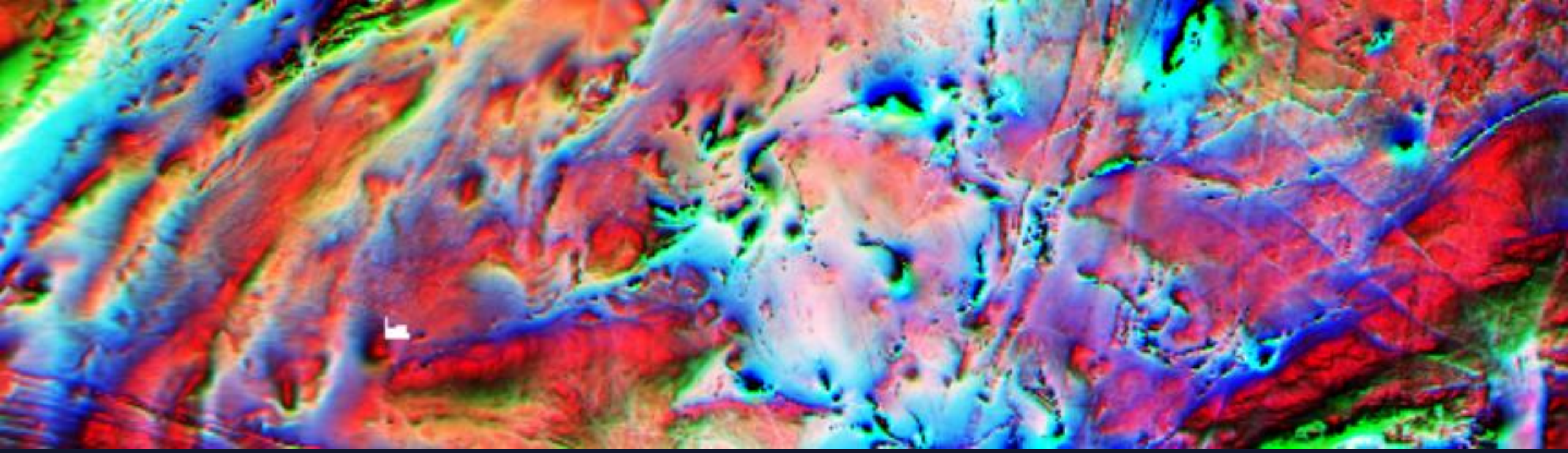


Linking deep lithospheric architecture to mantle-derived magmatism and associated mineralization in the Zimbabwe Craton:

insights from integrated satellite gravity and aeromagnetic data

Brian Mapingere[1]

Lyal B. Harris[1], Antoine Godet[2], Hielke Jelsma[3], Jérémie Lehmann[4]

[1]Institut national de la recherche scientifique, [2]Geological Survey of Canada, [3]University of Stellenbosch, [4]University of Johannesburg

Institut national de la recherche scientifique

Acknowledgements

Forbes Mugumbate & ZGS	Granting permission to use aeromag data & providing part of Zim kimberlite database
Jérémie Lehmann	Providing aeromag data & scientific discussions on tectonic controls on kimberlites
Hielke Jelsma	Providing a comprehensive Southern Africa kimberlite geochronology database & discussions on tectonic controls on kimberlites
Tom Blenkinsop	ZC tectonics and metallogeny discissions
Hillary Gumbo	Controls on kimberlites comments
Mark Tsomondo	Tectonics & metallogeny of the ZC, & other structural geology and tectonics related discussions

Some names may be missing, but my gratitude extends to all—thank you

"If I have seen further, it is by standing on the shoulders of giants."

