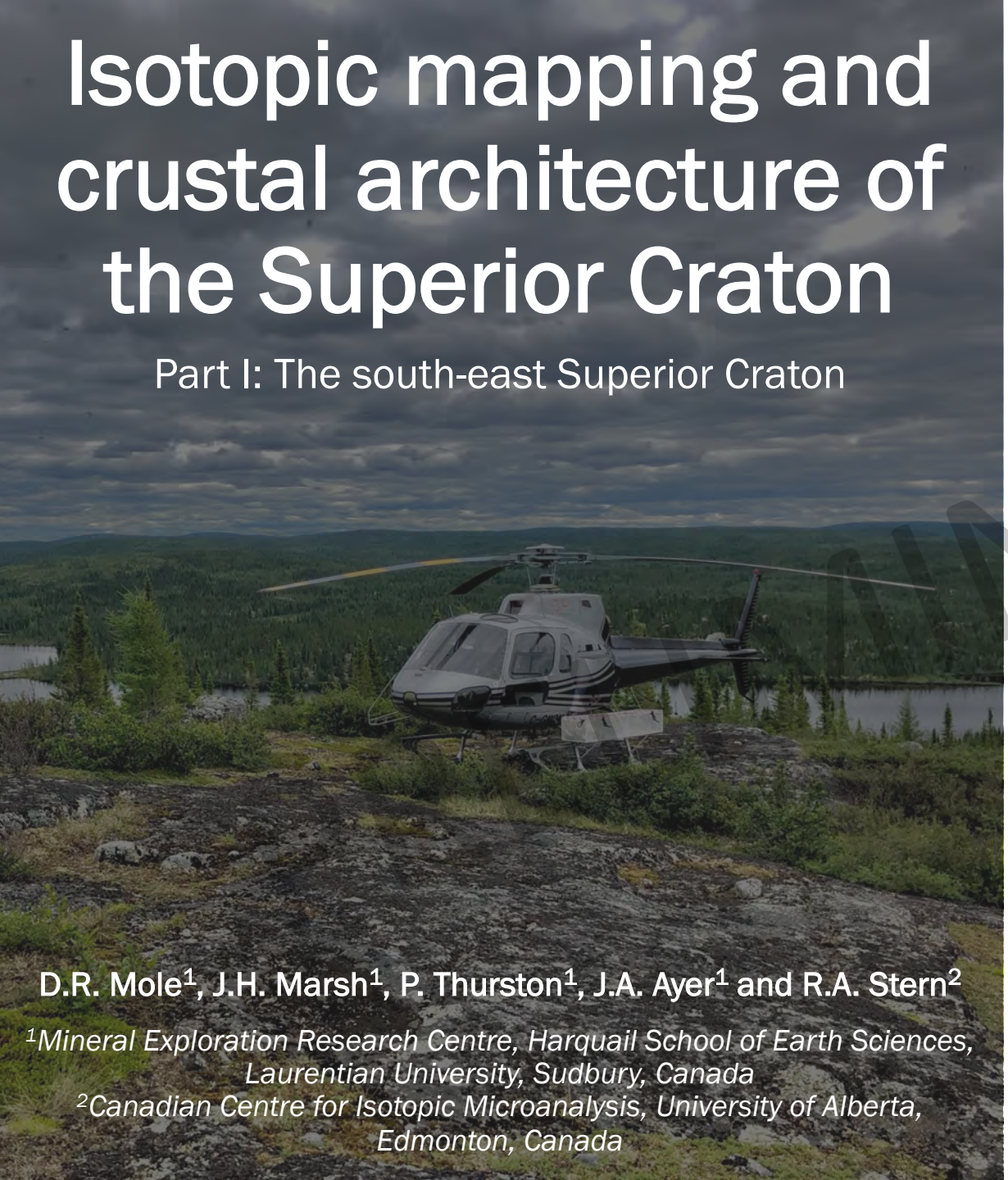
Isotopic mapping and crustal architecture of the Superior Craton

Part I: The south-east Superior Craton



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A new Canadian research initiative funded by Canada First Research Excellence Fund.

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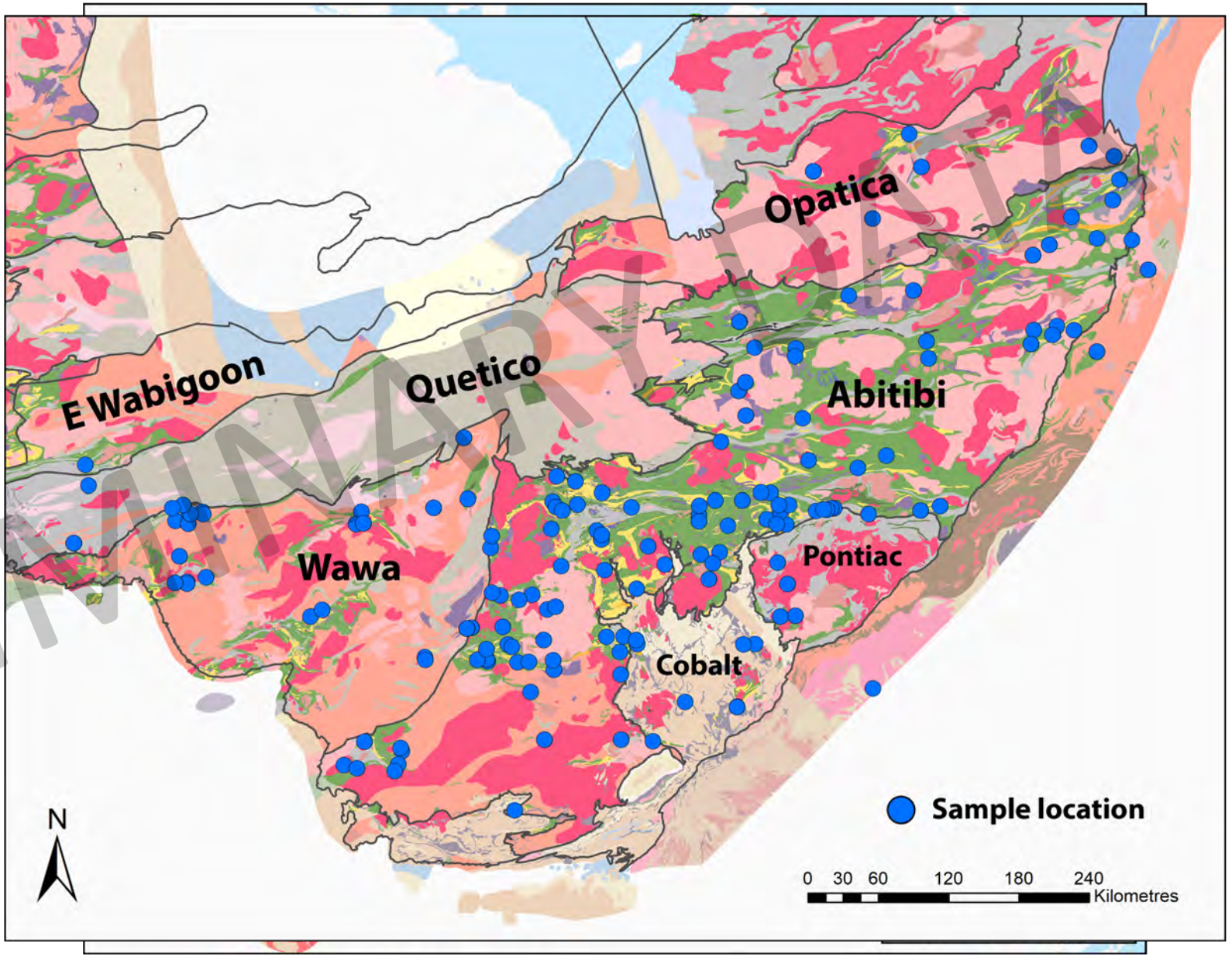
Background – why is this project important?

