Revisiting mantle sources for Ni sulfide deposits

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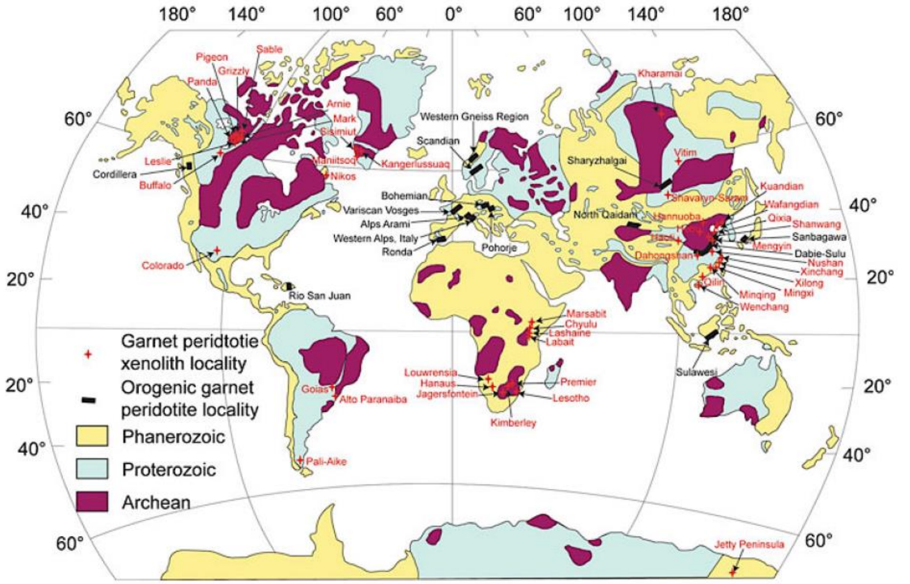
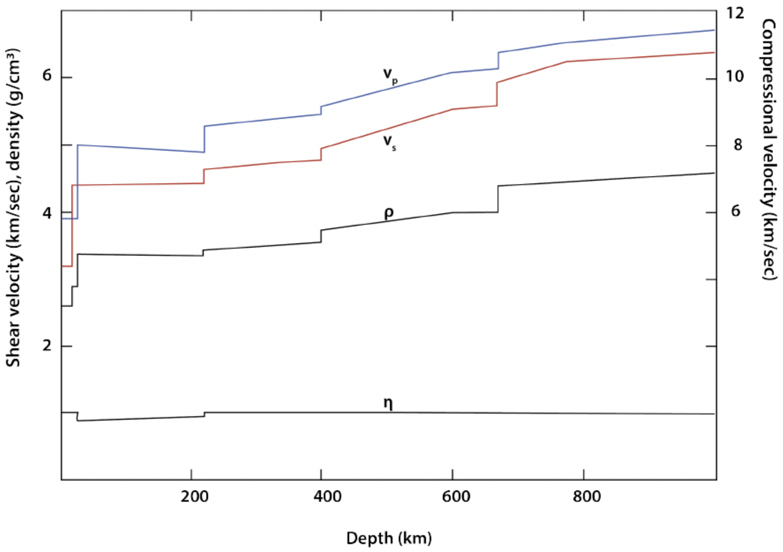
+ Martin Saunders, Slava Shcheka, Marco Fiorentini, Lauren Gorojosvky, Michael Förster, Stephen Foley