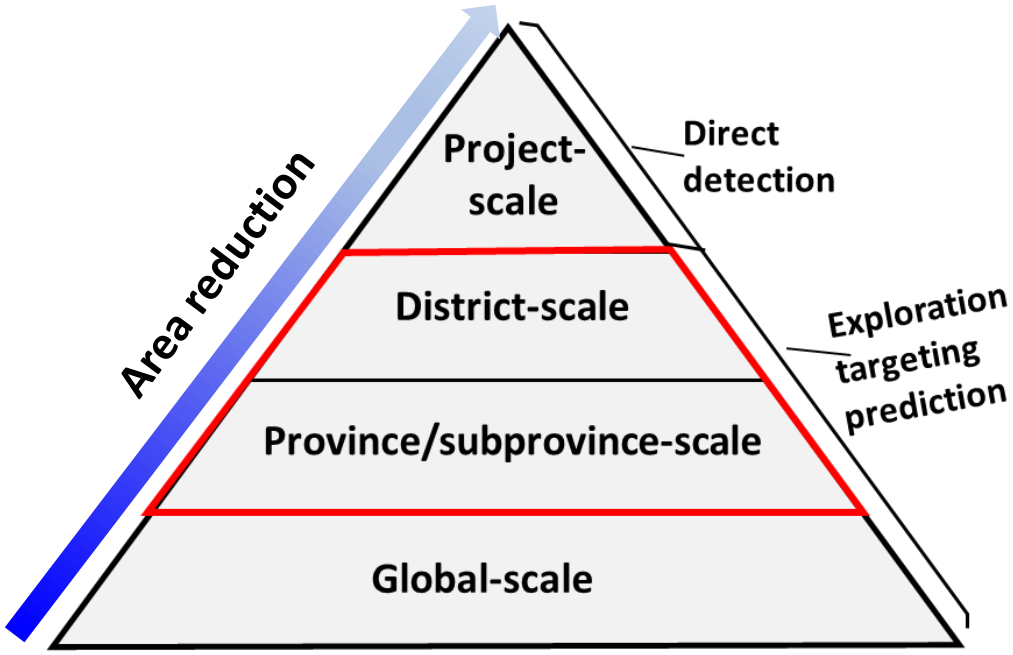
Isaac Newton

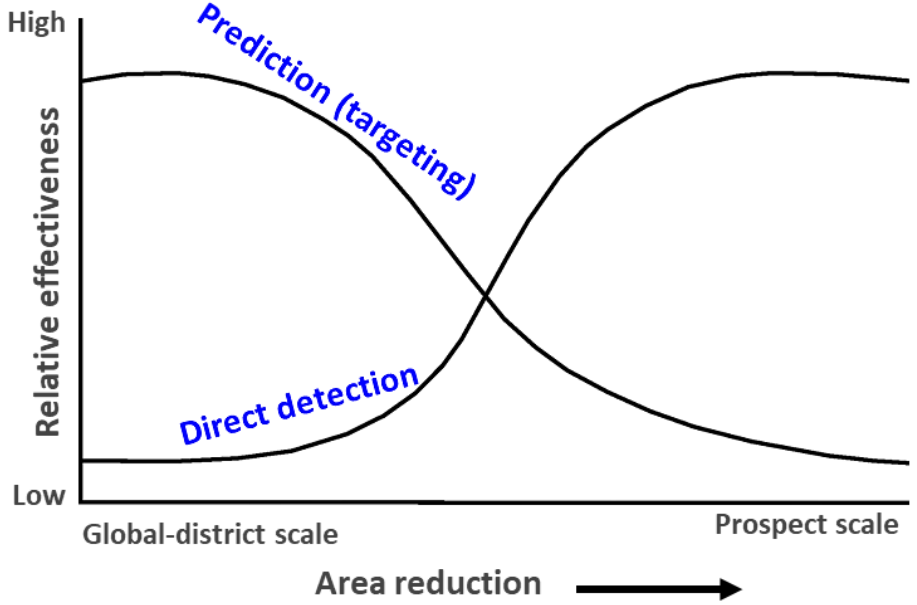
ZIMBABWE GEOLOGICAL SURVEY Z G S

ZIMBABWE

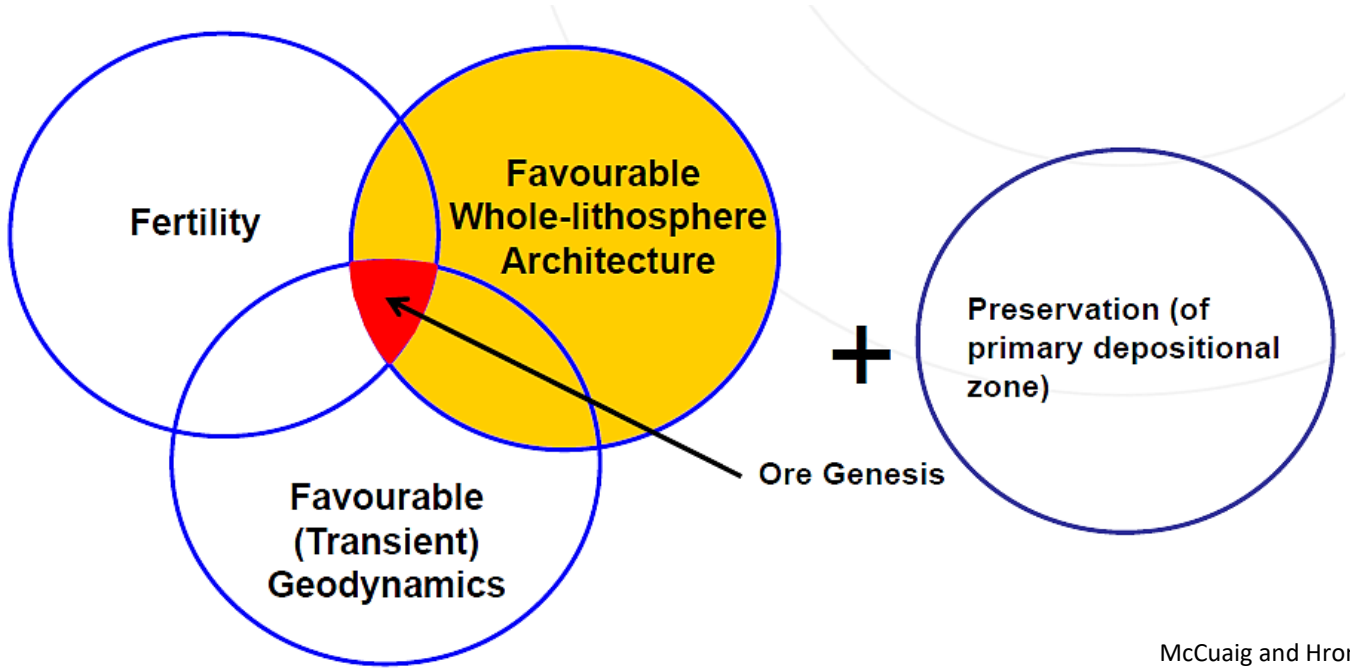
Context

Mineral systems parameters in predictive exploration targeting



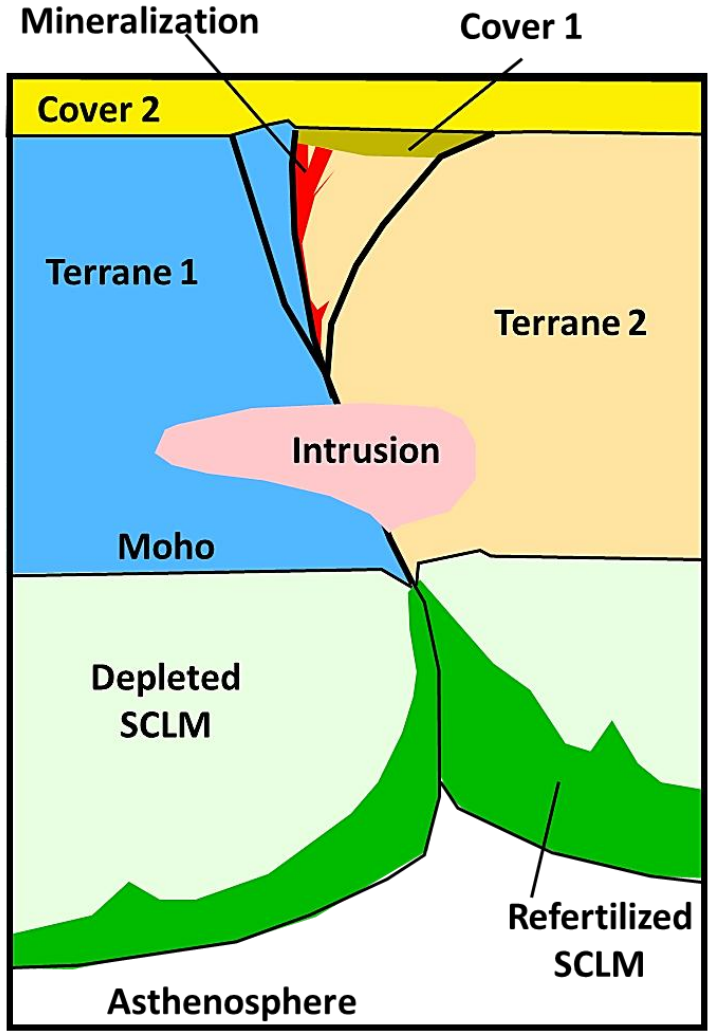


Modified after Hronsky and Groves (2008) AJES

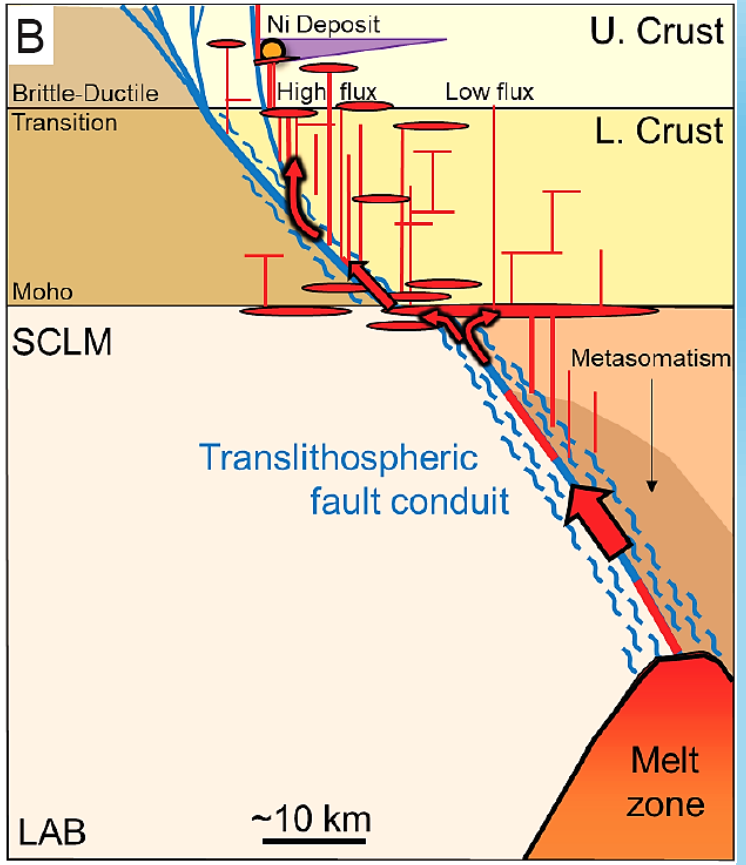


McCuaig and Hronsky (2014) AIG pres.

How are deep structures expressed?



Modified after Graham Begg presentation



Hayward et al. (2024) Econ. Geol.

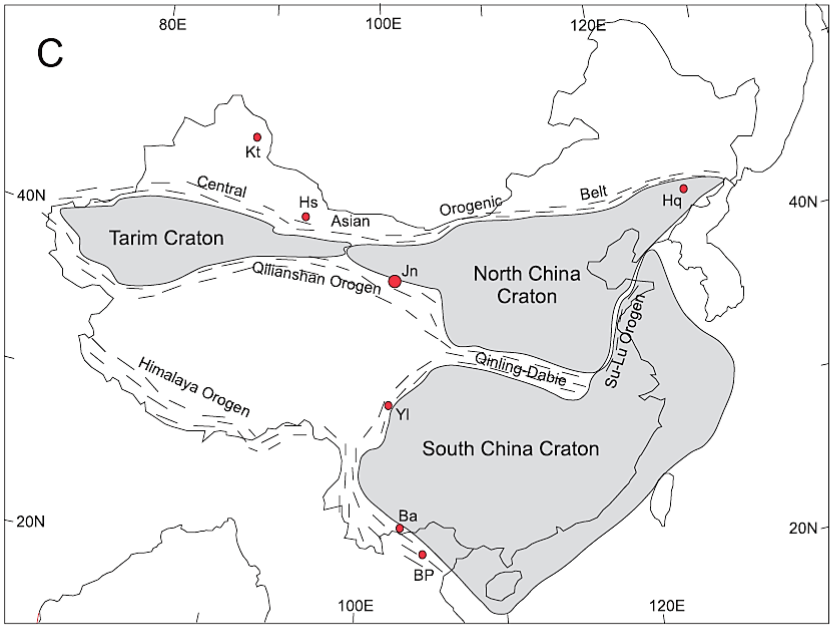
- Often lack uppermost crustal expression
- Connected to the upper crust by transfer faults

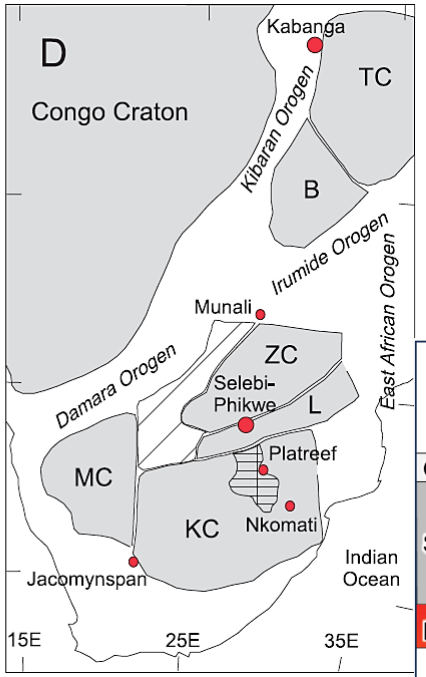
- Interaction between deep and upper crust structures is key to form:
  - *continuous lithospheric structural architecture*