- Archean cratons make up 12% of the continental crust, but represent the entire repository of the first 2.5 billion years of Earth's history
- Without the formation and evolution of continents in this early period, the atmosphere-hydrosphere-biosphere system would not have evolved to form a habitable world
- Furthermore, there would be no buoyant crustal reservoir - vital in the formation, and storage, of metallogenic systems
- Hence it is vital to understand crustal evolution in the early Earth
- Radiogenic (Nd, Sr, Hf) and stable isotopes (O, S) have been vital in understanding the history of the continents, but rarely applied in a spatial context
- What could 4D crustal evolution tell us about continent growth and evolution?

The project

- Metal Earth: Craton-scale
  - New project aims to perform multi-isotopic mapping of the Superior Craton
  - Collection of large U-Pb-Hf-O-TE dataset on archived zircons
  - Ultimate goal is to constrain time-space evolution of the craton
- Stage 1: SE Superior
  - First ROI is the SE Superior
  - Data collection and processing recently finished for isotopic data from this area
  - New dataset = 8435 analyses from 158 samples, for U-Pb, O- and Hf-isotopes, and trace elements – in zircon
- The Future
  - Stage 2: SW Superior
  - Quebec and NW Ontario



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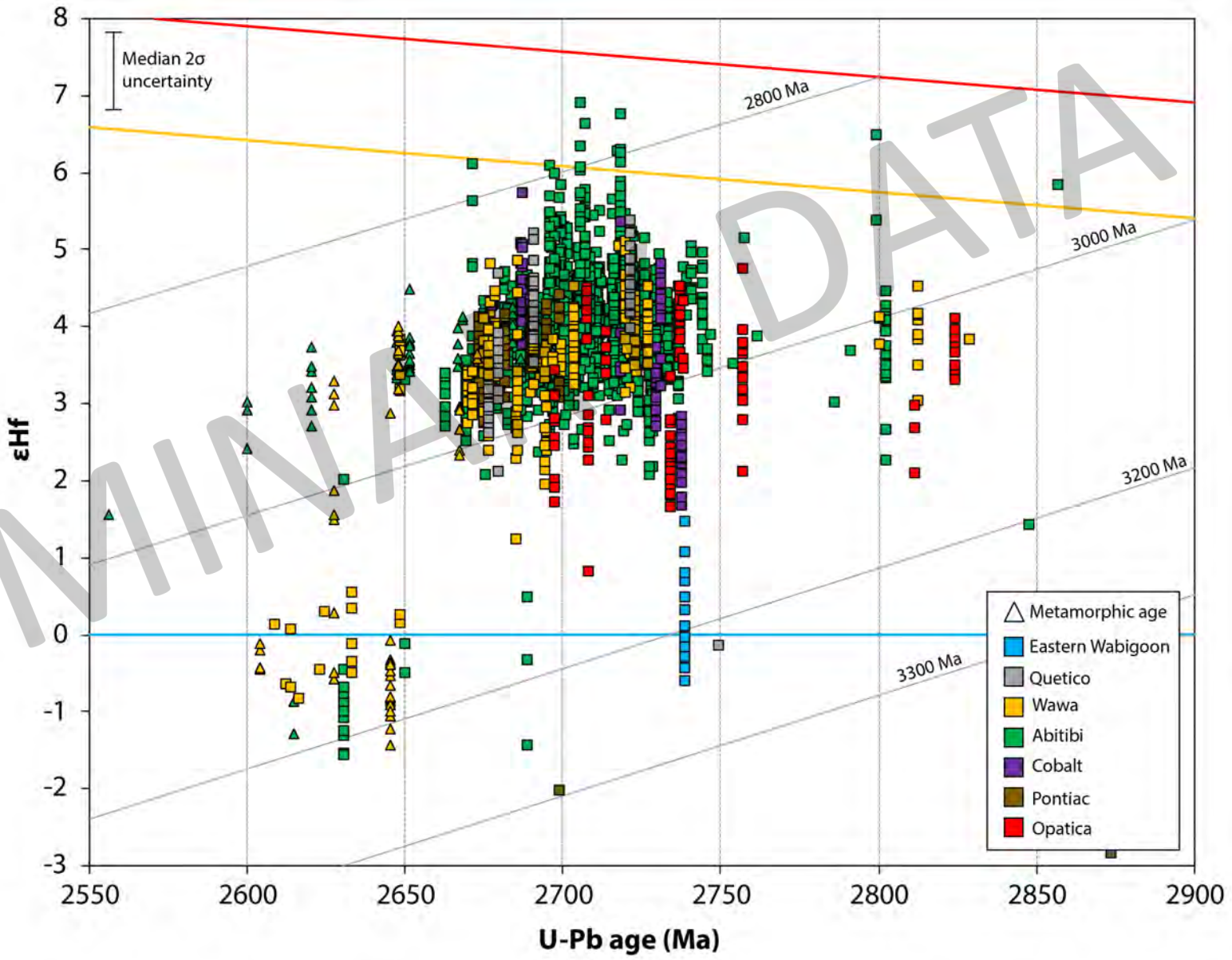
Results: Multi-isotopic crustal mapping