Determining the composition of the mantle

Natural samples + geophysical modelling + experiments = the green interior

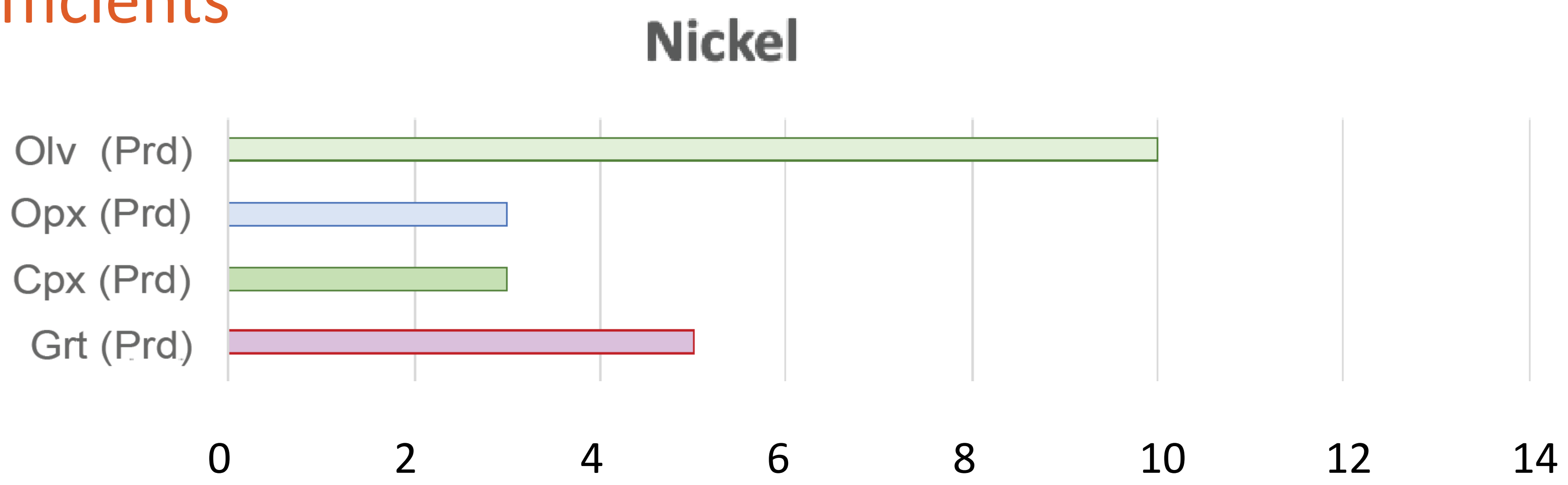




Locations of garnet peridotite globally. Su et al. 2011

Distribution of Ni in peridotite minerals

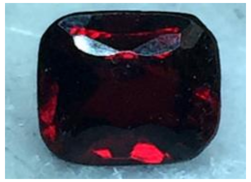
Partition coefficients



Olivine

Orthopyroxene

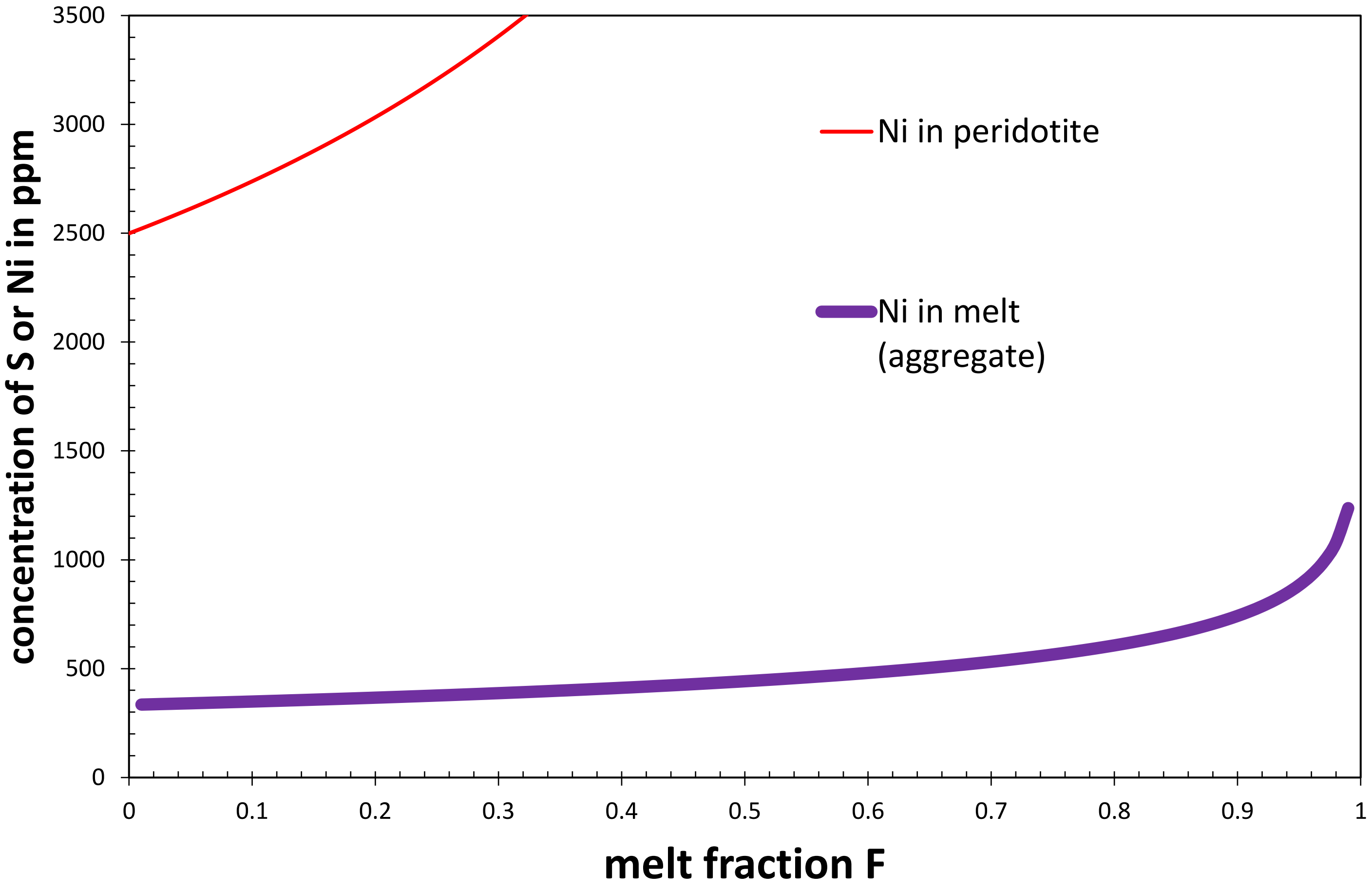
Clinopyroxene



Garnet

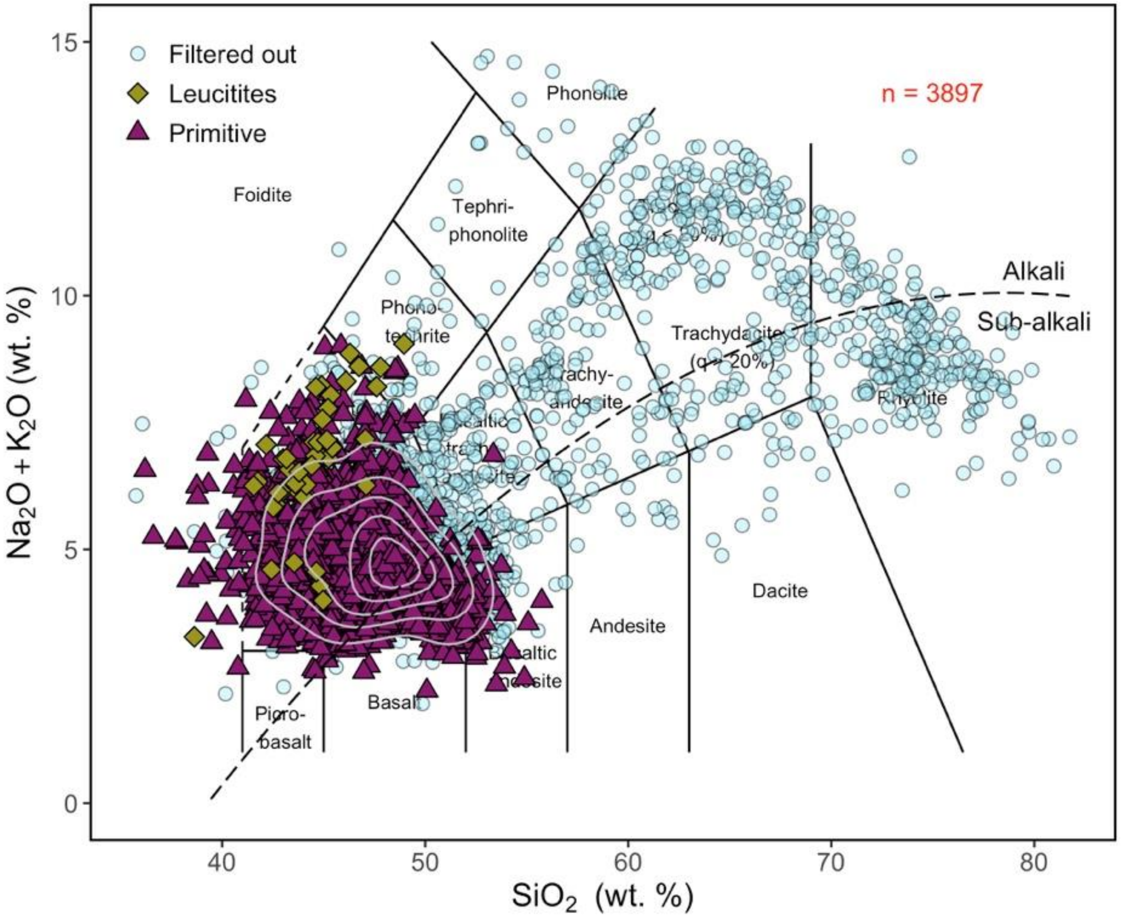
Why revisit Ni-systems?

Revisiting the Naldrett model



- Melting begins at 1325°C at 25 km (~90km)
- The melting reaction is ***incongruent, olivine is crystallising as melting begins***
- With the **exception of komatiites – melting olivine is not feasible**
- This model is great for a young hot Earth

Peridotite and primitive melts

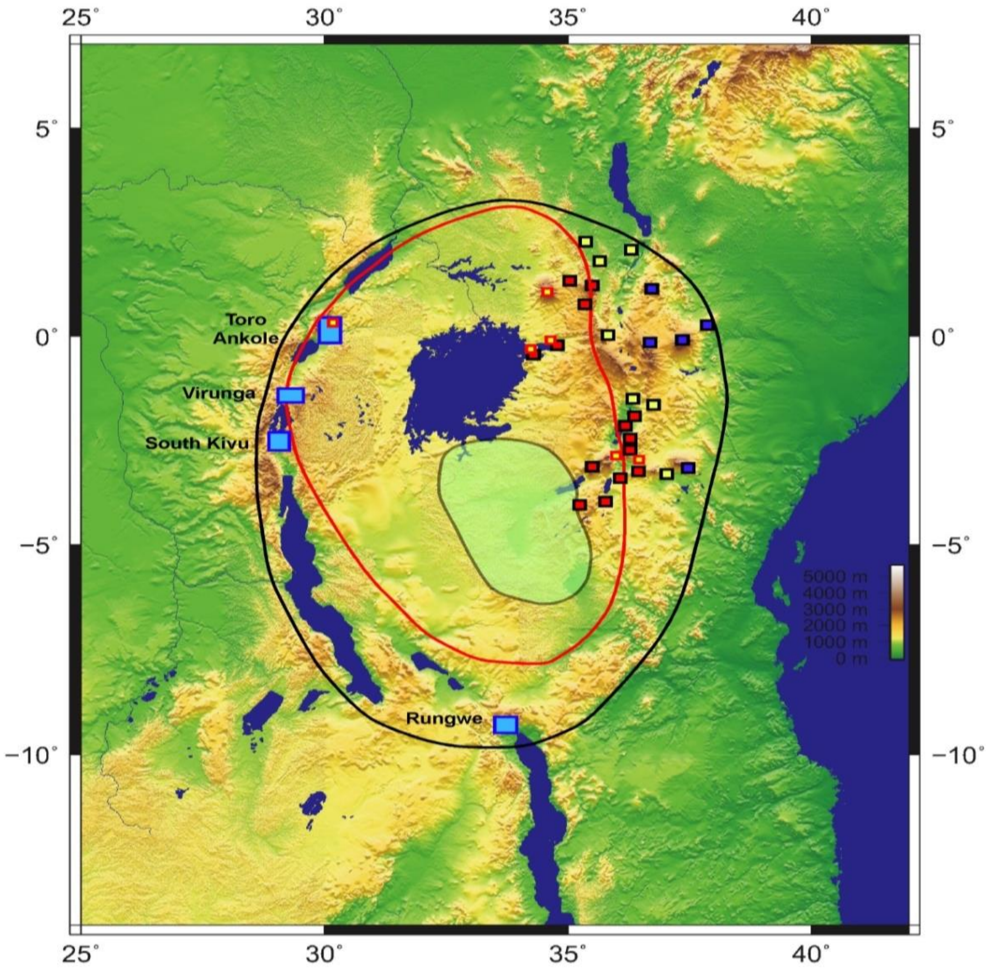


Shea et al. (2022)

- Primitive melts are considered to be in equilibrium with their mantle sources.
- This results in melts which are restricted in SiO_2 and total alkalis, reflective of the mantle source composition.

Alternative mantle sources – the other primitive melts

Tanzanian craton area



Kimberlites

Kamafugites (K-rich melilitites/nephelinites)

Nephelinites

Basanites & Alkali basalts

Carbonatites

Conard et al. (2011), After Foley et al. (1987), Edgar (1996)