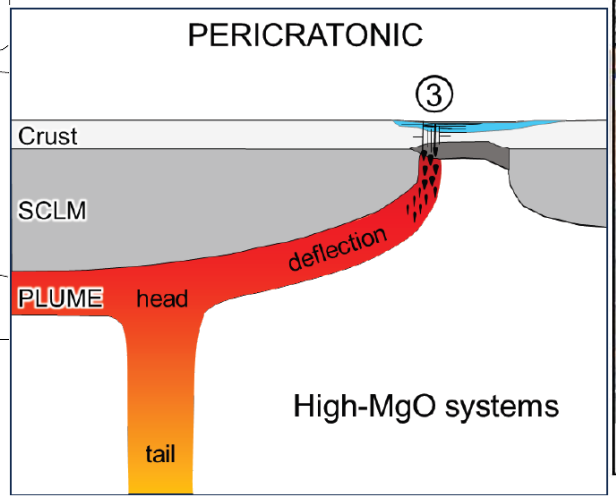
Lithospheric control on mineral deposits

Craton margin model – magmatic Ni-Cu-PGE deposits

- Magmatic Ni-Cu deposits spatially associated with cratonic lithospheric architecture
  - *Craton edge deposits – within 25 km*
  - *Near craton edge deposits – 25-100 km*
- Craton margins transected by transverse faults are more prospective



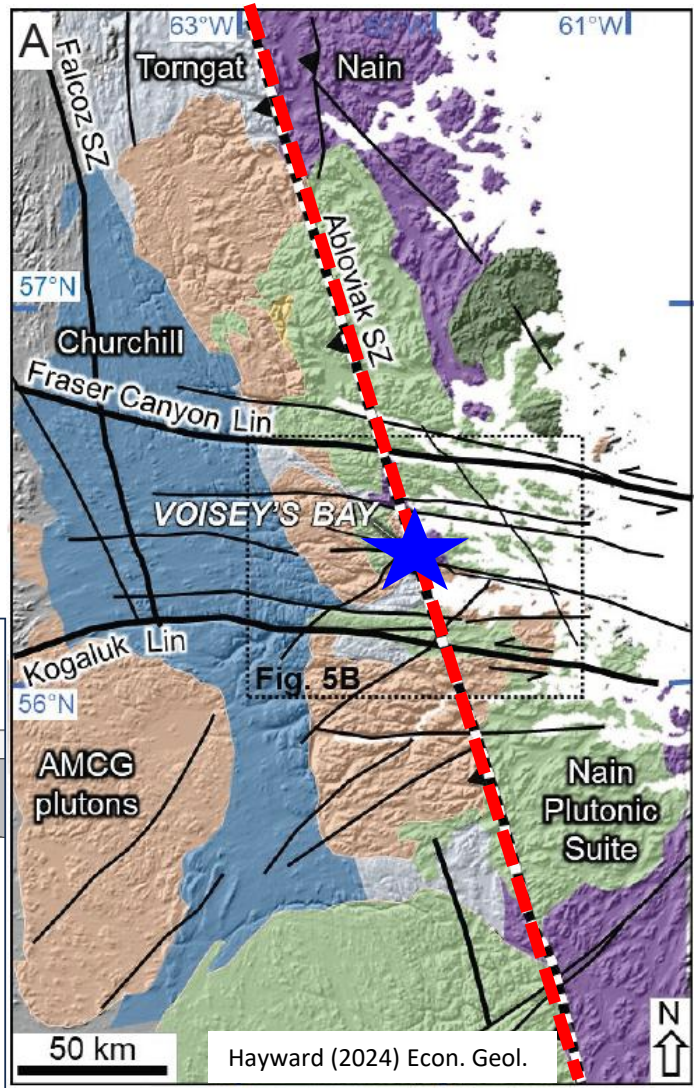




Begg et al. (2010) Econ. Geol.

1.33 Ga Voisey's Bay

- 141 million tonnes
- 1.63% Ni, 0.85% Cu & 0.09%)



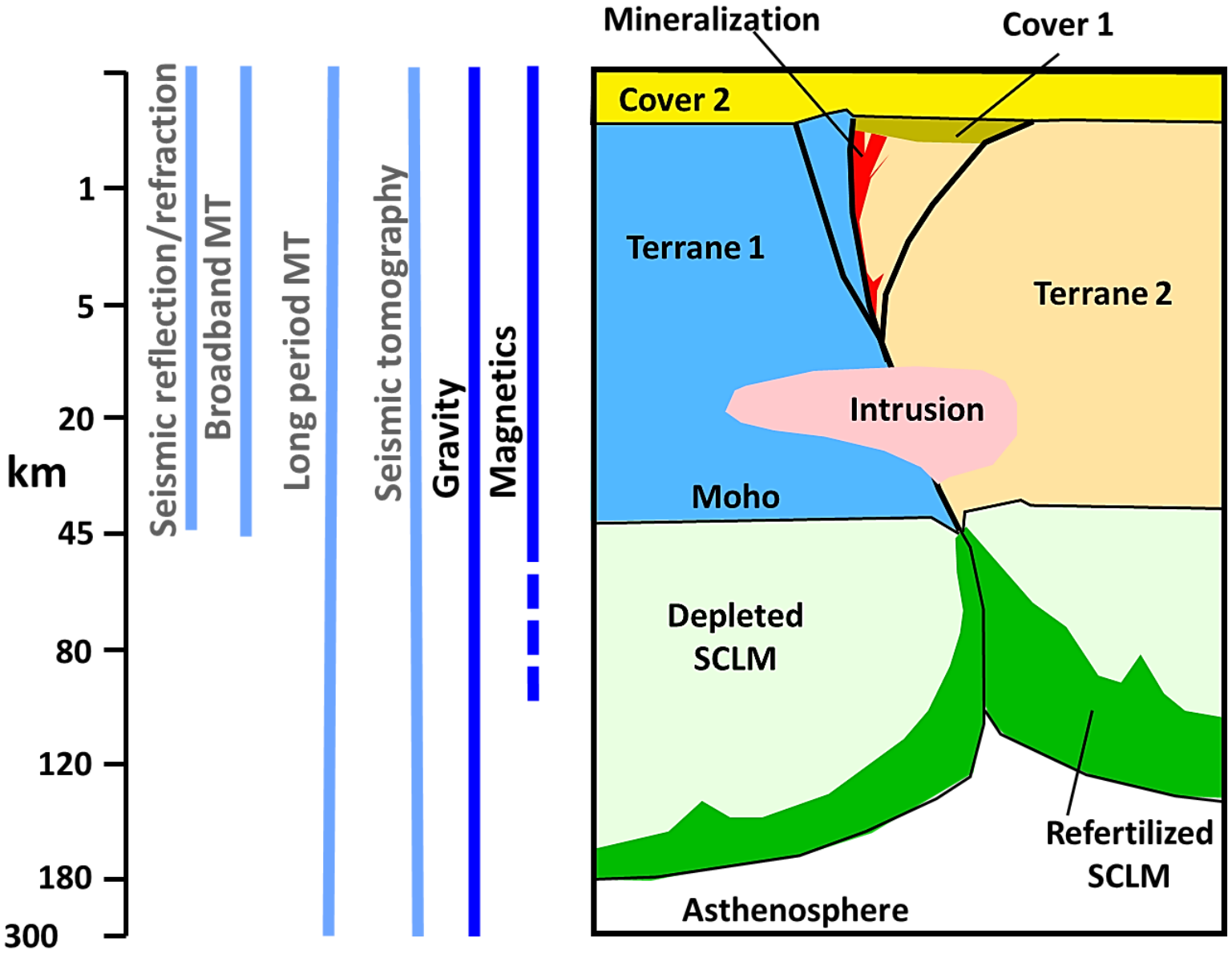
Hayward (2024) Econ. Geol.

