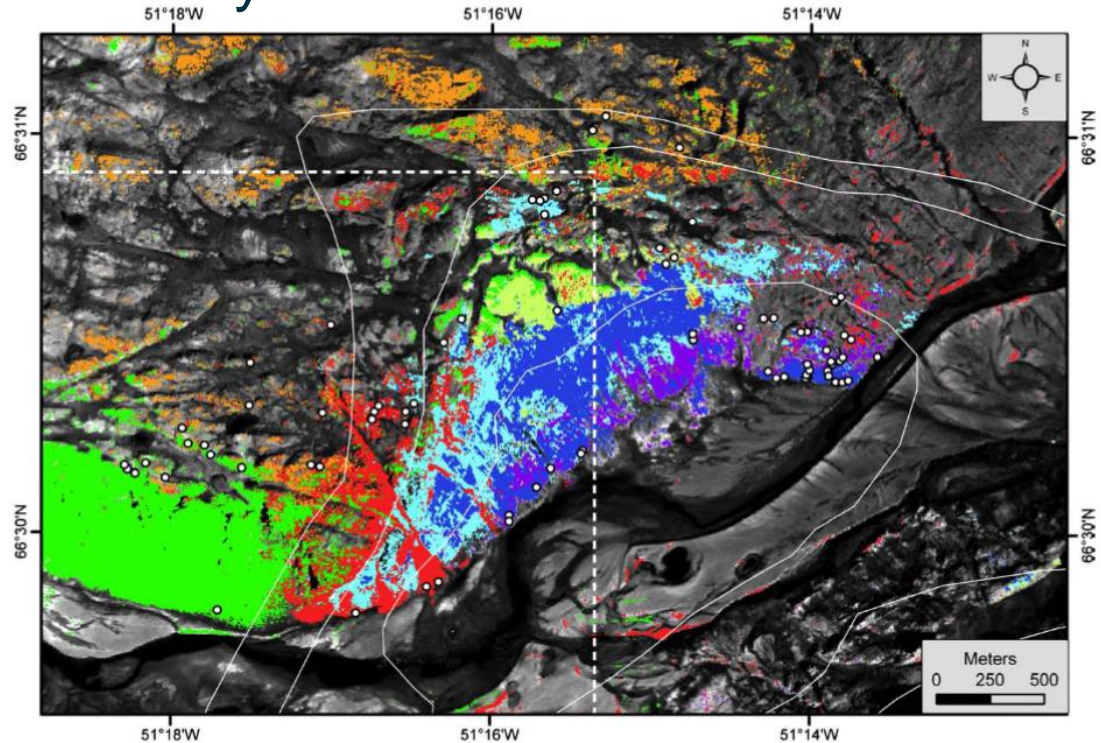
- U & Th often concentrated in REE deposits
- Monazite is Th rich
- K found in surrounding fenite

Source: Namibia Rare Earths Ltd –  
Lofdal, Namibia Th

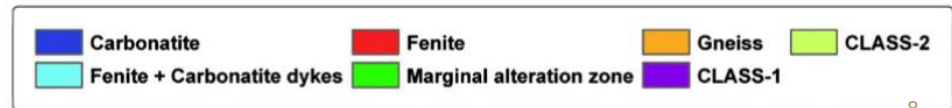




# Exploration: hyperspectral surveys



Source: Bedini (2009) – Sarfartoq carbonatite, W. Greenland





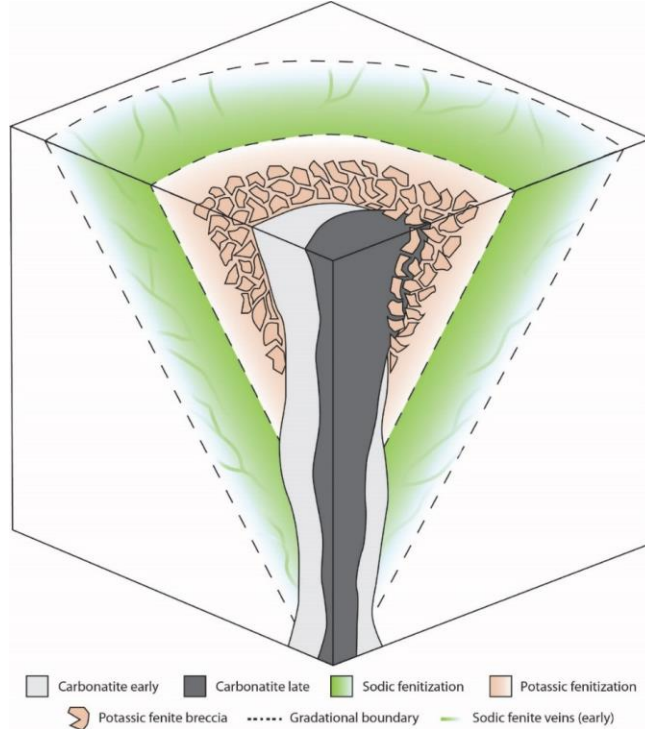
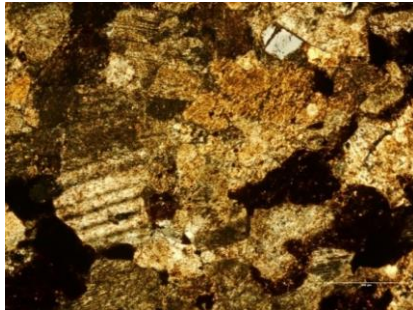
# Exploration: fenite vectoring