The dark side of the mantle – hydrous pyroxenites

Amphibole, mica pyroxenite from Uganda

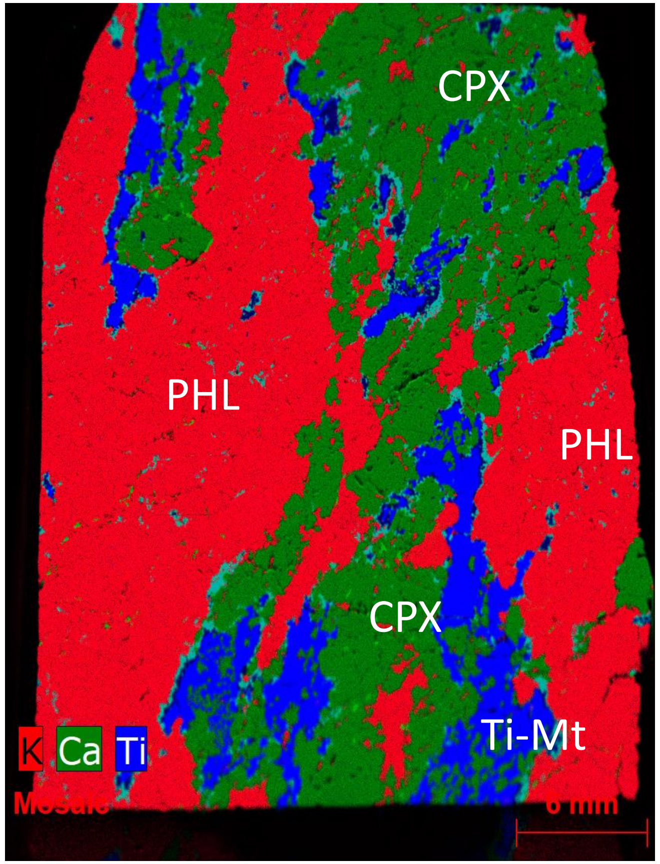
MARID

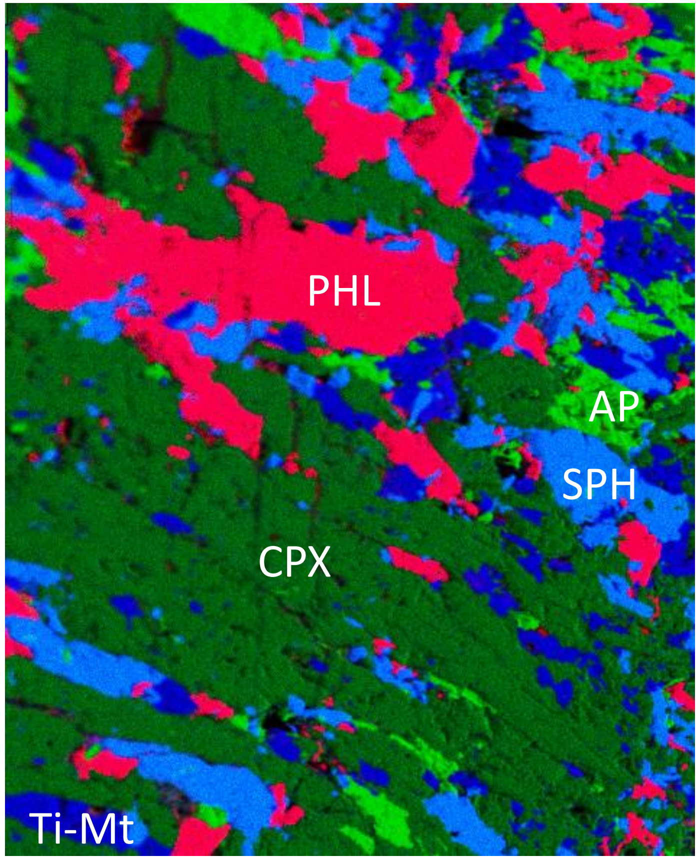
Mica – Amphibole – Rutile – Ilmenite – Diopside

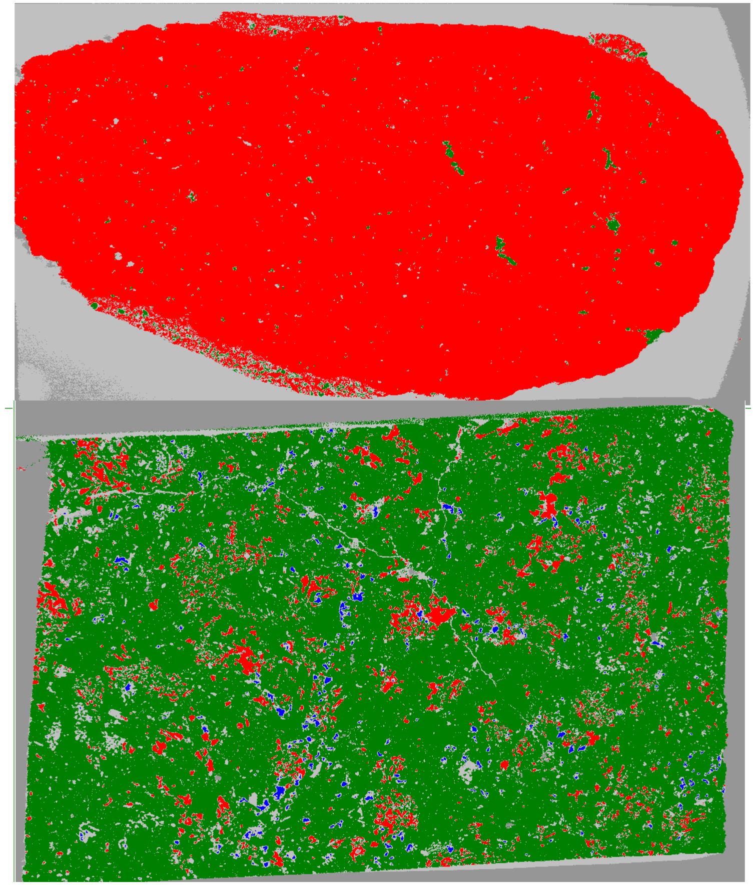
PIC

Phlogopite – Ilmenite - Clinopyroxene

Hydrous pyroxenites – mineralogical variety

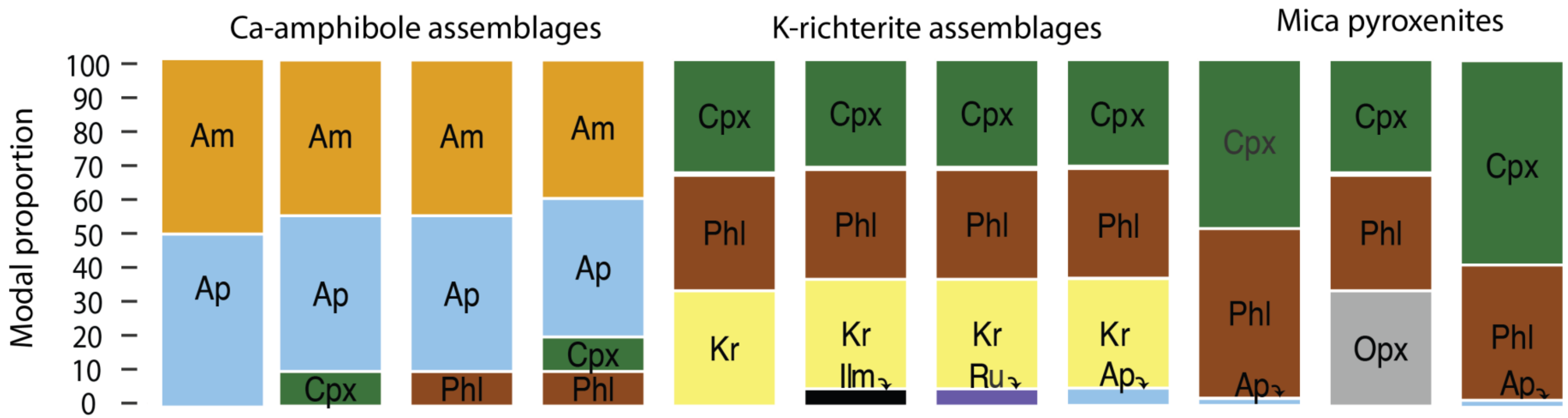






Micro-XRF scans of sections/section blocks

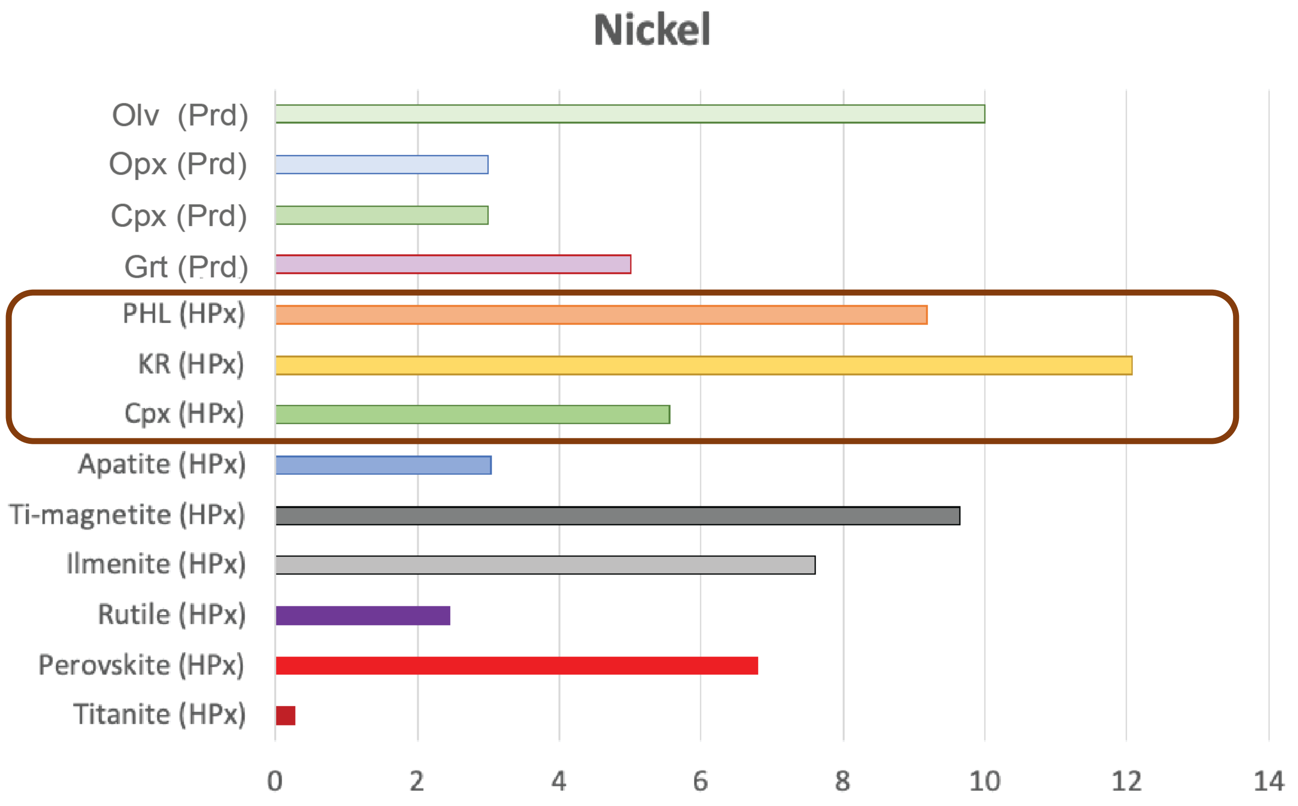
Hydrous pyroxenites



Huge variety of hydrous olivine free mantle rocks

Foley et al. (1999), Funk and Luth (2013), Foley et al (2022), Shu (2023), Ezad et al. (accepted, Min Dep)