Mapping deep structures

-

Lithospheric scale

Integration of interpretations from multiple geophysical datasets with surface-mapped geology



Modified after Graham Begg presentation

From lithospheric architecture to mineral systems

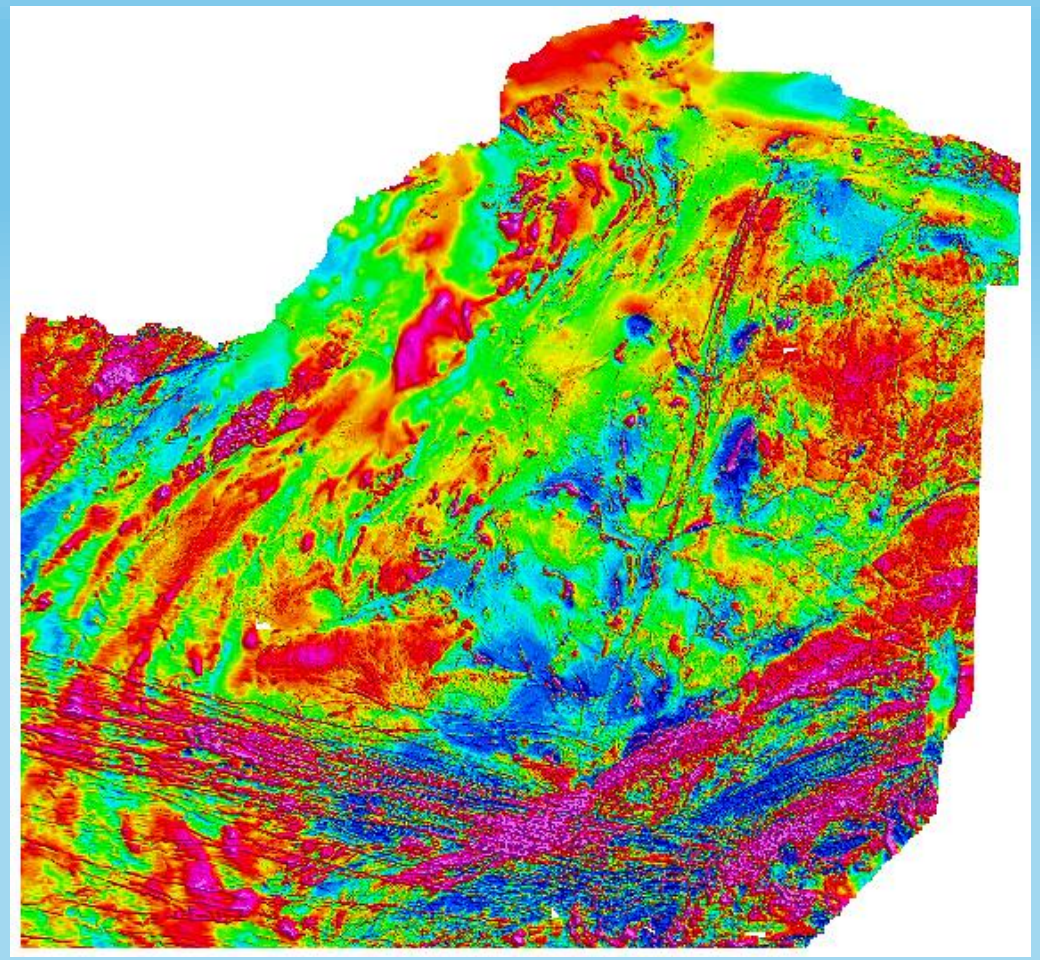
The case of the Zimbabwe Craton & its marginal orogenic belts

- What lithospheric-scale features lies beneath the ZC and its marginal orogenic belts?
- How does the deep lithosphere link with the upper crust?
- Where does mantle-derived magmatism and associated mineralisation occur relative to these structures?
  - Carbonatites, diamondiferous kimberlites and magmatic Ni-Cu
- Can these spatial relationships provide a framework for understanding the distribution of mantle-derived intrusions and related mineralisation?
- How can these spatial relationships translate into improved predictive exploration targeting strategies?

Geophysical data

Aeromagnetic data

- CIDA-funded surveys
- Surveys between 1983 & 1988
- 1 km flight line spacing
- 305 m terrain clearance



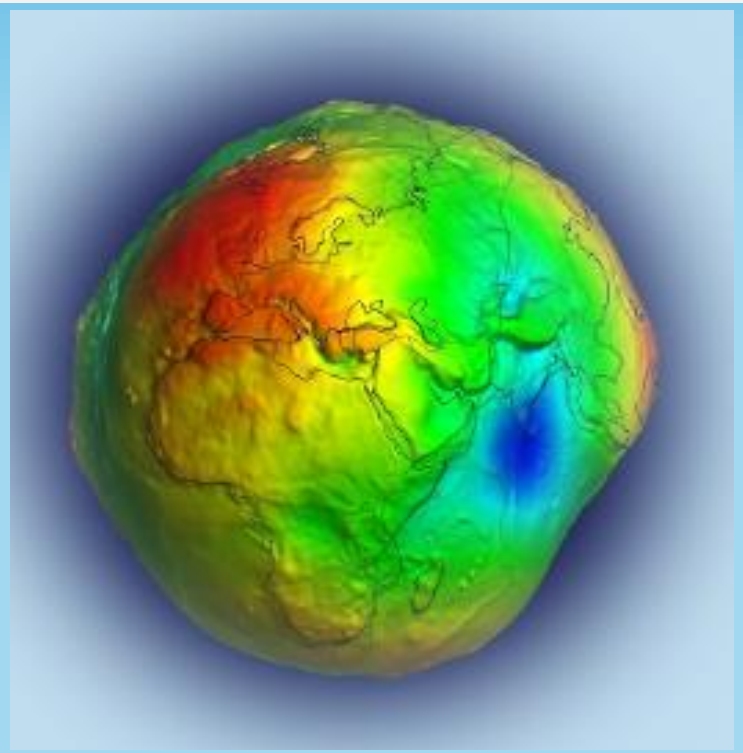
Satellite gravity data

XGM2019e_2159

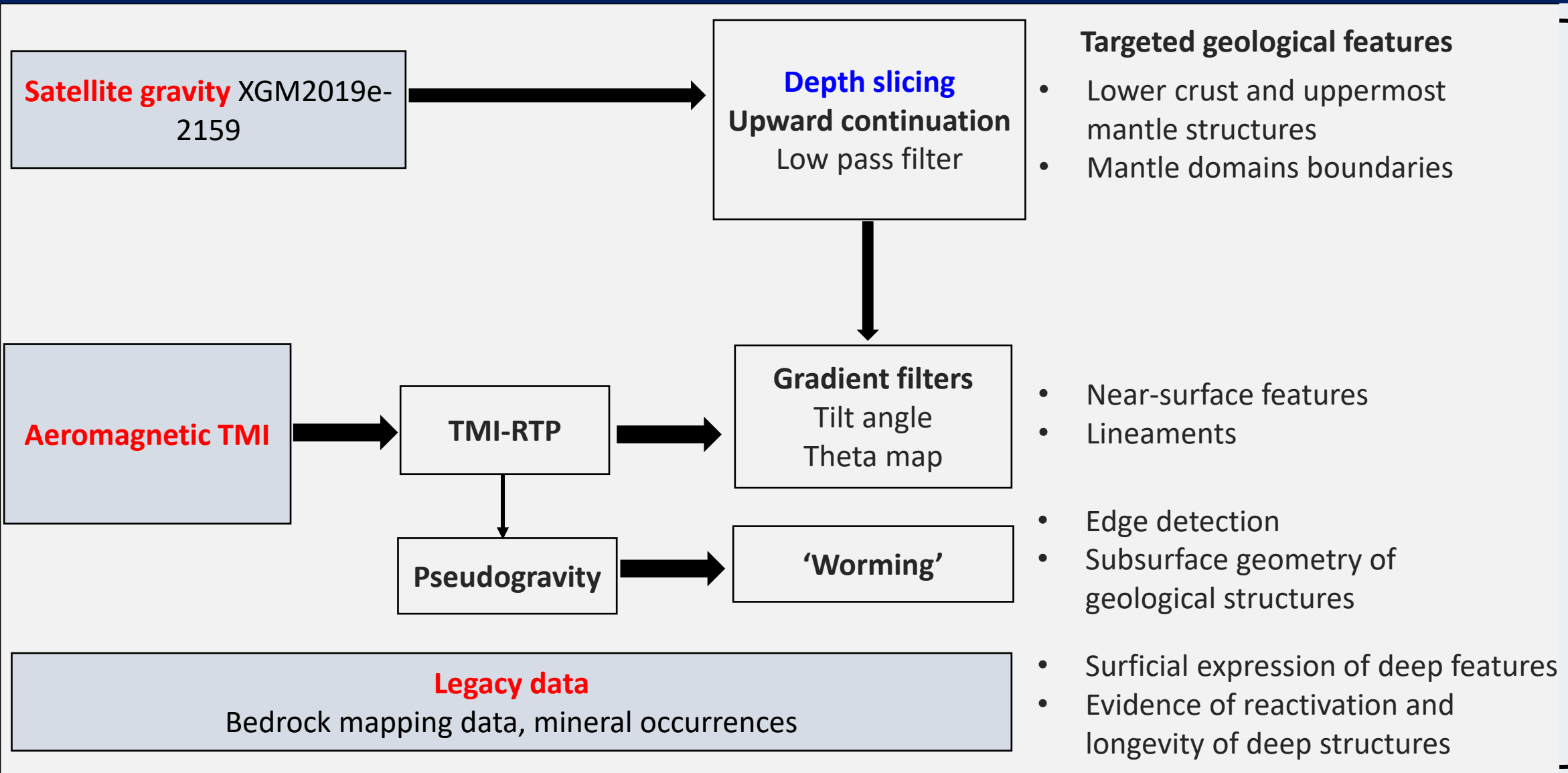
- Gravity anomaly (corrected for elevation)
- Bouguer gravity anomaly
- Gravivity disturbance anomaly