Metasomatically altered aureoles of country rock, extend <2km

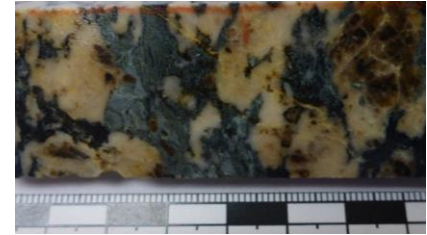
Potassic



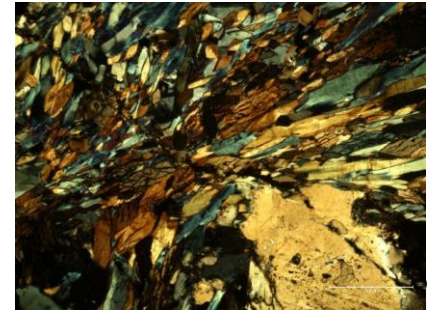
Chenga, Malawi



Sodic



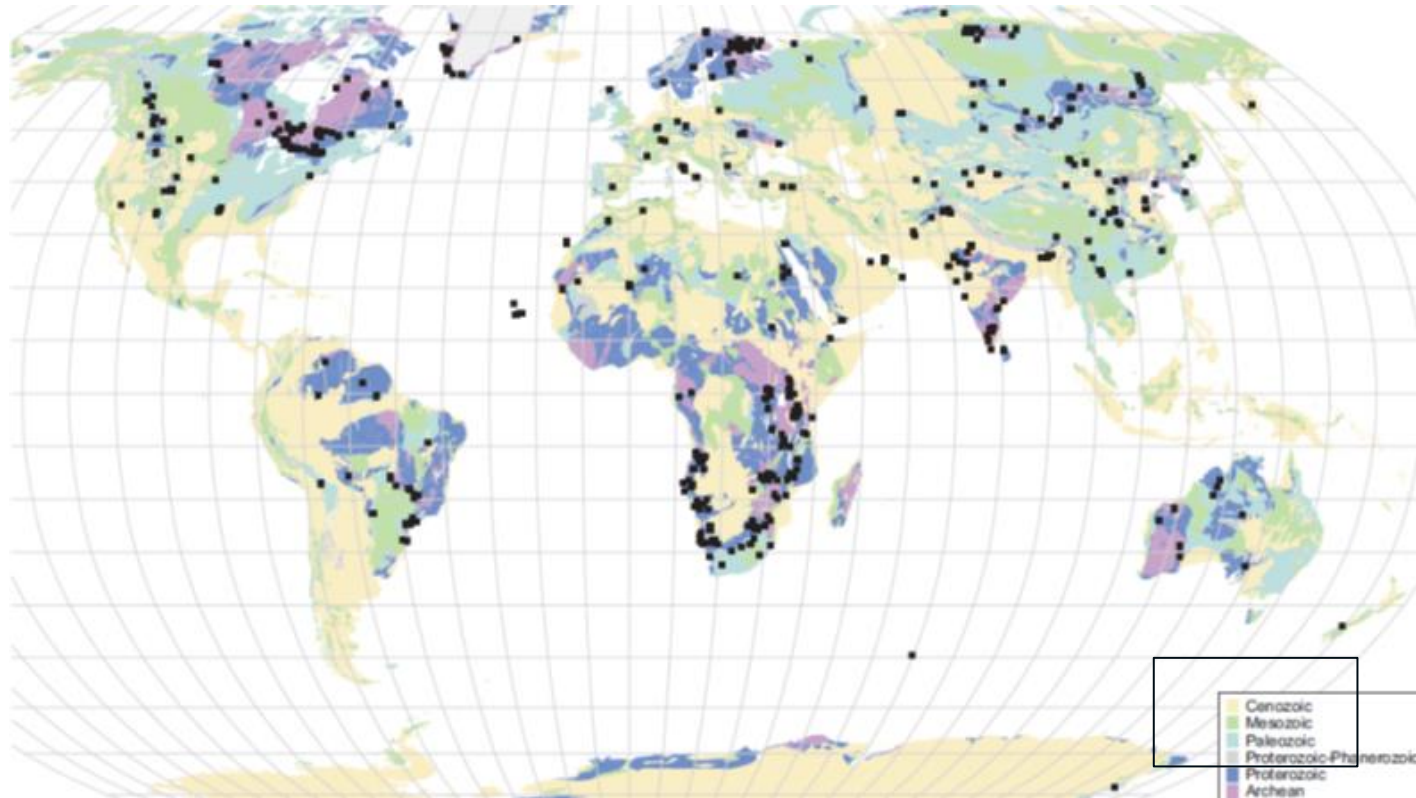
Sokli, Finland



Source: Elliott et al. (2018)

# Carbonatite occurrences

2008: 527 known occurrences



Source: Woolley, 2008



# Carbonatite occurrences

Database: [alkcarb.myrocks.info](http://alkcarb.myrocks.info)



# REE fertility indicators

REE are highly incompatible => enriched in residual liquid during magma fractionation



REE-poor