Temporal Data: Lu-Hf

- The Lu-Hf system: εHf
  - Radiogenic isotope system
  - Young, mantle-derived crust typically has εHf>0
  - Once formed, crustal sources evolve along Lu/Hf lines
  - New crust does not always plot on the DM line
- SE Superior εHf data:
  - The ~2.8 Ga magmatism forms an older source
  - <2750 Ma juvenile magmatism appears to mix with that source
  - Juvenile peaks at 2720, 2705 and 2700 Ma
  - After 2660 Ma this mixed crust is reworked
  - Also evidence for older crust which correlates with the Eastern Wabigoon
  - Suggests shared crustal history for terranes of the SE Superior



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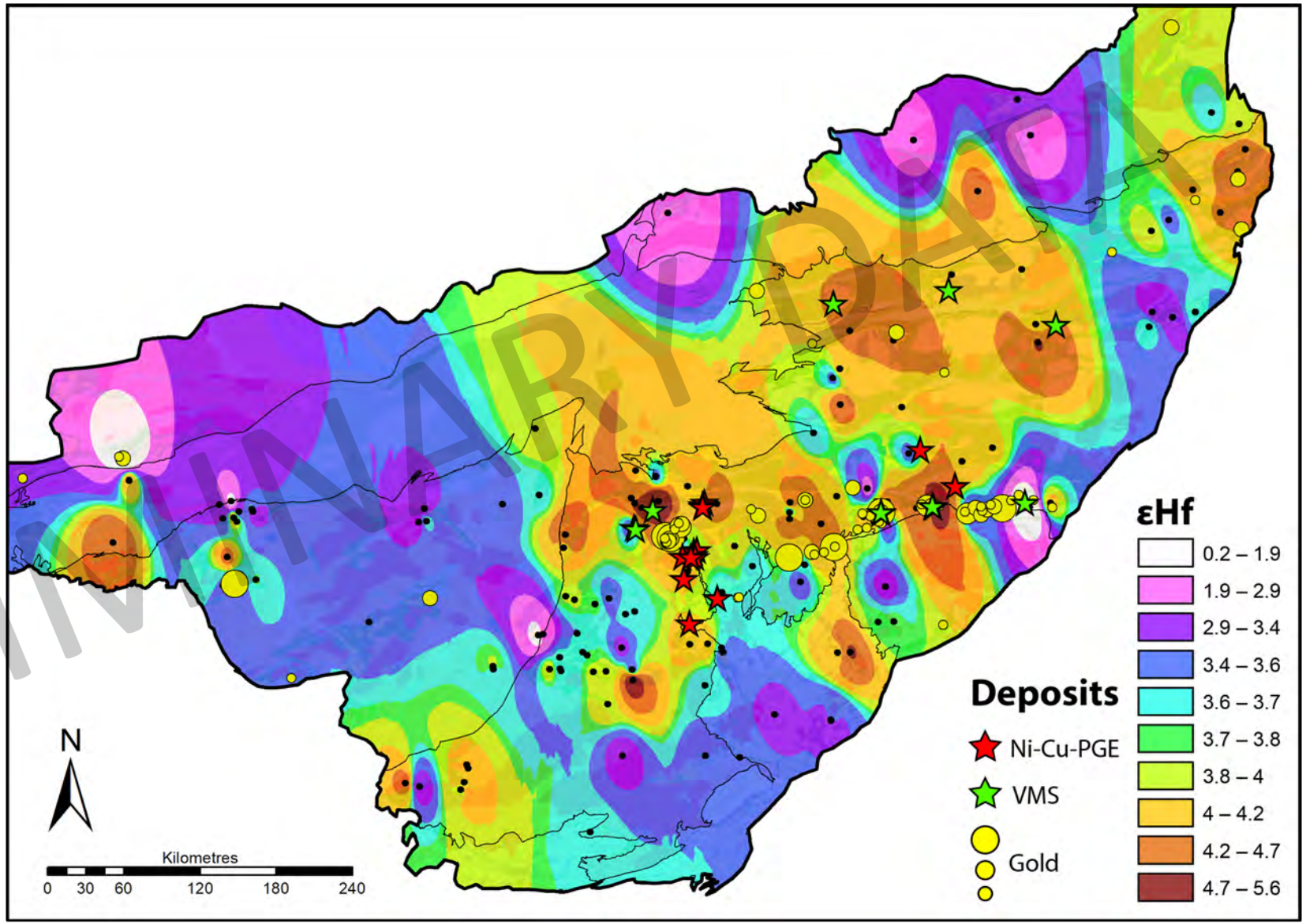
Spatial data: Lu-Hf

- Lu-Hf isotopic mapping:
  - SE Superior represents juvenile crust
  - However - subtle variations within that signature
  - The east and west appear more unradiogenic
  - Central area most juvenile and consists of N-S trending zones
  - Abitibi is highly juvenile crust surrounded by less juvenile material
- Influence on mineral systems:
  - Komatiite-hosted Ni-Cu systems are concentrated in juvenile zones
  - VMS deposits show similar trend, but more numerous
  - Gold also generally prefers juvenile crust, apart from Val-d'Or?