ICGEM

Global Gravity Field Models



Approach



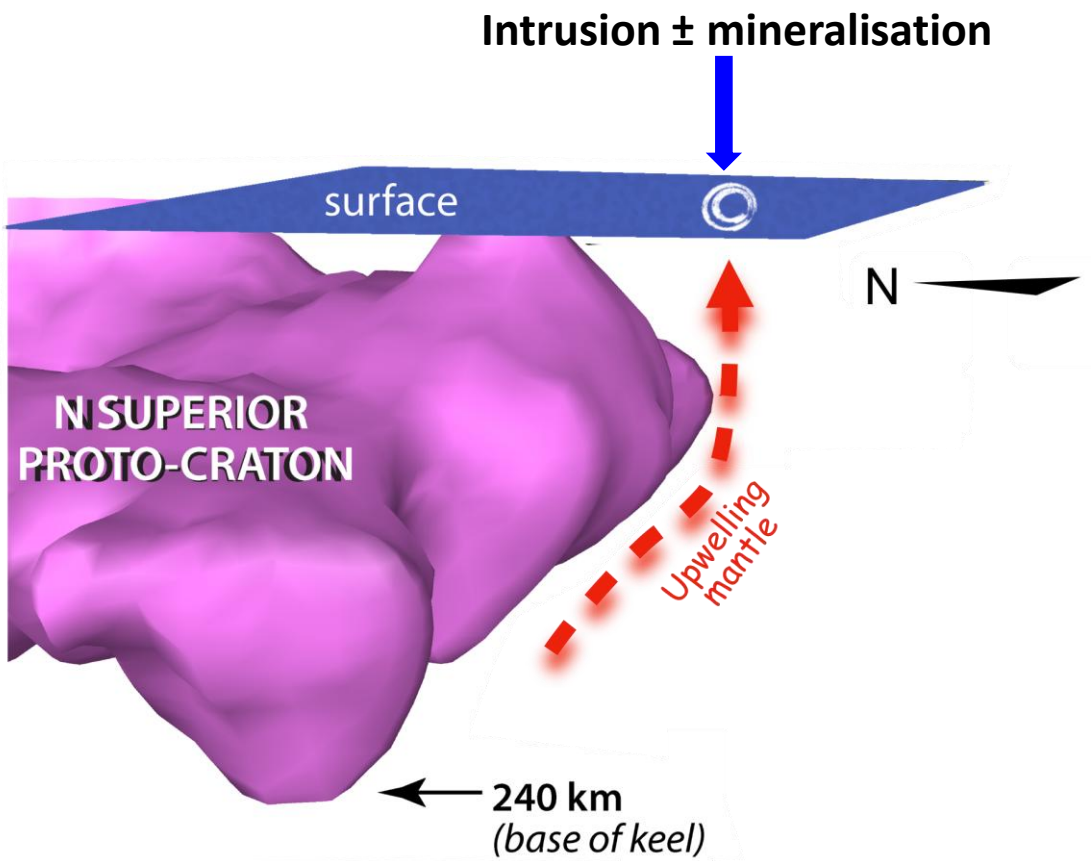
Oasis montaj

QGIS 4.0 Norrköping

SGTool

Limitations – structural interpretations from satellite gravity

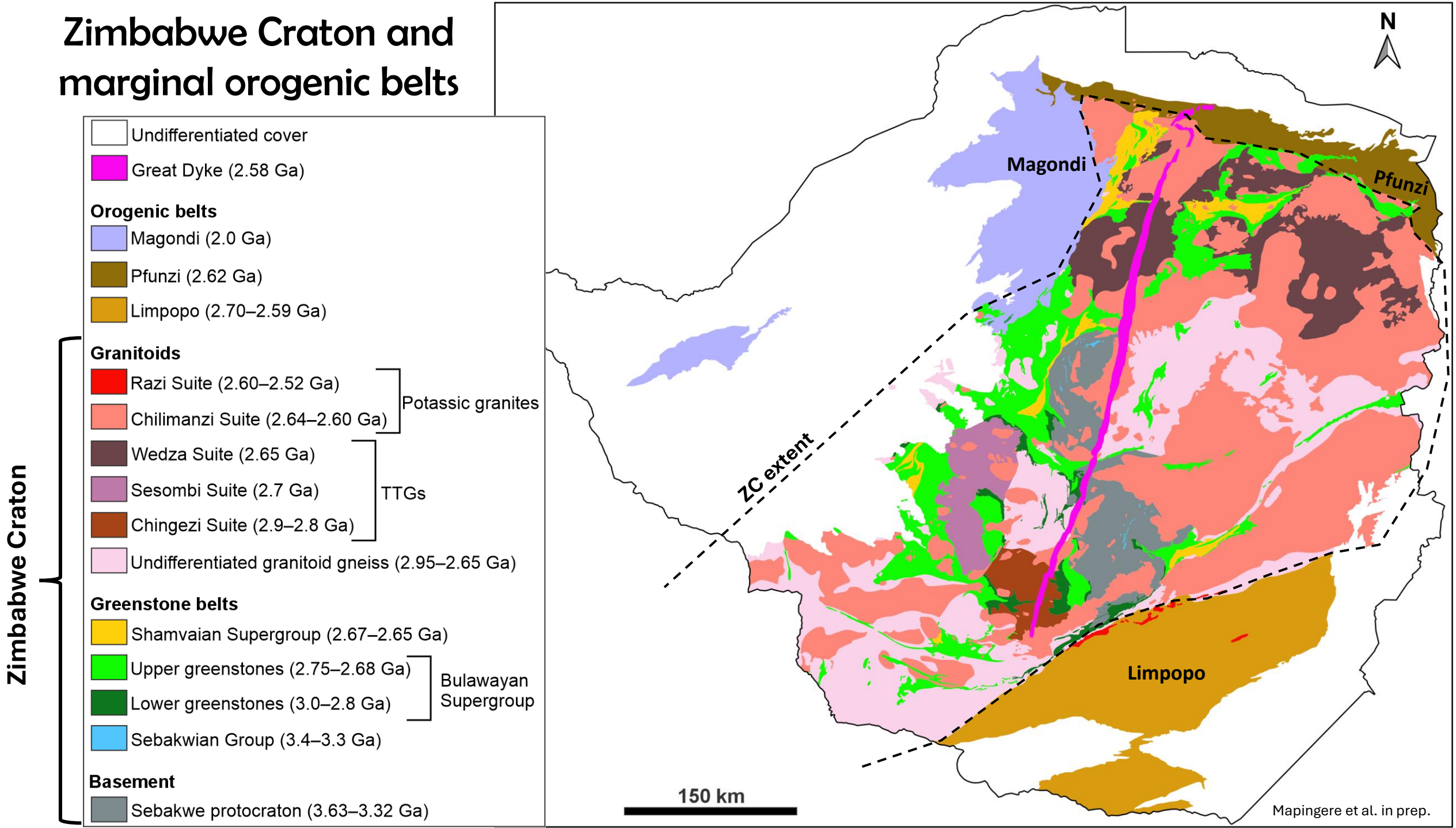
- The effective resolution of the used XGM2019e_2159 satellite gravity is generally low, ~9–10 km resolution
  - Smaller-scale structures are unresolved
- Enhancements on satellite gravity data therefore accentuates only the first-order regional SCLM features
- SCLM structural interpretation is limited to 2D, which is a simplified representation of actual complex SCLM geometries
- Seismic tomography provides improved 3D constraints on SCLM architecture and allows:
  - estimating the lithosphere-asthenosphere boundary (LAB) depth
  - characterizing the extent of chemical mantle depletion
  - characterizing the geometry of the upper mantle
- The interpreted SCLM structural features represent present-day geometries reflecting cumulative tectonic modification especially near orogenic belts



Seismic tomography proto-craton
(6% dVs isosurface)