REE-rich



# REE fertility indicators

REE are highly incompatible => enriched in residual liquid during magma fractionation



REE-poor



REE-rich

# REE fertility indicators

Sokli, Finland: 3 magmatic phases – REE in late-stage Jammi dykes

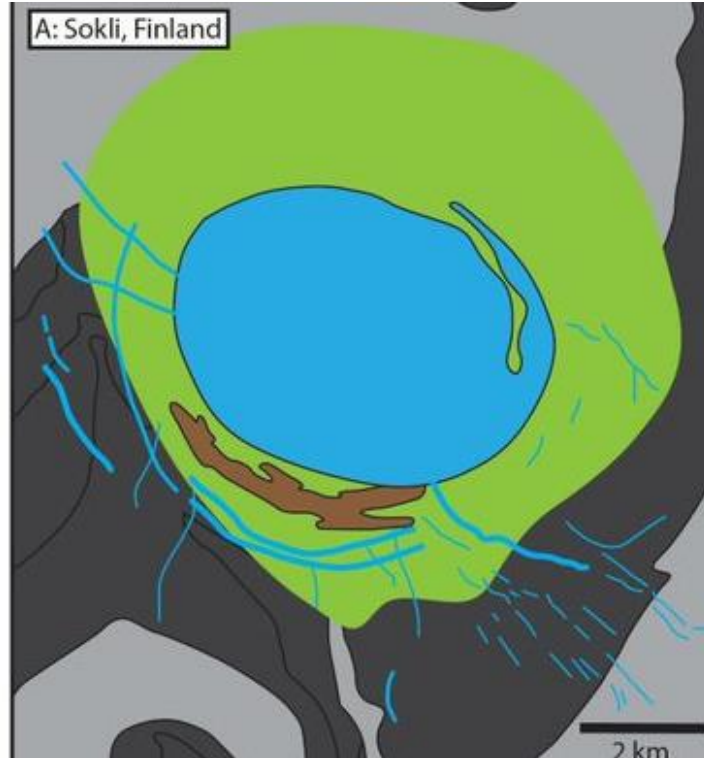
**Key:**

Igneous Complex:

- Extrusive deposits
- Syenite
- Carbonatite
- Phonolite
- Trachyte
- Essexite
- Phoscorite
- Fenite / alteration
- Diatreme breccia

Country Rock:

- Sedimentary rock
- Metamorphic rock
- Mafic to ultra-mafic rock
- Carbonate rock
- Quaternary sediments