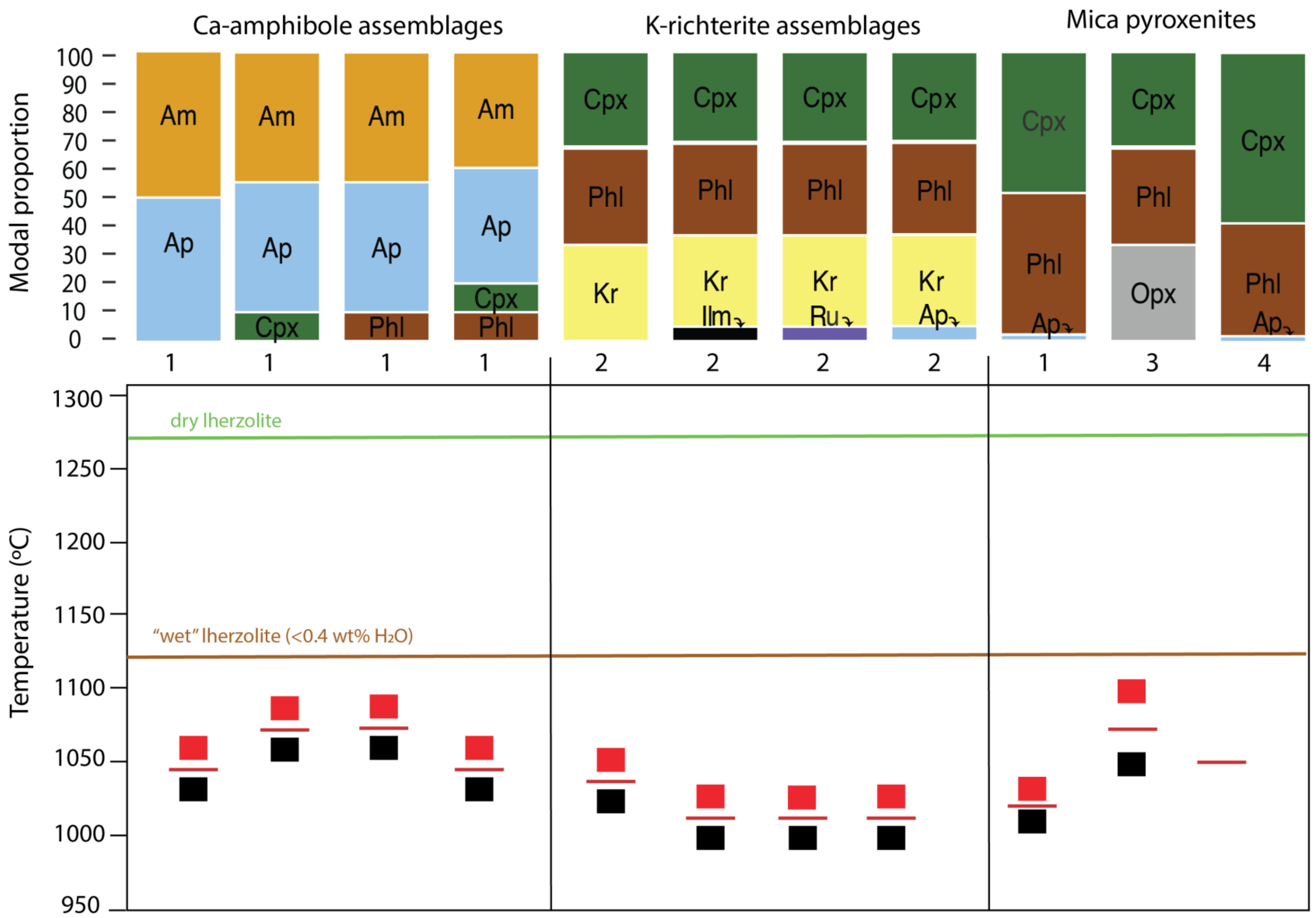
Where is the Ni?



Components of hydrous pyroxenites are comparably rich in Ni to olivine

- Partition coefficients measured in natural rocks and experiments
- Ni is compatible in phlogopite, amphibole and clinopyroxene

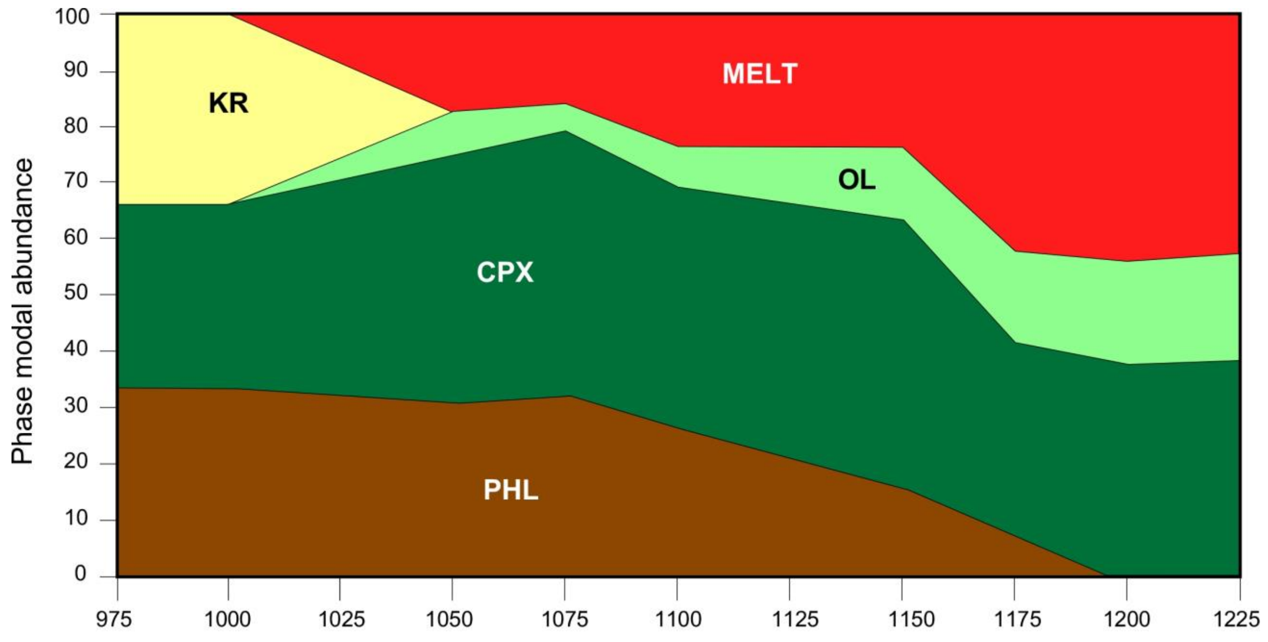
Hydrous pyroxenites

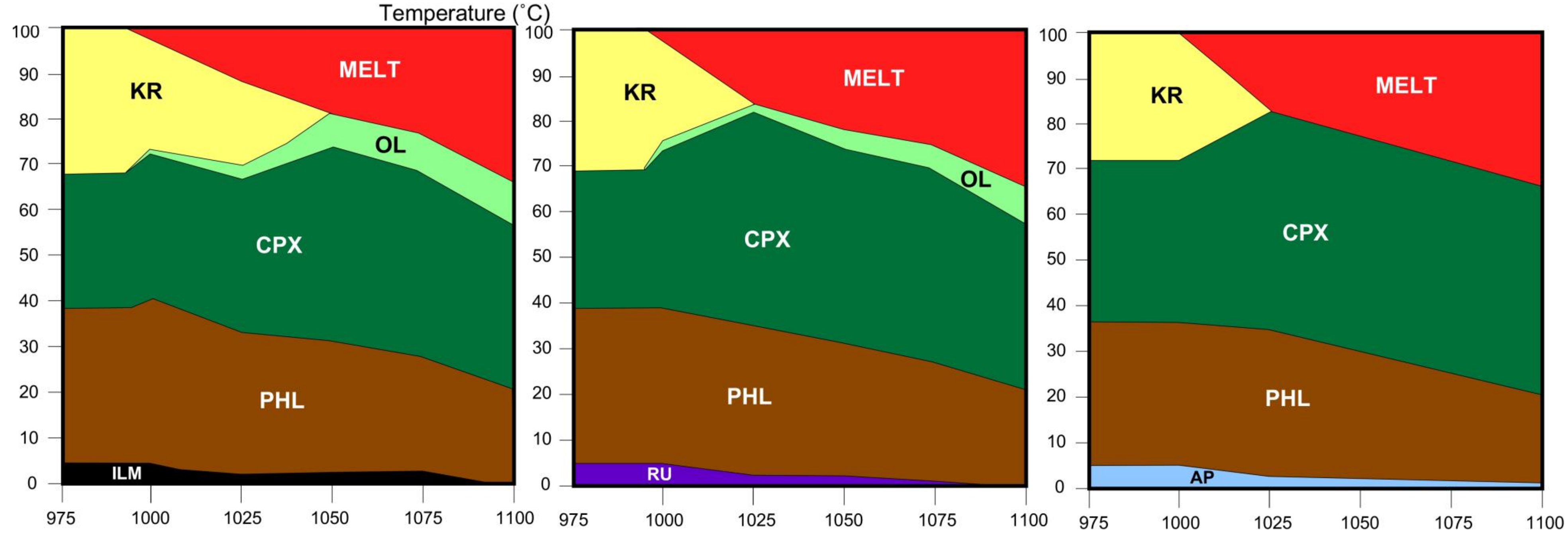


ALL melt at lower temperatures than peridotite

Foley et al. (1999), Funk and Luth (2013), Foley et al (2022), Shu (2023), Ezad et al. (accepted, Min Dep)

Melting of hydrous pyroxenites





1/3 each PHL, CPX, KR (alk amph)
+ 5% Ilm, rutile or apatite in some

Amphibole melts quickly and completely

Potassic silicate melts (lamproite)

Foley et al. (2022) Geosci. Fron.
Foley and Ezad (2024) Geosci. Fron.