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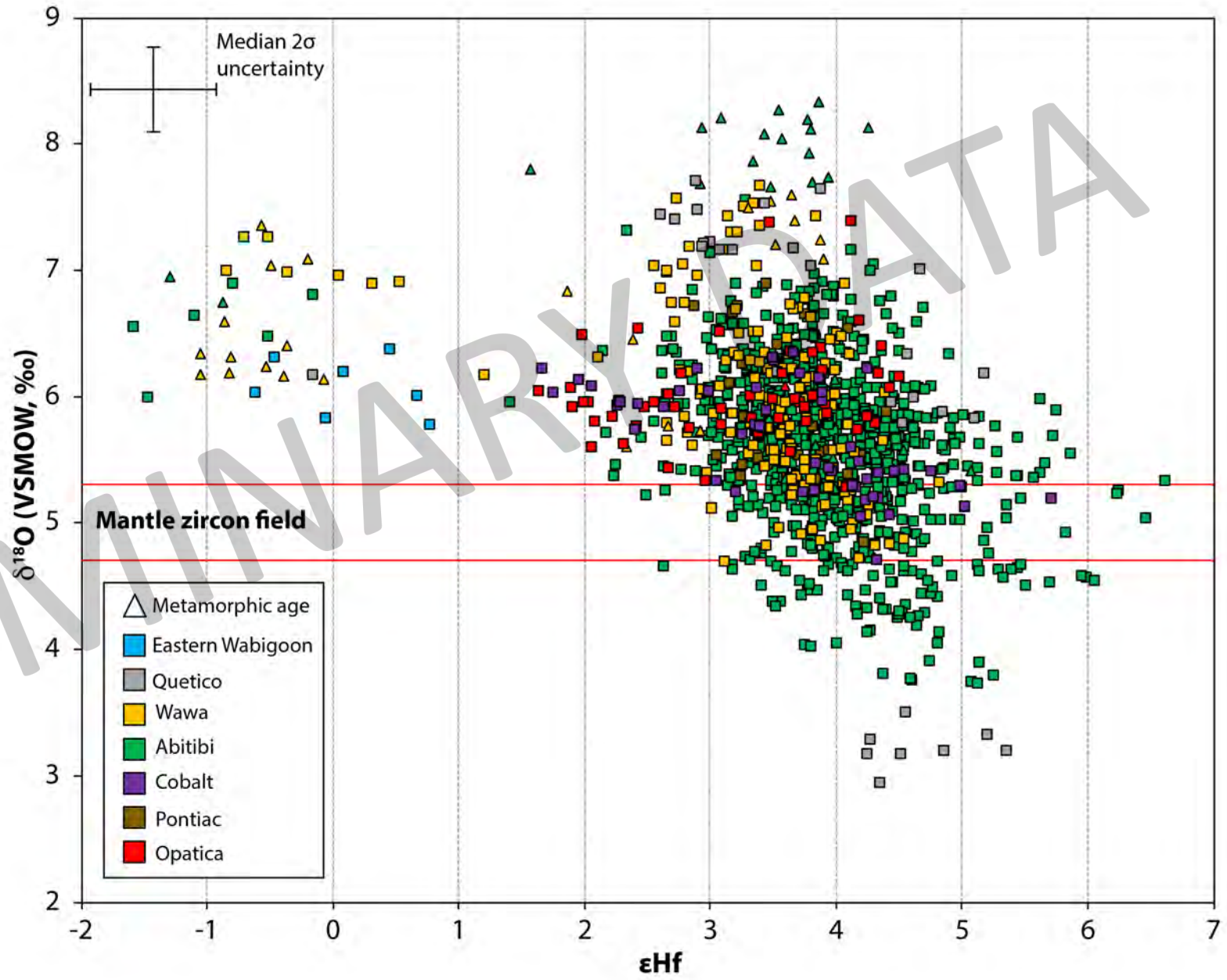
Temporal data: O-isotopes

- O-isotopes vs time:
  - Restricted $\delta^{18}O$ range at ca. 2.8 Ga
  - Expands to more heavy values after 2750 Ma
  - Trends to light values at 2700 Ma in Abitibi
  - After 2695 Ma, $\delta^{18}O$ increases with time
  - Significant shift at the cessation of volcanism
- O-isotopes vs εHf:
  - Weak negative correlation between εHf and $\delta^{18}O$
  - Reworked/contaminated crust has a higher $\delta^{18}O$
  - Eastern Wabigoon source present in the Abitibi and Wawa?



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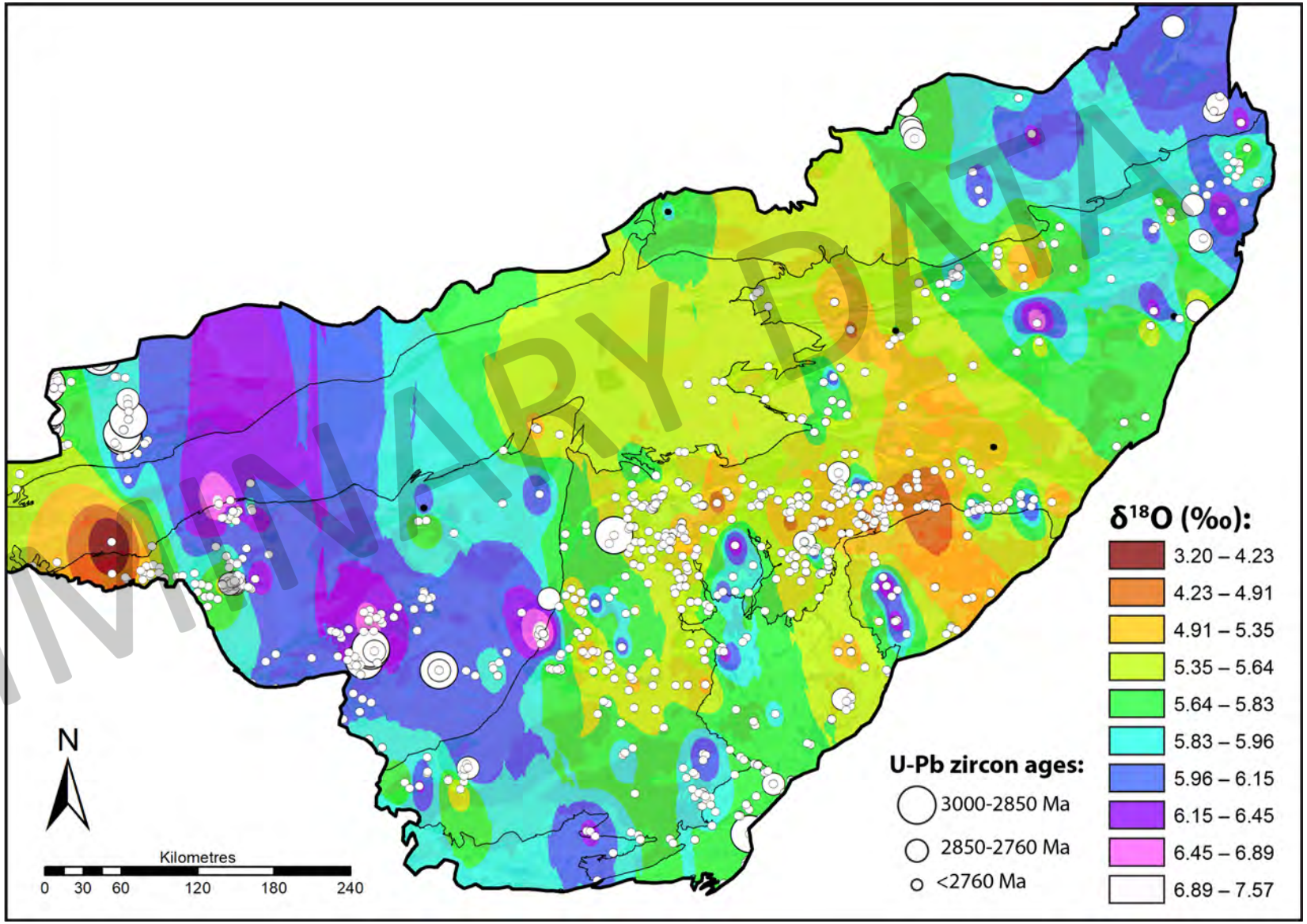
Spatial data: O-isotopes