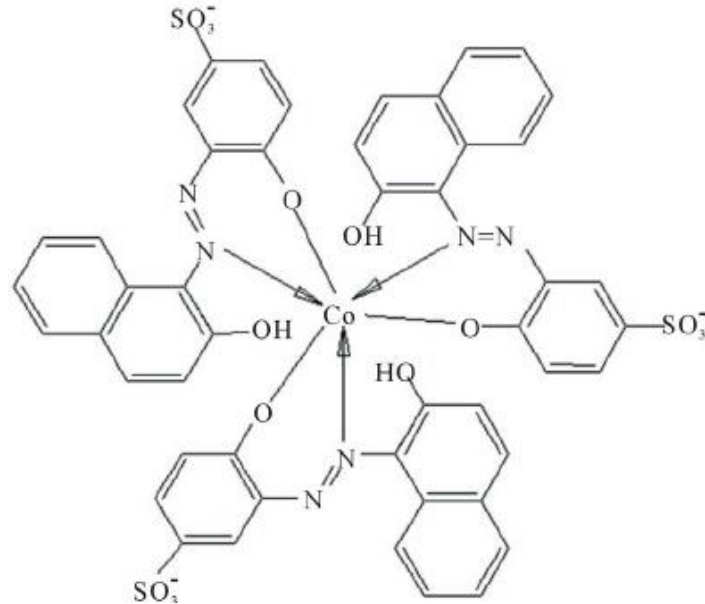
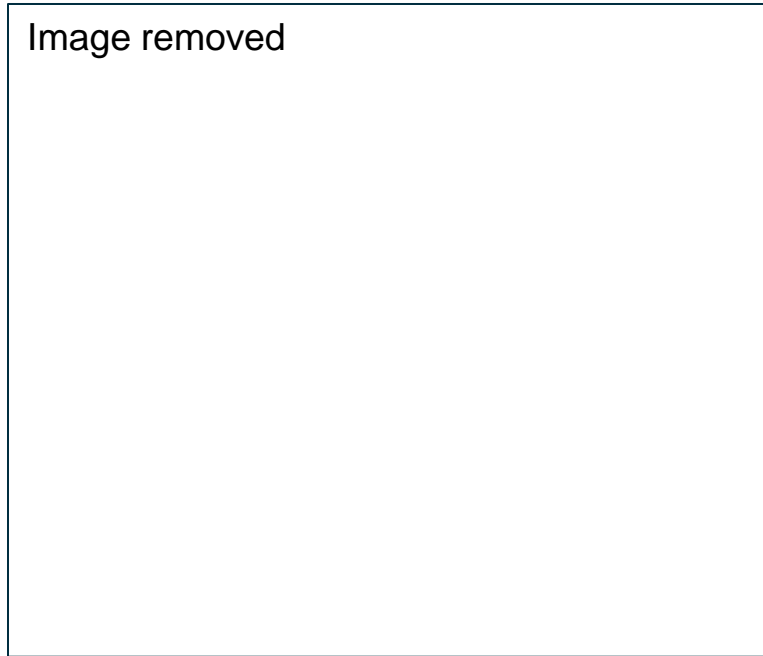


Source: Elliott et al. (In Prep)



# REE fertility indicators

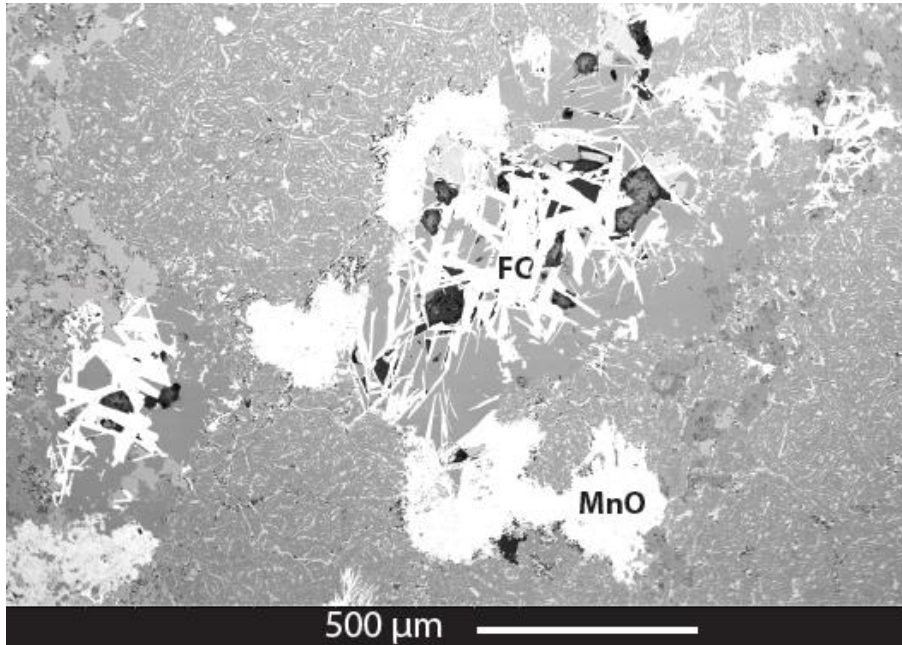
Fertilising fluids contain complexing ions e.g.  $\text{Cl}^-$ ,  $\text{F}^-$ ,  $\text{CO}_3^{2-}$ , enhancing REE and Nb solubility.