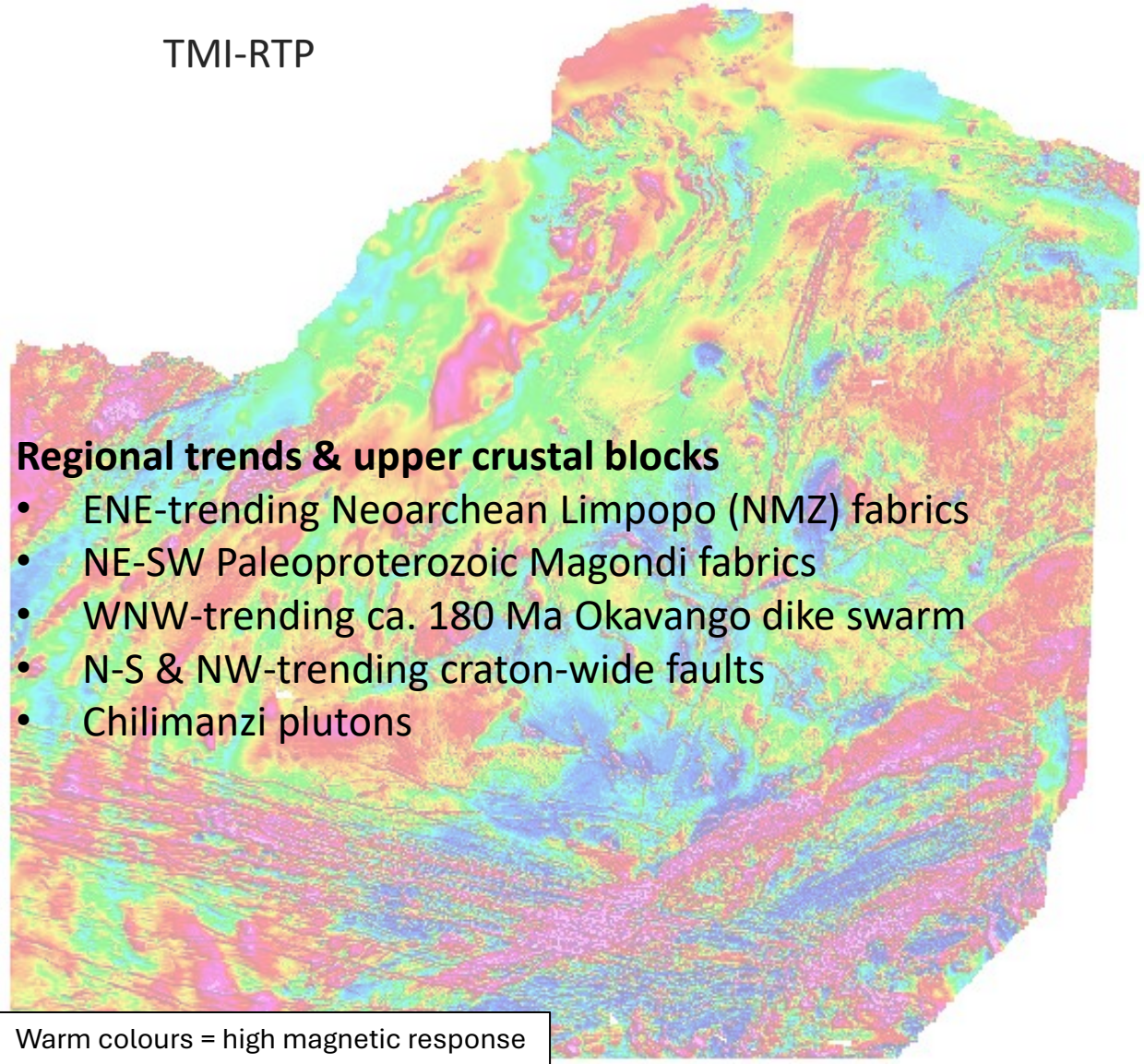
Provided by Lyal Harris

Zimbabwe Craton and marginal orogenic belts



Near-surface structures - *edge-enhanced pseudogravity*

TMI-RTP

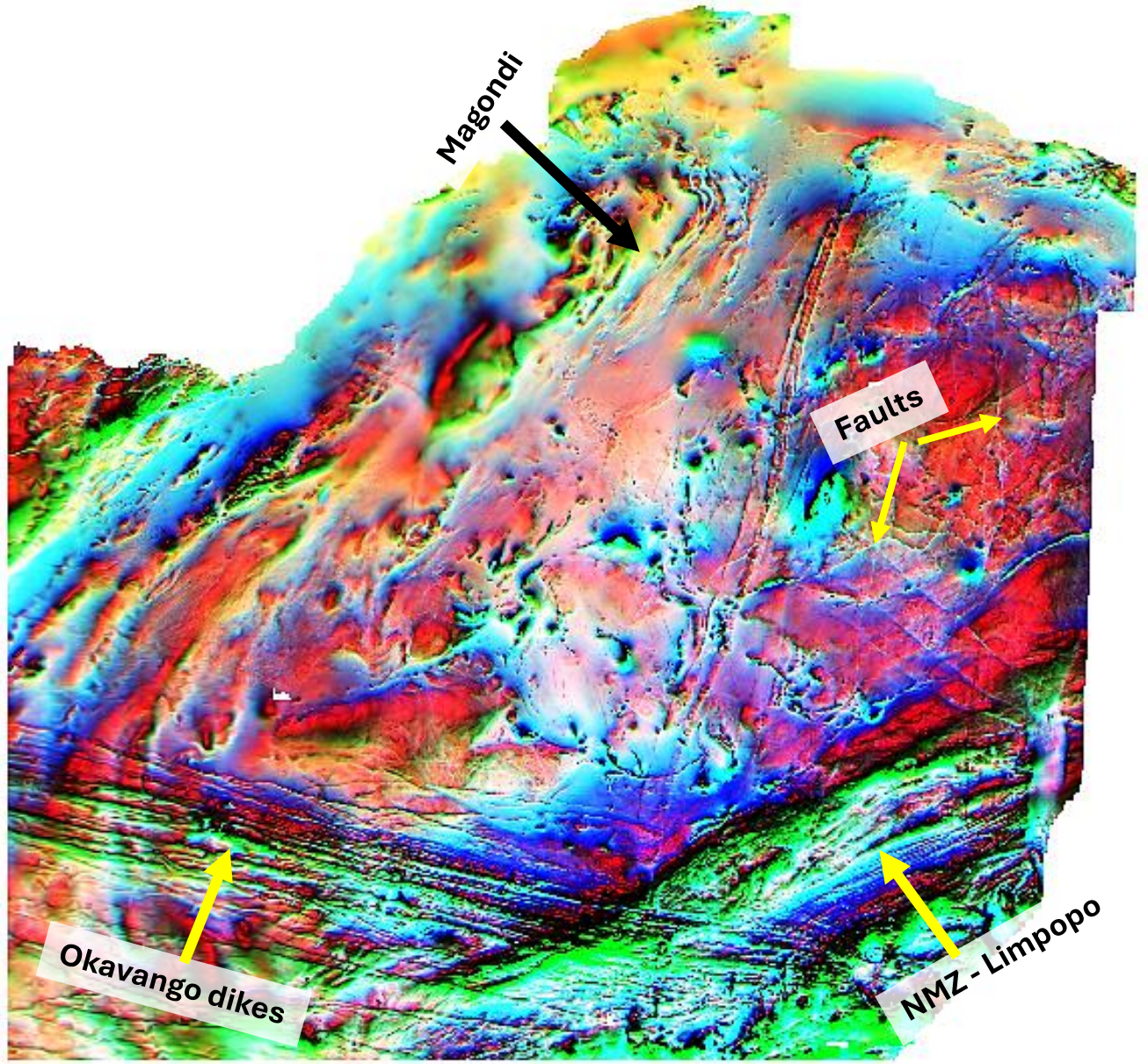


Regional trends & upper crustal blocks

- ENE-trending Neoarchean Limpopo (NMZ) fabrics
- NE-SW Paleoproterozoic Magondi fabrics
- WNW-trending ca. 180 Ma Okavango dike swarm
- N-S & NW-trending craton-wide faults
- Chilimanzi plutons