- O-isotopic mapping:
  - Central Abitibi relatively low $\delta^{18}O$
  - N-S trends of lowest $\delta^{18}O$
  - Correlates with εHf trend
  - Blocks of crust with heavier $\delta^{18}O$ in the east and west
  - $\delta^{18}O$ of 3-5‰ is suggestive of interaction of magmas with high-temperature hydrothermal systems
- Controls on ore systems?
  - Location of VMS, Ni-Cu-PGE, and most gold deposits closely correlates with light $\delta^{18}O$
  - Crust with heavier $\delta^{18}O$ relatively less deposits
- Rifted crust?
  - 2760-3000 Ma ages are concentrated in the relatively high $\delta^{18}O$ crust



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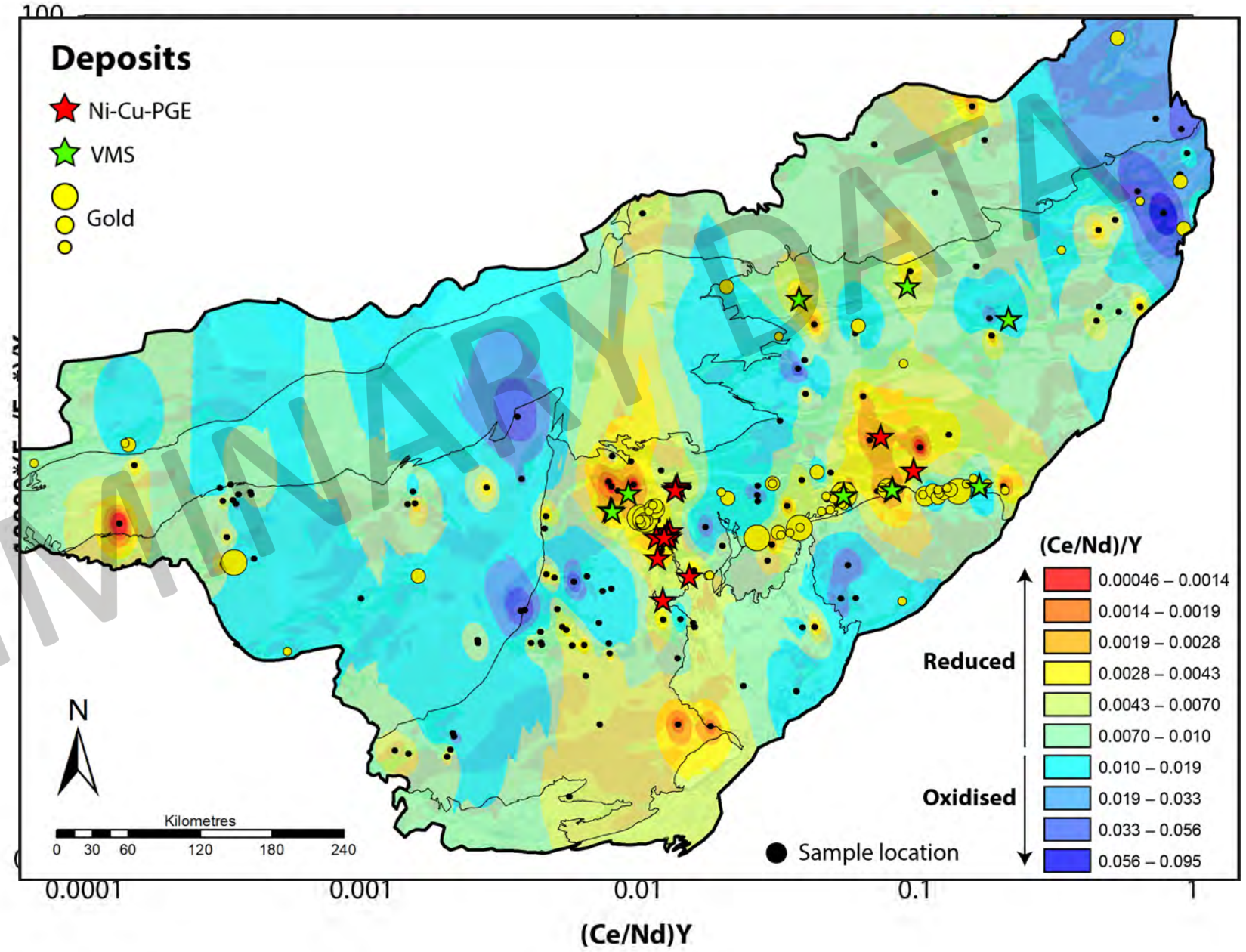
Zircon trace element data

- Numerous zircon TE petrogenetic indicators:
  - (Eu/Eu*)/Y = Hydration (>1)
  - (Ce/Nd)/Y = Oxidation (>0.01)
  - U/Yb = oceanic vs continental zircon (U/Yb <0.4 = oceanic)
- Results:
- (Eu/Eu*)/Y = Less hydrated areas correlate with high εHf
- (Ce/Nd)/Y = More reduced areas correlate with high εHf