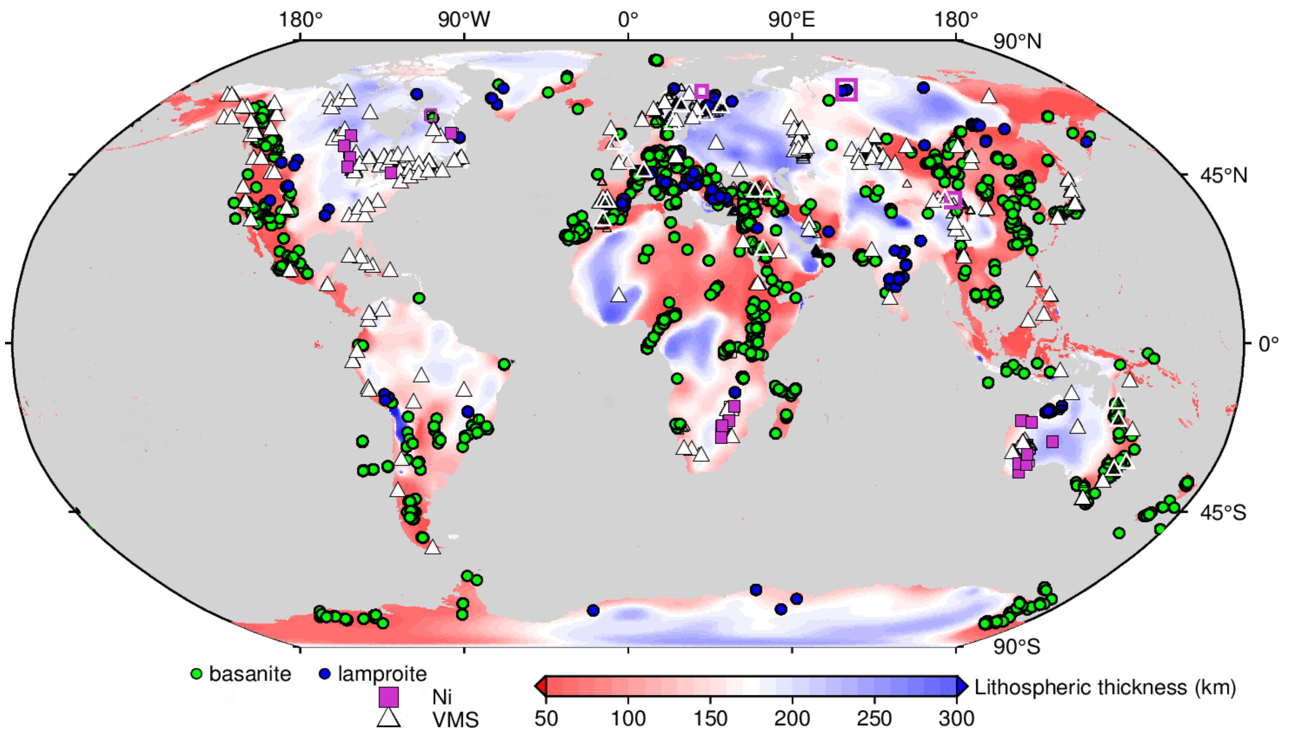
Evidence for hydrous pyroxenites is – widespread!

[1] **Cratonic** assemblages with K-richterite

Amphibole melts quickly and completely, phlogopite more slowly

Hydrous minerals always melt incongruently

Melt composition resembles amphibole => lamproitic

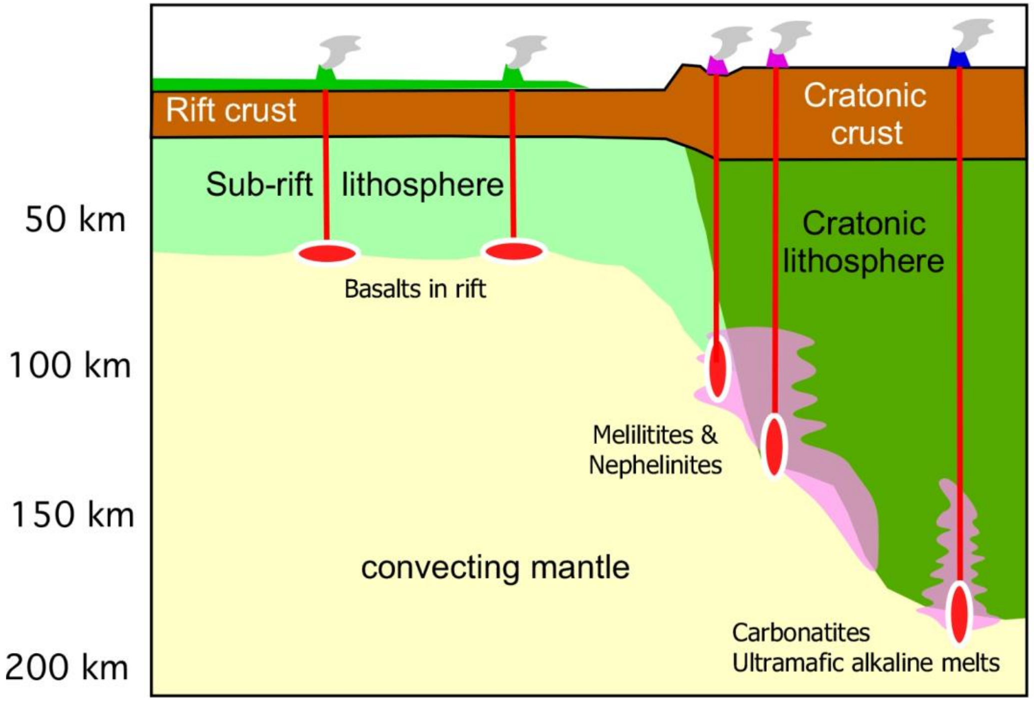


Evidence for hydrous pyroxenites is – widespread!

[2] **Non-cratonic** continental assemblages with Ca-amphibole

Amphibole melts quickly and completely, phlogopite more slowly

Melt composition resembles amphibole => nephelinitic



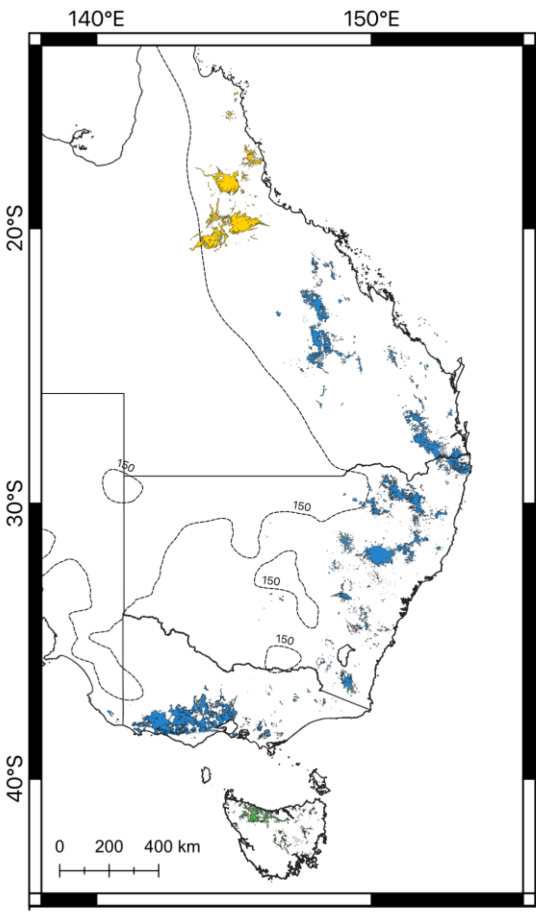
Foley and Fischer (2017)

Evidence for hydrous pyroxenites is – widespread!