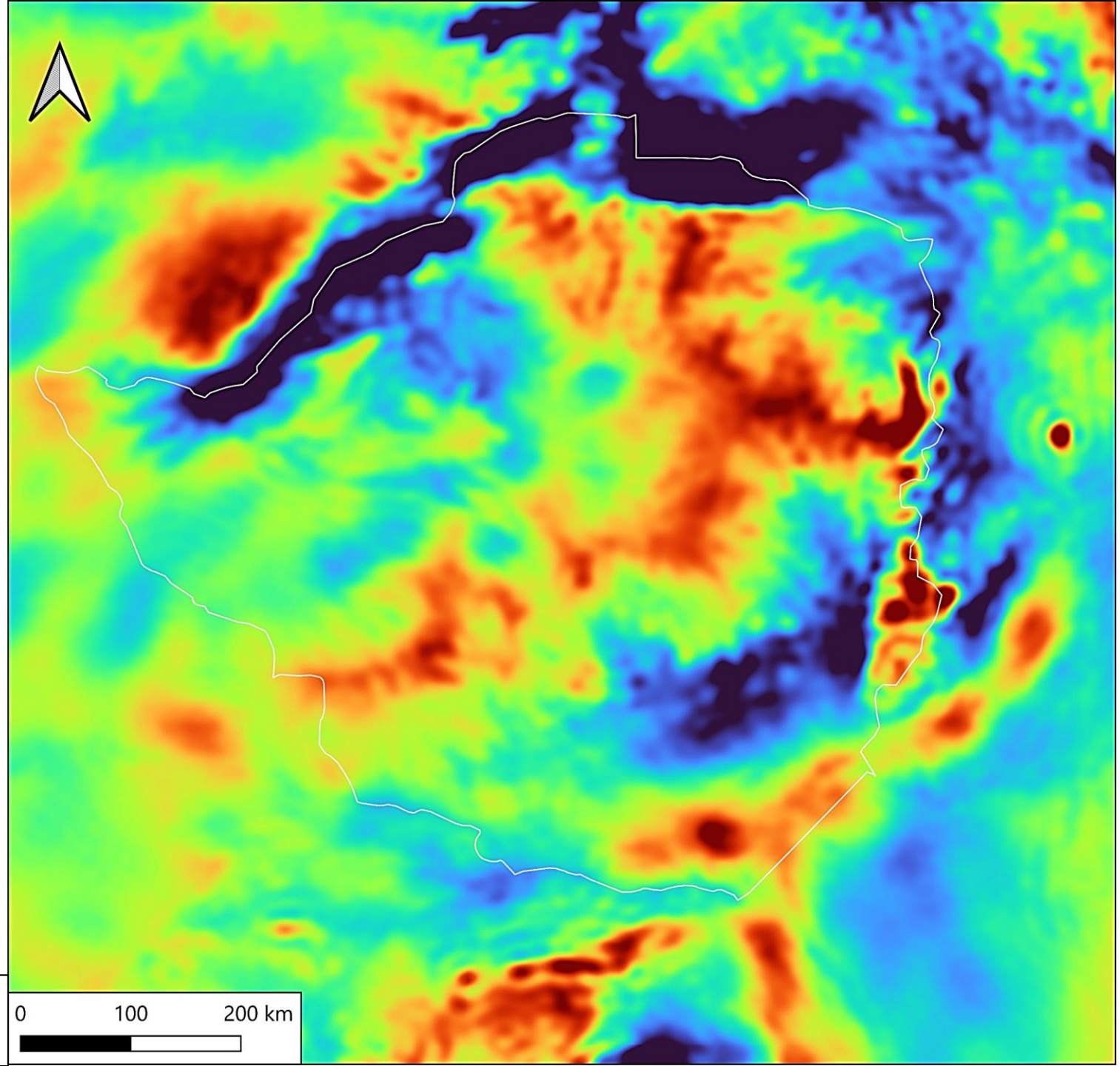
Warm colours = high magnetic response
Cool colours = low magnetic response

Ternary map (TMI-RTP–VI–THDR)



Total field - satellite gravity disturbance anomaly

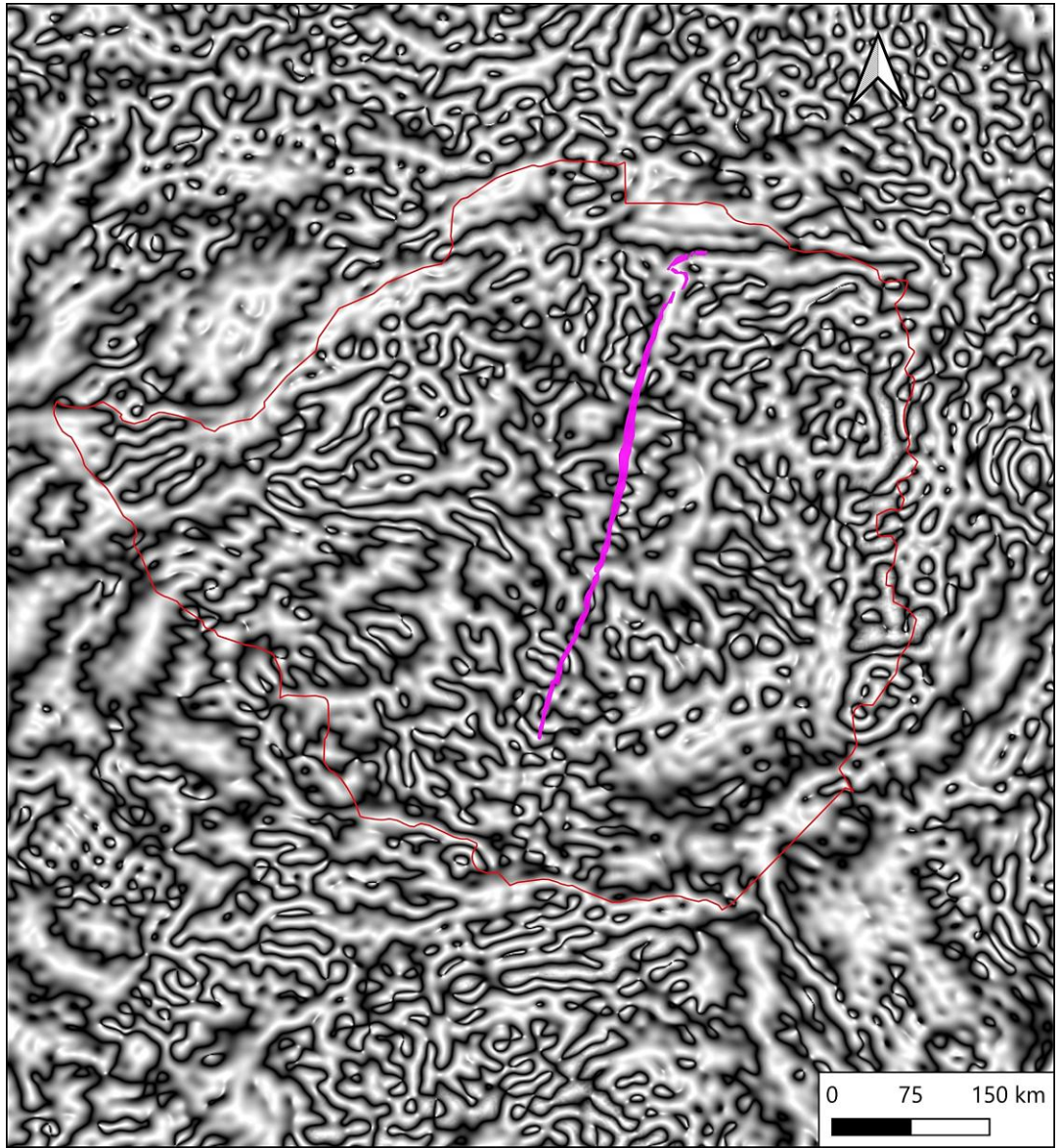
- Appreciable gravity highs and lows
- *But not much structural information is apparent*



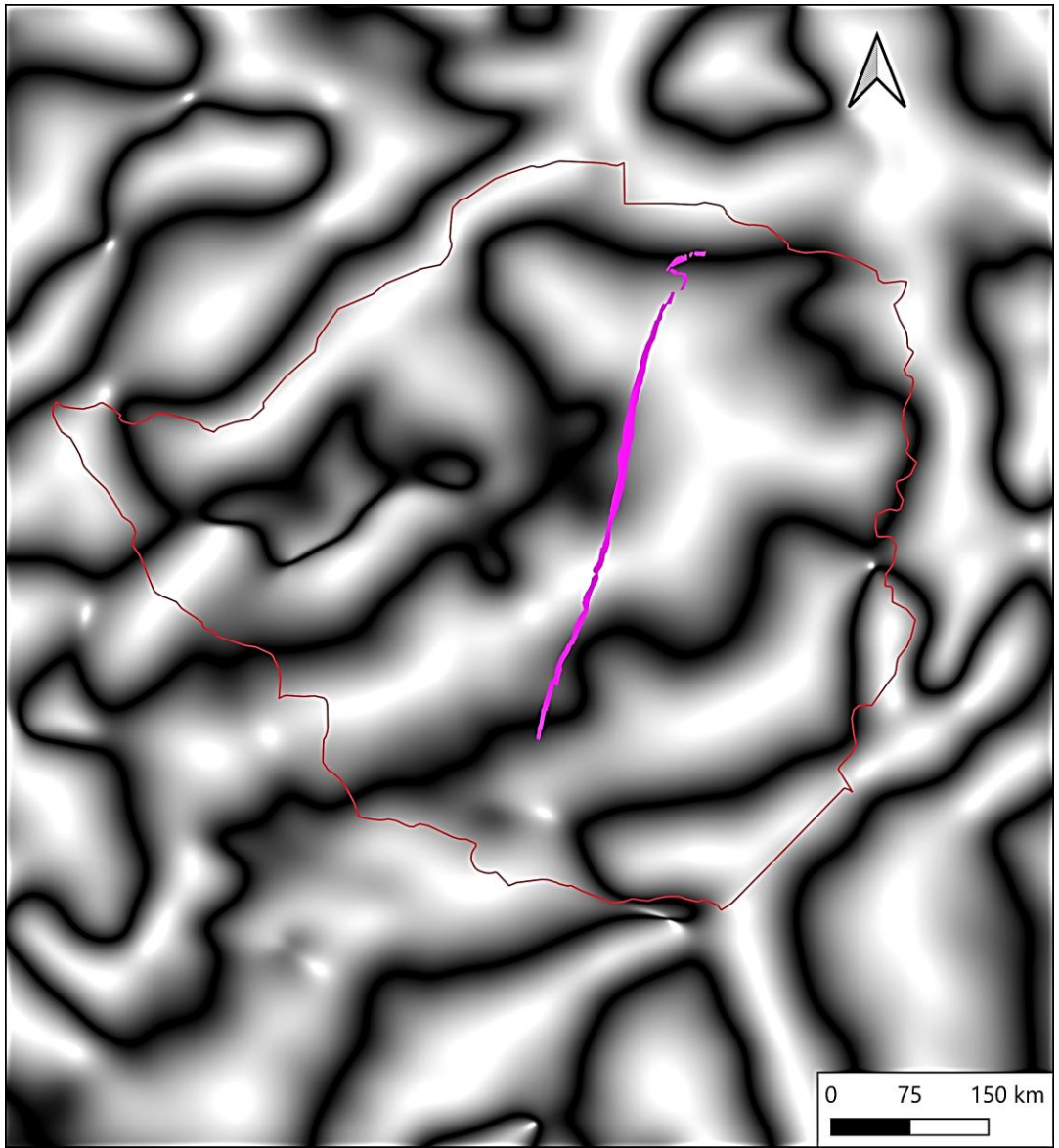
Warm colours = high gravity response
Cool colours = low gravity response