Lu *et al.* (2016) *SEG Special Pub. 19*

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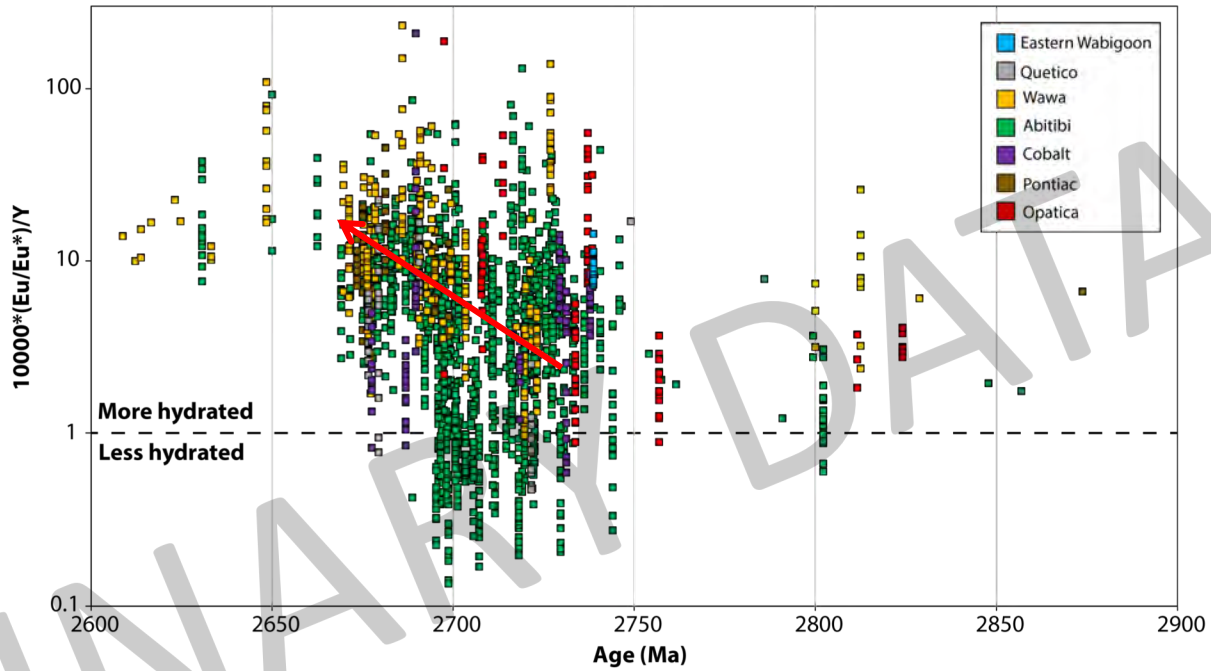