[3] Phlogopite clinopyroxenites (Eastern Australian Volcanic Province)

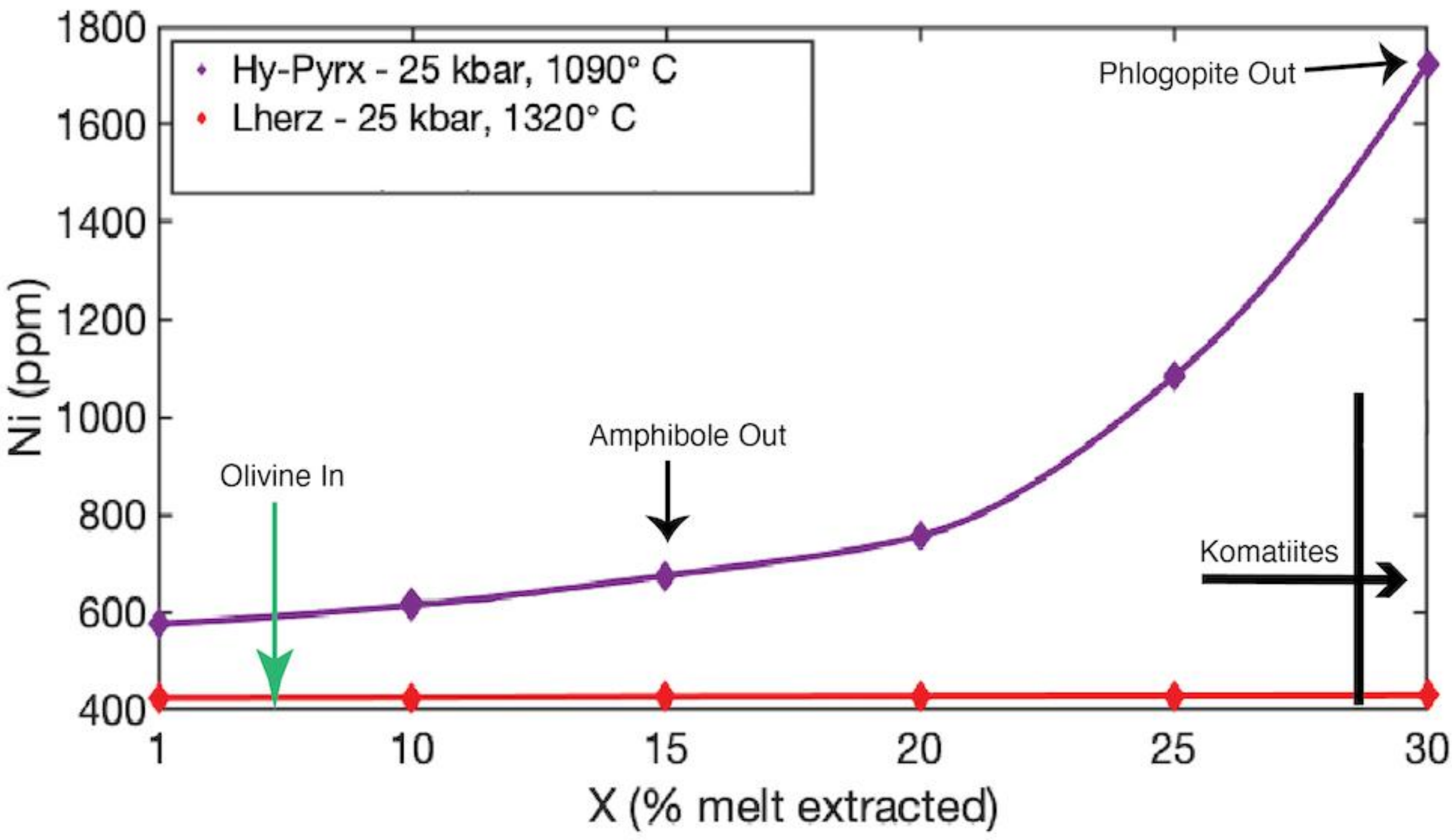
Chutian Shu (PhD MQ, 2023) and older publications

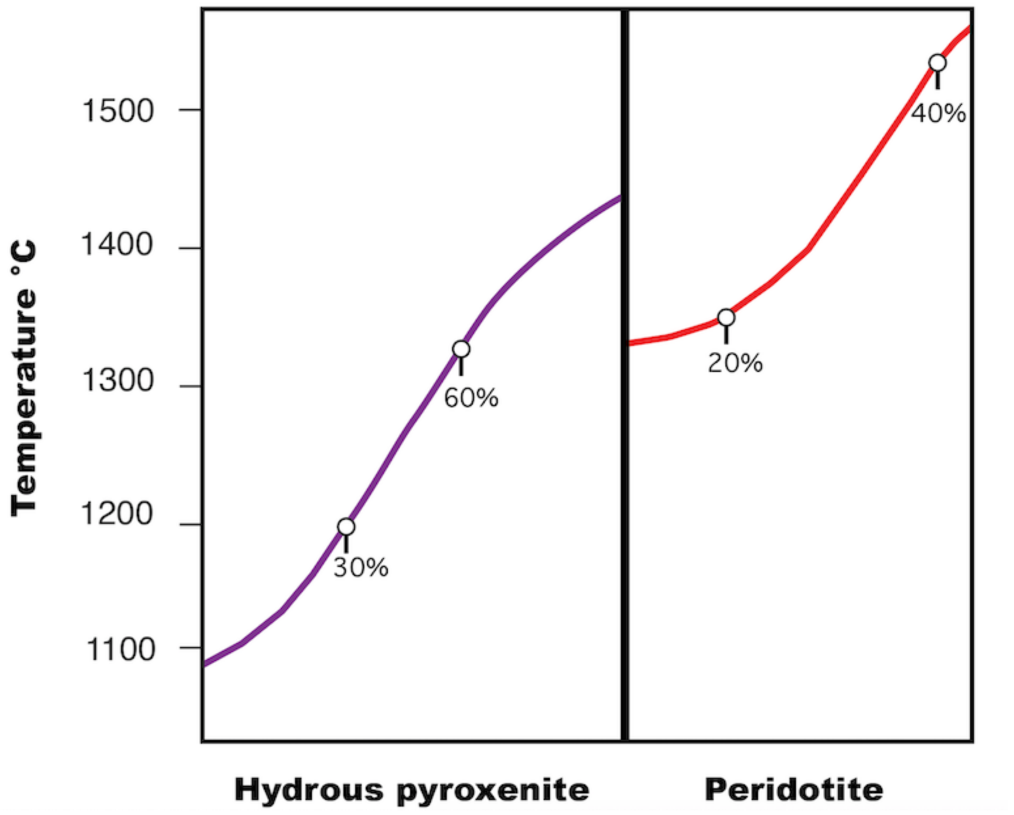
Phlogopite always melt incongruently => higher CaO melts



Shea et al. (2022)

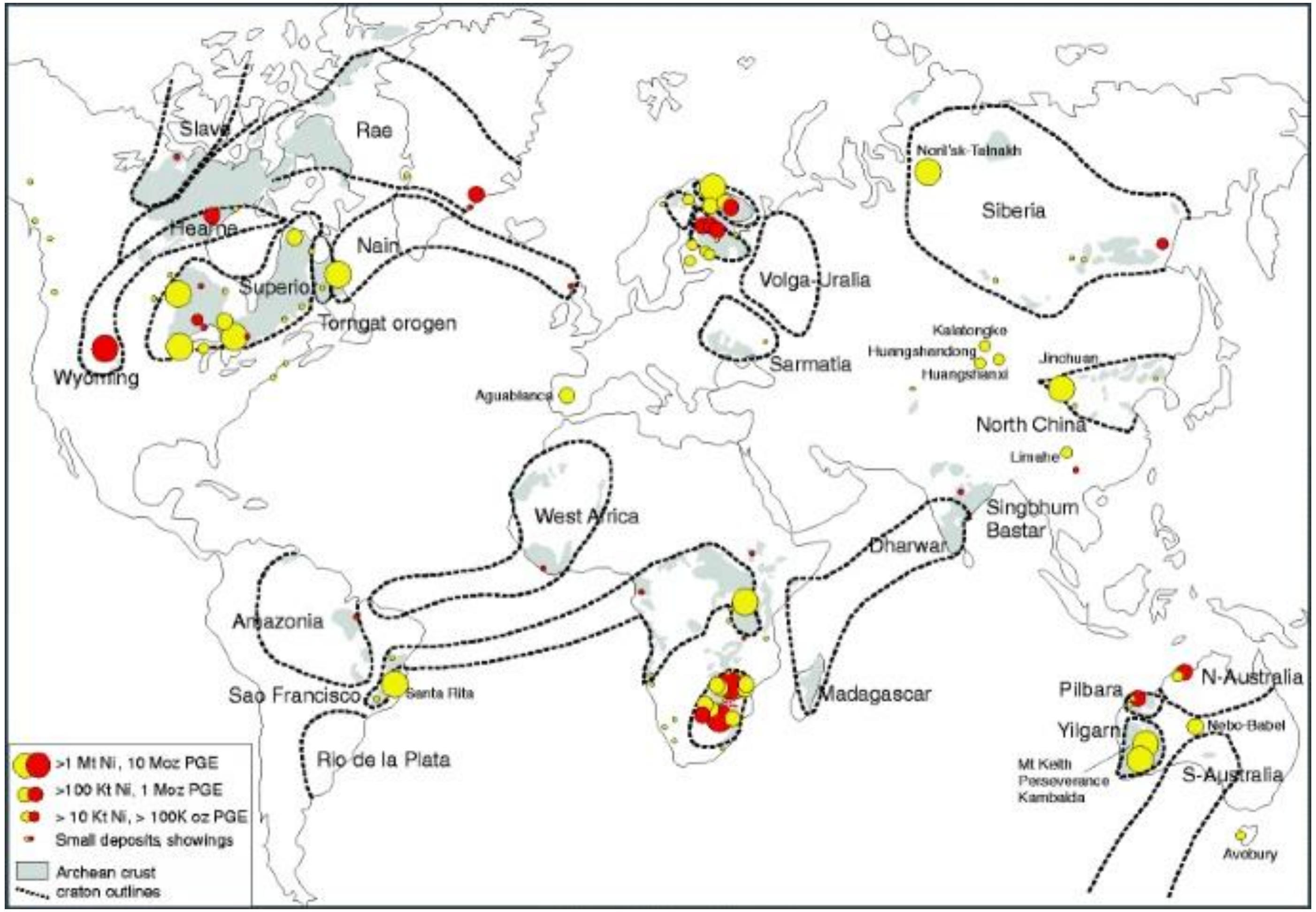
Producing Ni rich melts from the mantle





Ezad et al. (accepted, Min Dep)