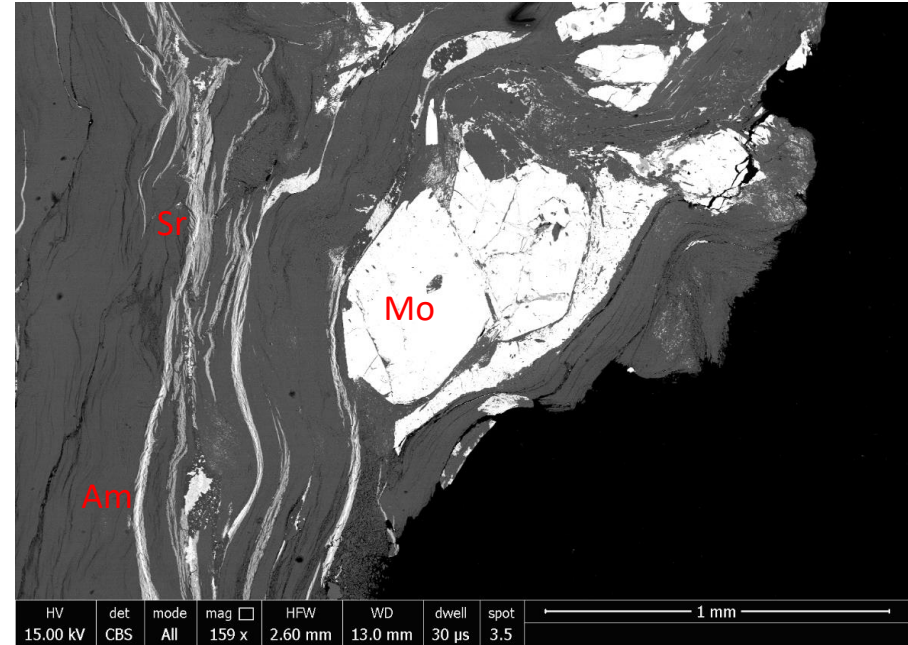
Source: Elliott et al. (In Prep)

# REE fertility indicators

REE precipitate in the fenite as REE-enriched micro mineral assemblages.



Synchysite:  $\text{CaCe}(\text{CO}_3)_2\text{F}$



Monazite:  $(\text{REE})\text{PO}_4$

Source: Holly Elliott



# REE fertility indicators

50  $\mu\text{m}$

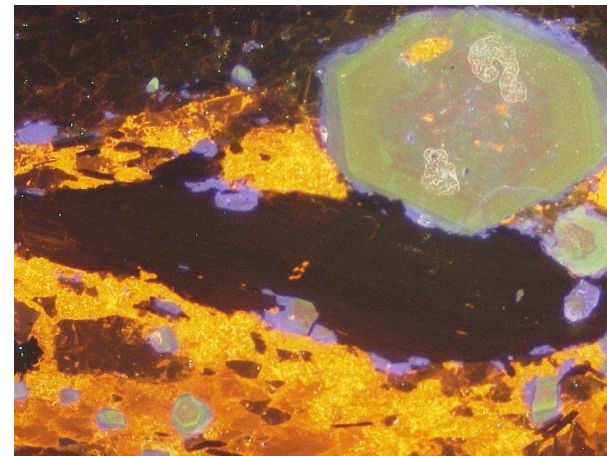
REE-Rich

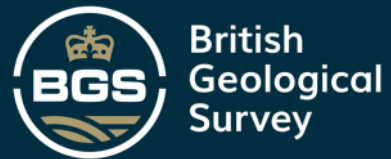
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REE-Poor

# Summary

- Energy transition requires increased CRM demand
- Carbonatites are significant REE source
- Well established exploration strategy
- Alteration (fenite) can be used as vectoring tool
- Fertility indicators can determine REE potential early:
  - Late-stage, Fe-rich
  - REE-enriched micro mineral assemblages
  - CL apatite zoning
  - Apatite chemistry (Y-Sr)
- Hydrothermal remobilisation can concentrate HREE





THANK YOU

Any questions?

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