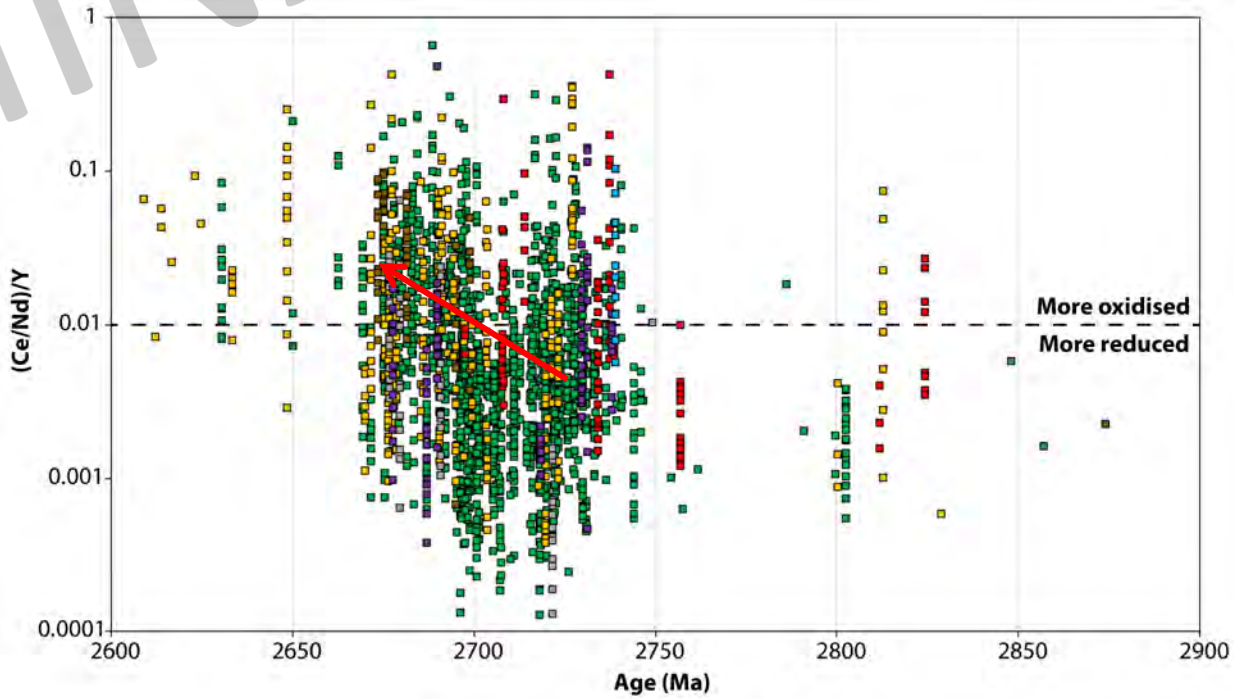

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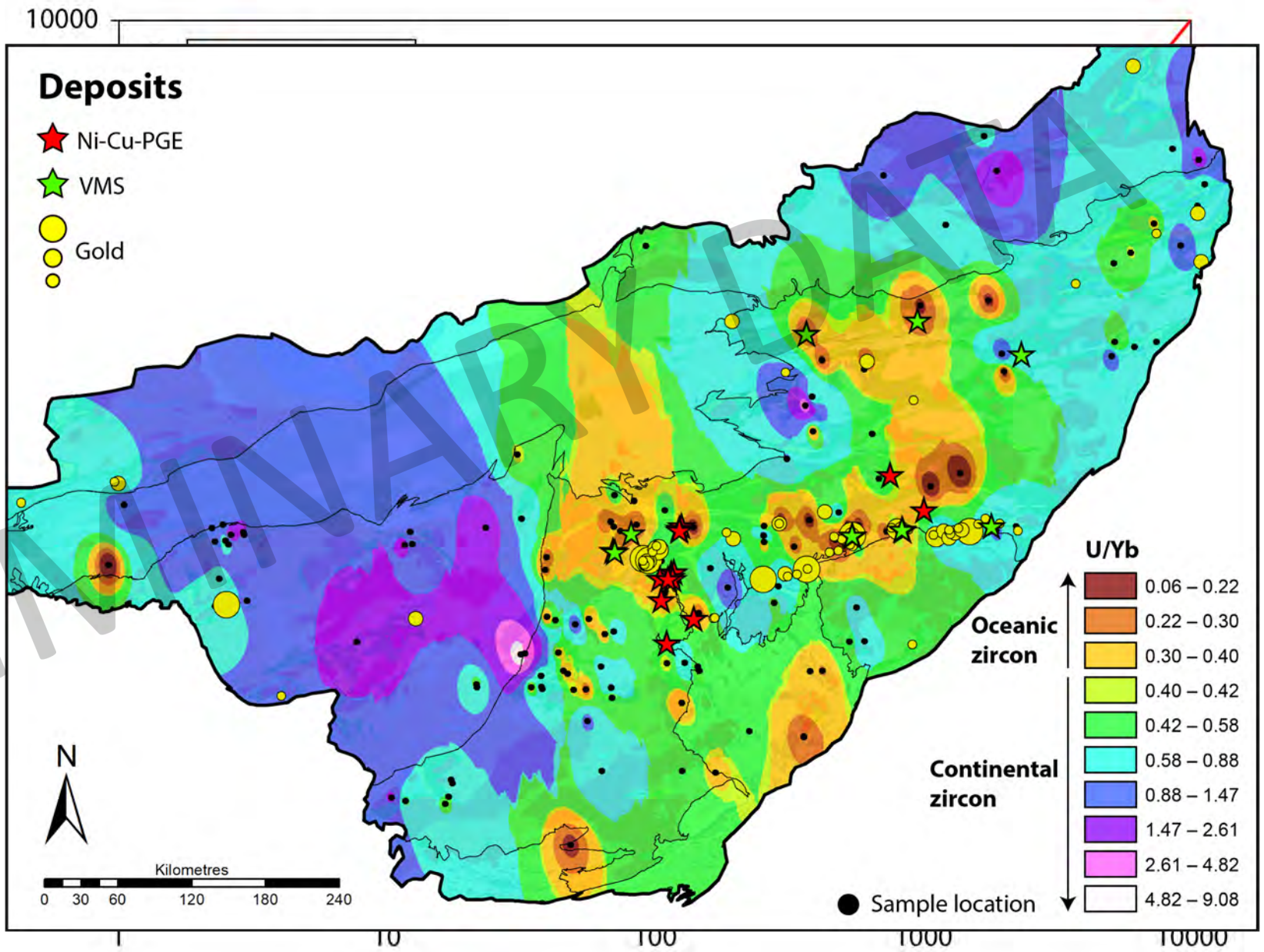
- Oxidation and hydration of magmas increases after 2.7 Ga
- U/Yb = High εHf areas show oceanic zircon occurrence



Grimes *et al.* (2015) *Contrib. Mineral. Petrol.*

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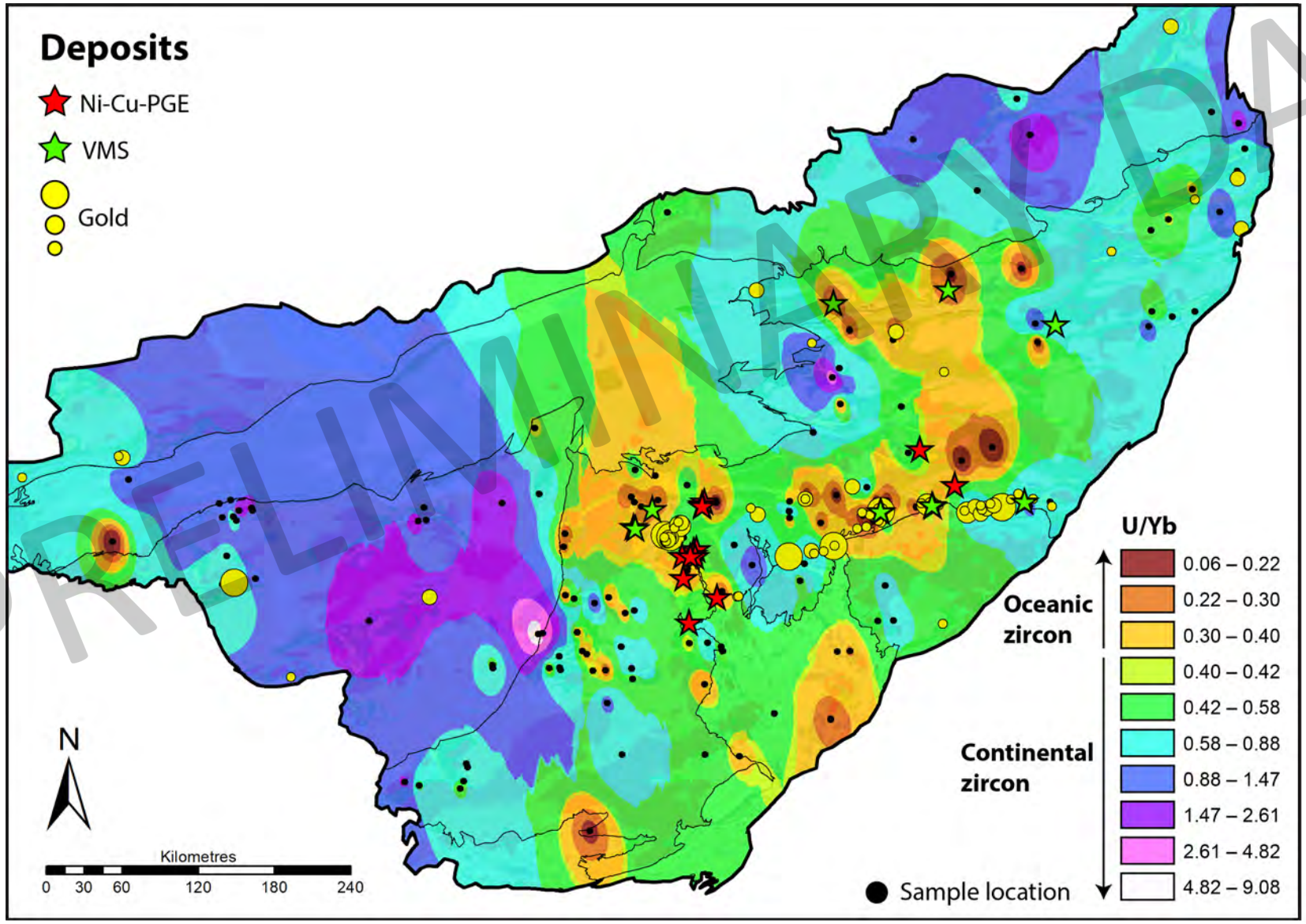
Combining Hf-O-TE map data