The global distribution of Ni-Cu-PGE magmatic sulfide deposits

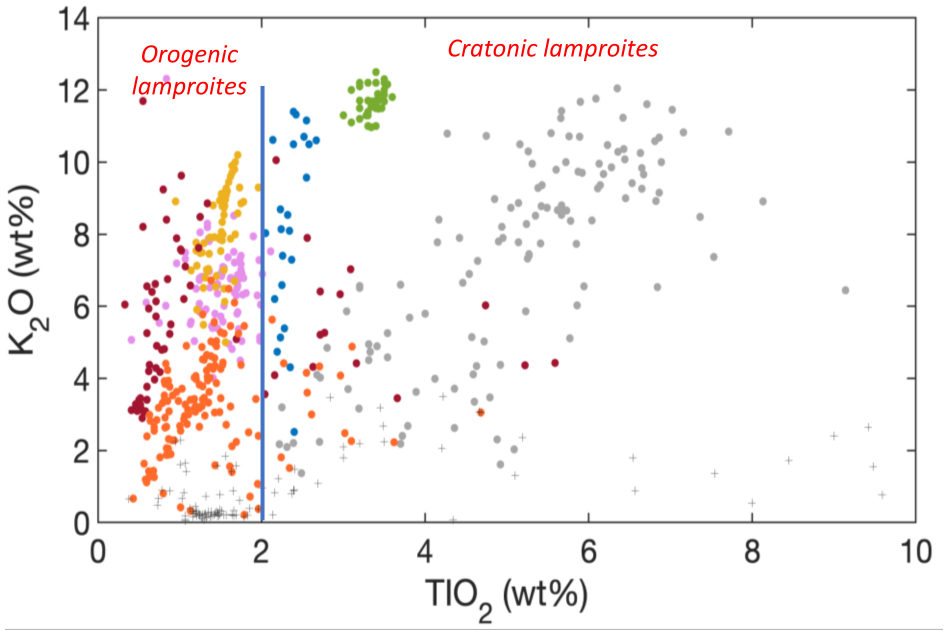


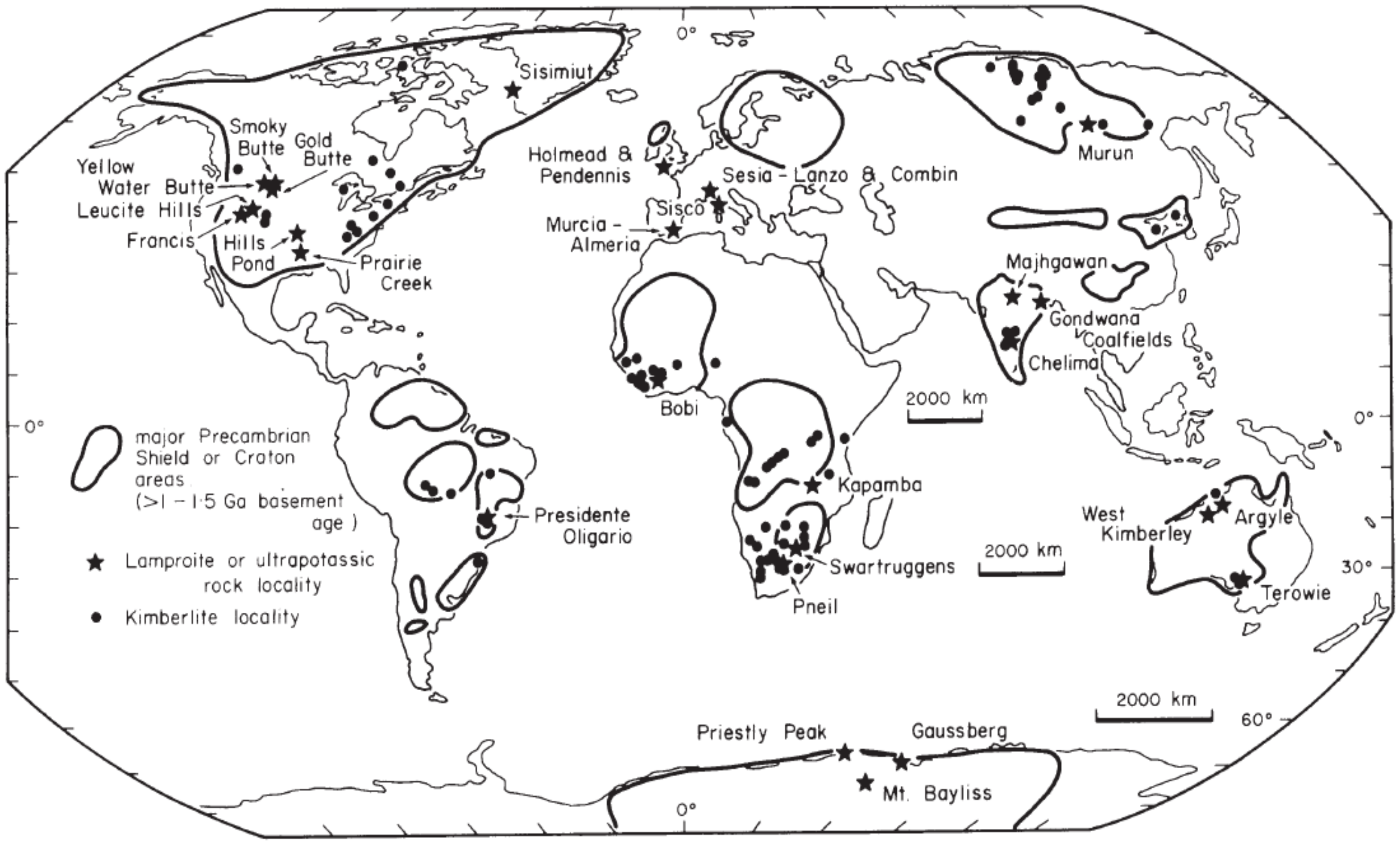
- Many Ni-Cu-PGE deposits are magmatic sulfides
- Most are associated with cratonic margins

Maier and Groves (2011)

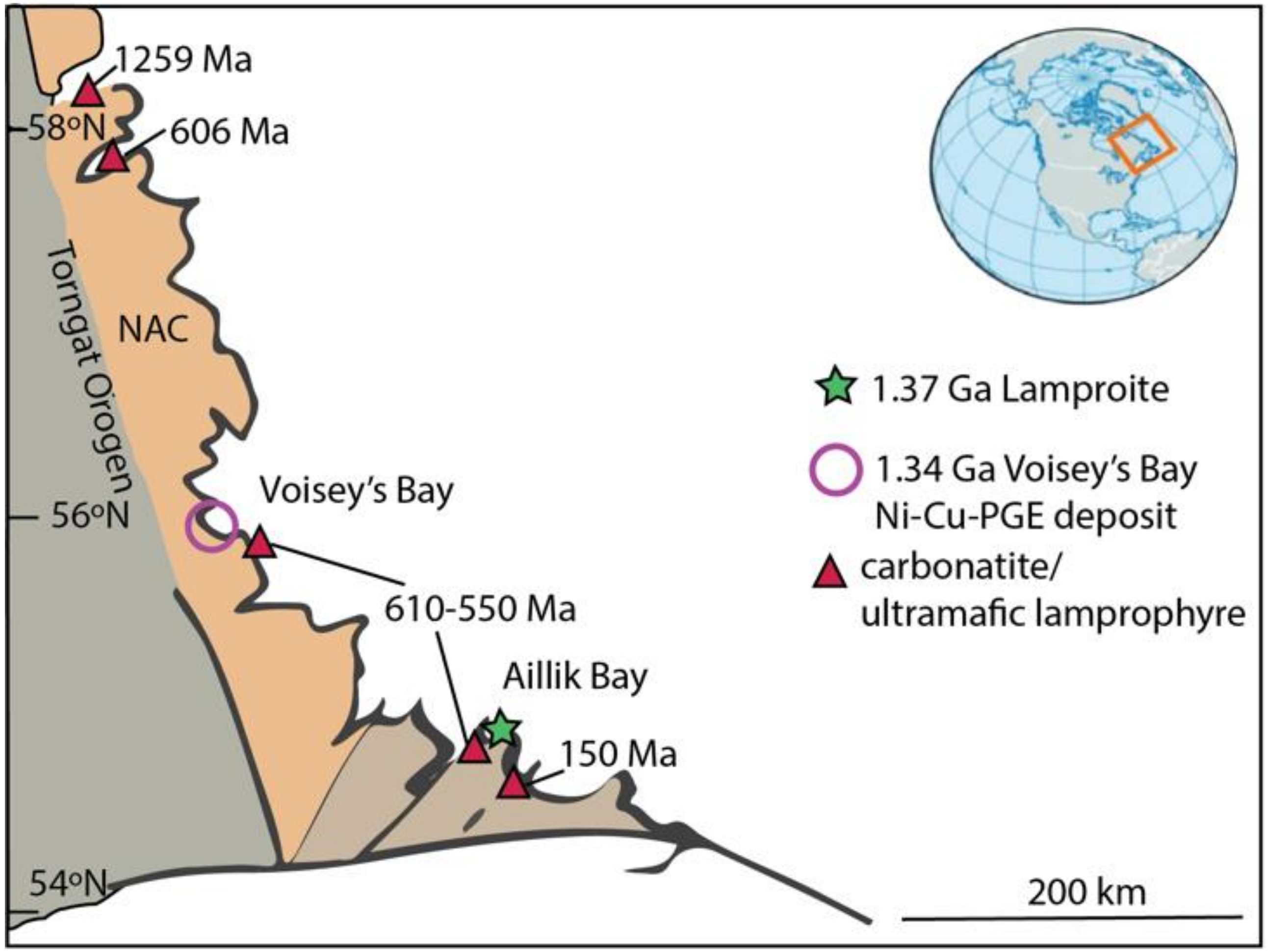
Hydrous pyroxenites and alkaline hydrous melts

Global occurrences of lamproites and kimberlites

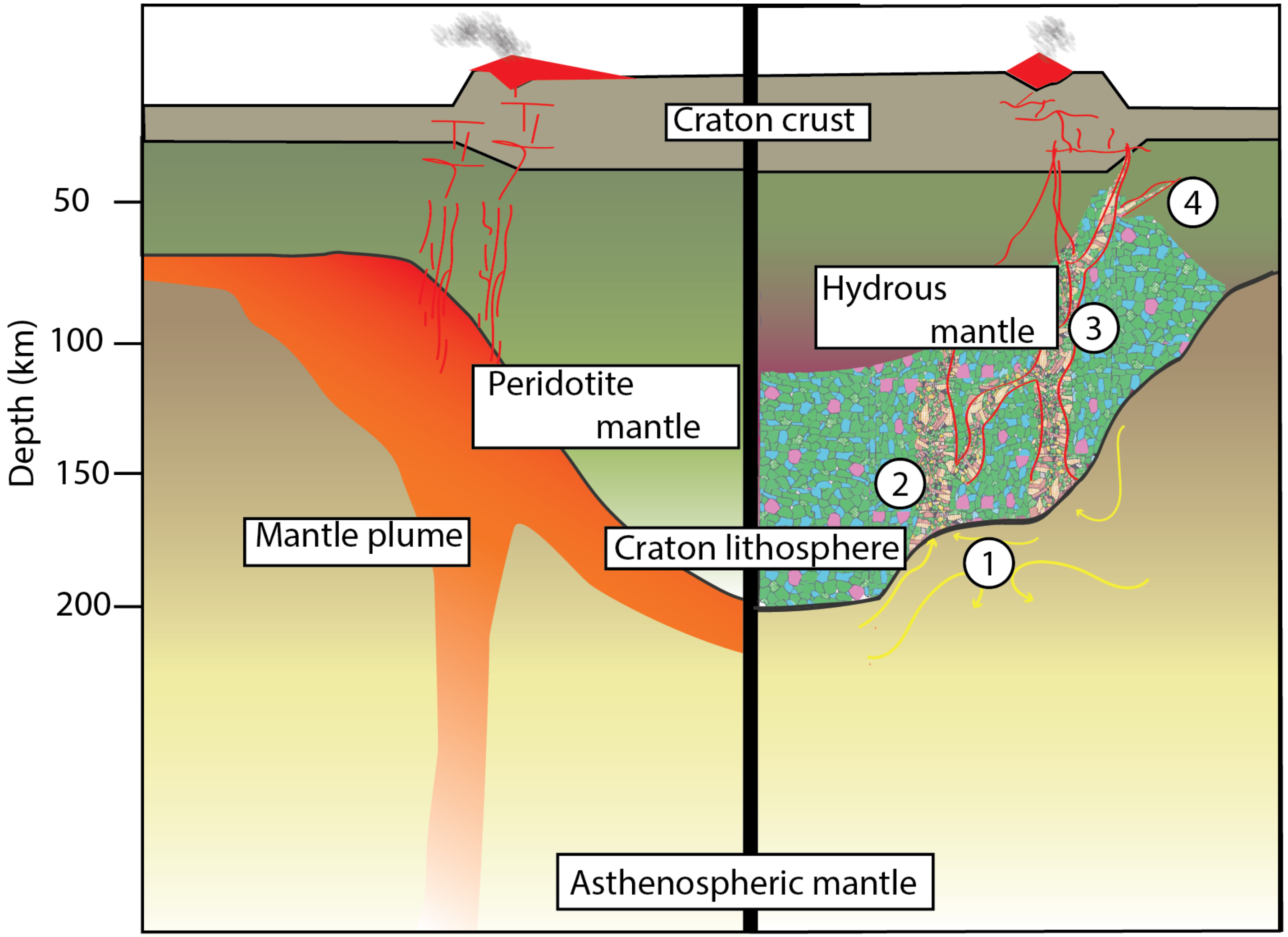




Voisey's Bay – a metasomatic origin?



Hydrous mantle sources



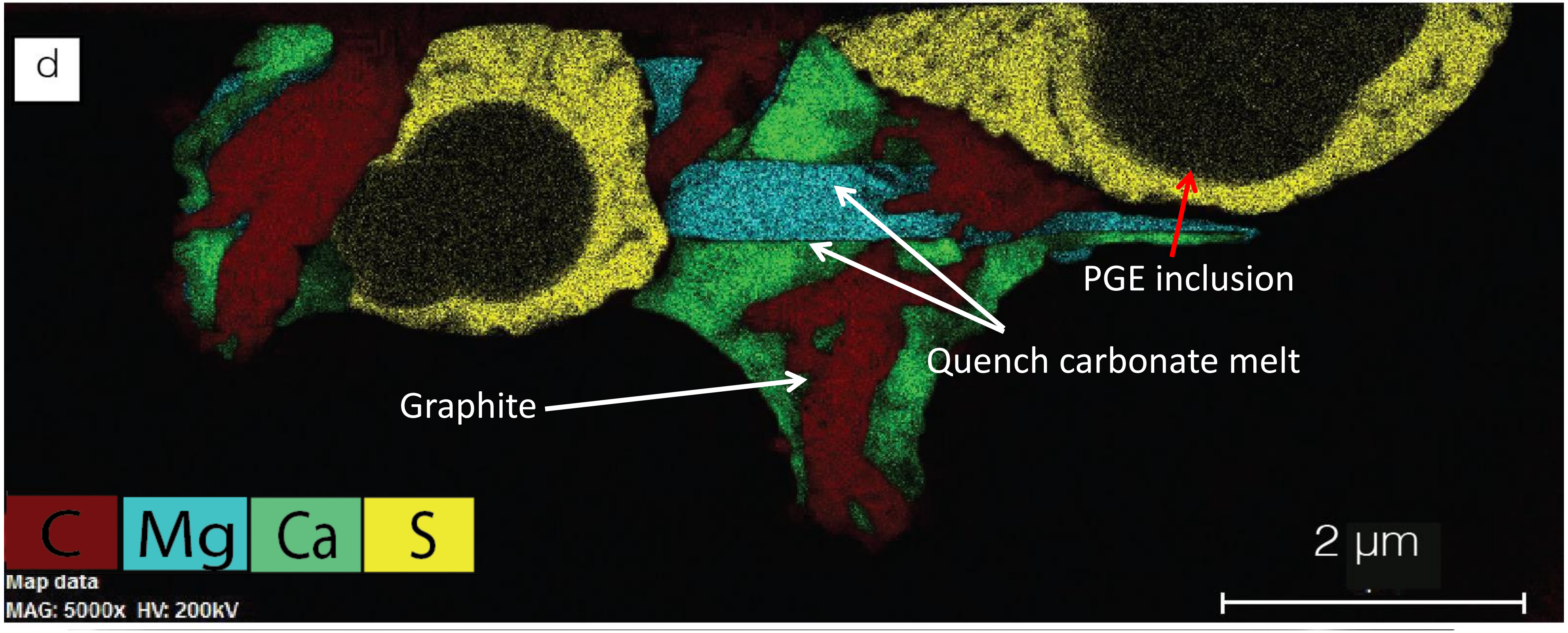
4. Small tectonic nudges cause melting of metal rich hydrous pyroxenites

3. Over time, hydrous pyroxenites become enriched in metals and physically separated from peridotite

2. Reactions of melt and peridotite – hydrous pyroxenites

1. Metasomatism of cratonic root by incipient melts

Hydrous Pyroxenite TEM



<u>High-angle annual dark field, scanning transmission electron image</u>

Heavier atoms are brighter, atomic scale features less visible

Ezad et al. (accepted) Science Advances

Future directions

- Cratonic margins have overthickened metasomatised roots
  - Incipient melts will be active at these low geotherms – *Geophysical imaging?*
- Hydrous pyroxenites typically melt to higher degrees forming potassic primitive melts, which are rich in chalcophile elements
  - *These melts occur close to known ore deposits, African Ni belt*
- Proto-rifts tend to erupt geochemically unusual primitive melts
  - Metasomatism may be required to initiate rifting and telescoping of precious metals
- Measuring chalcophile elements (Ni, Cu, Co, Cr) in hydrous minerals or accessory minerals such as micas, apatite and amphibole
- Need experiments to understand the S capacity of carbonate systems
- Carbonate lavas are geologically "young" – what changed? Reduced to oxidised mantle?

Thank you!