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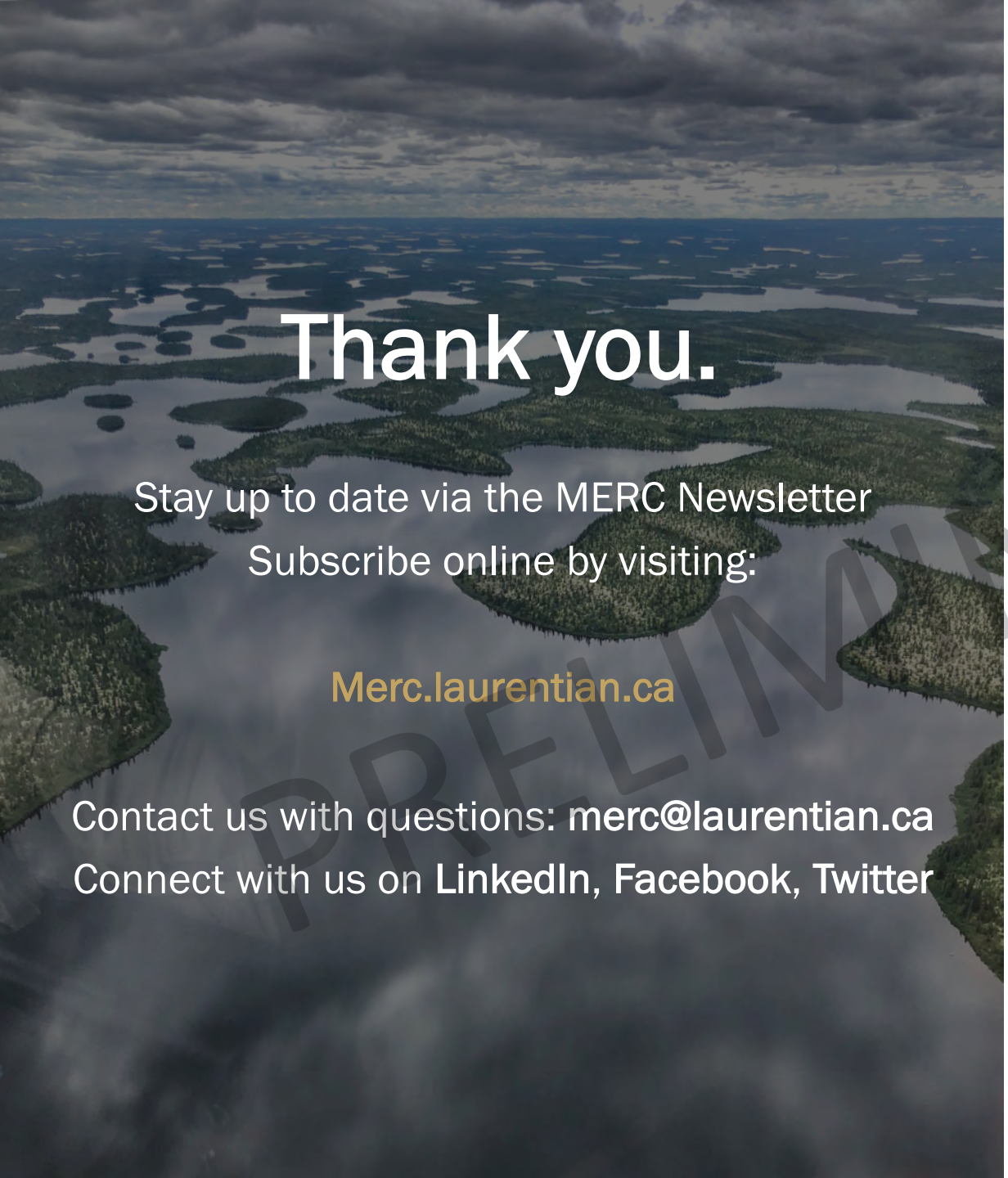
Summary

- The 4D multi-isotopic analytical approach allow us to integrate information on the source, temperature, oxidation, hydration and setting of SE Superior crust
- Hf-isotopes suggest a potential link between all terranes in the SE Superior
- The εHf data identifies N-S orientated highly-juvenile areas of the Abitibi
- These areas correlate with the lowest $\delta^{18}O$, indicating high-temperature hydrothermal activity, and the N-S orientation is replicated
- Trace elements suggest these areas are the least hydrated, most reduced, and most oceanic-like crust in the area
- These regions also appear to host the majority of VMS, Ni-Cu, and Gold systems
- We suggest a N-S orientated rift system was active in the Abitibi until ca. 2695 Ma, at which point the rift was inverted by N-S compression
- This shift in geodynamics is marked by the secular shift in $\delta^{18}O$, and increasing hydration and oxidation of the <2695 Ma magmas
- The SE Superior may be a continental rift that was hyper-extended, with oceanic crust produced within the major grabens, where the driest, most reduced magmas occurred, fuelling the world-class VMS systems



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Centre for Microscopy, Characterisation and Analysis (CMCA), Australia

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