ZC lithospheric keel margin – edge-enhanced satellite gravity

Gravity disturbance theta map (original grid)

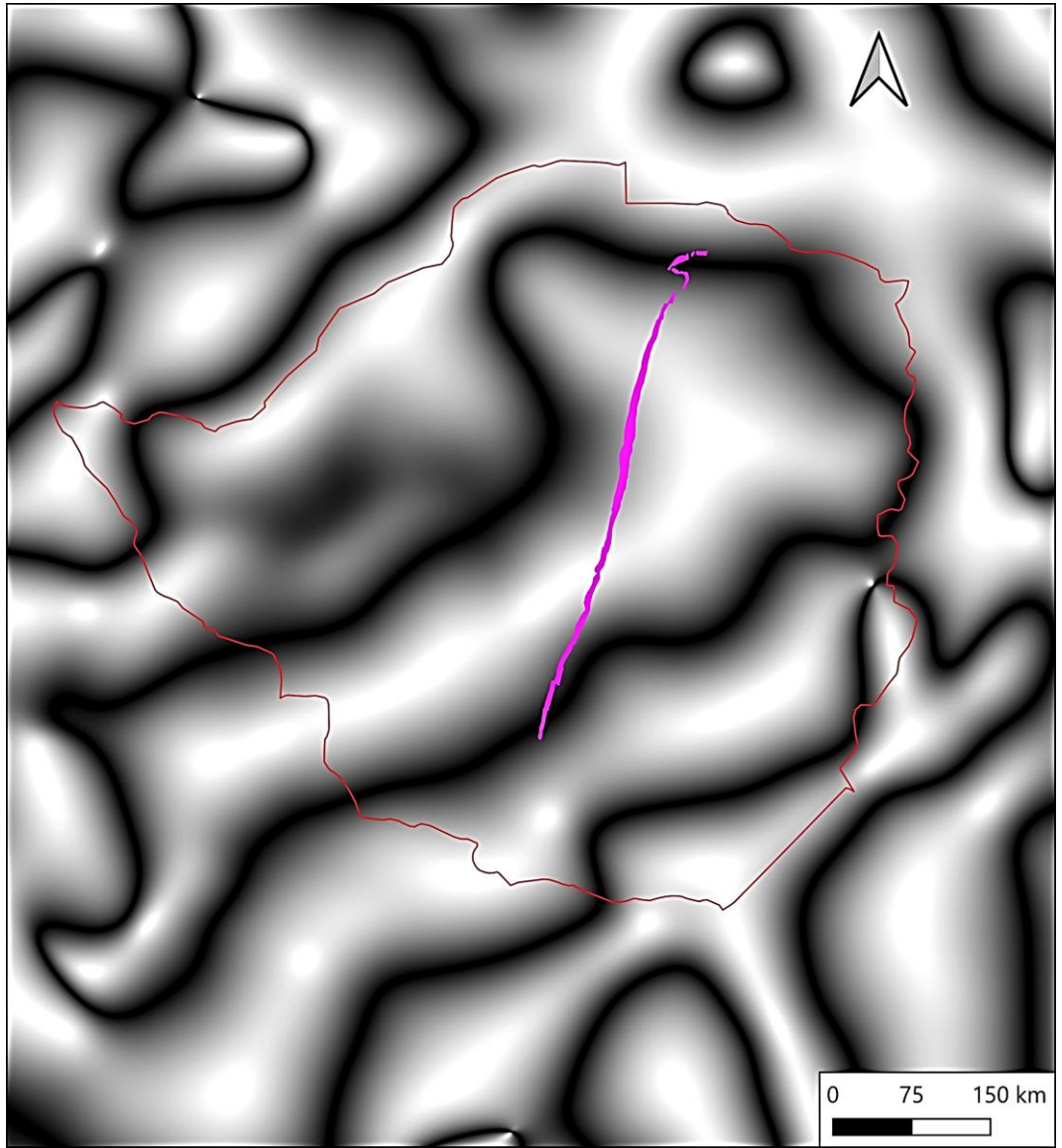


Gravity disturbance theta map (UC 30km)

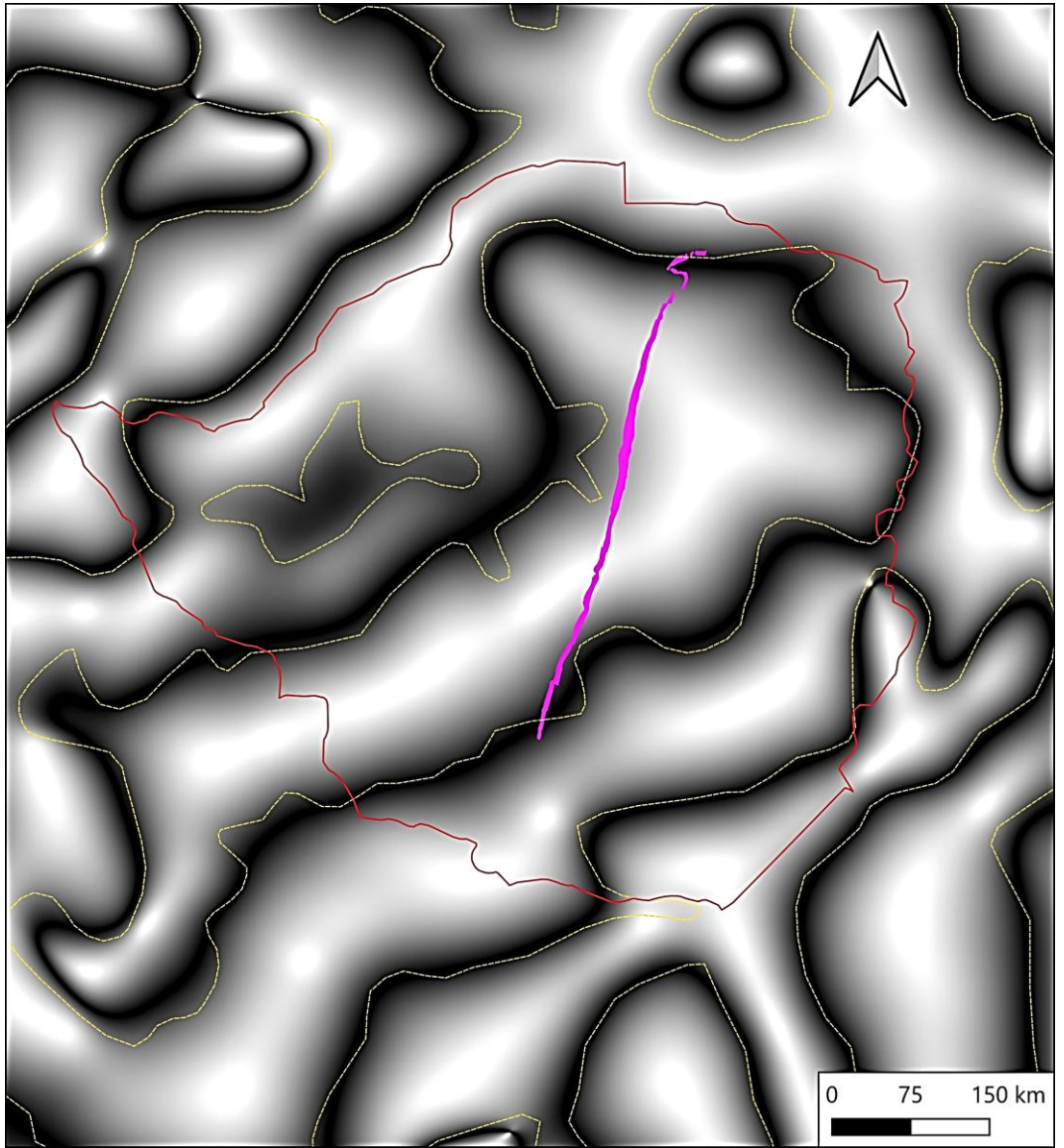


ZC lithospheric keel margin – edge-enhanced satellite gravity

Gravity disturbance theta map (UC 50km)

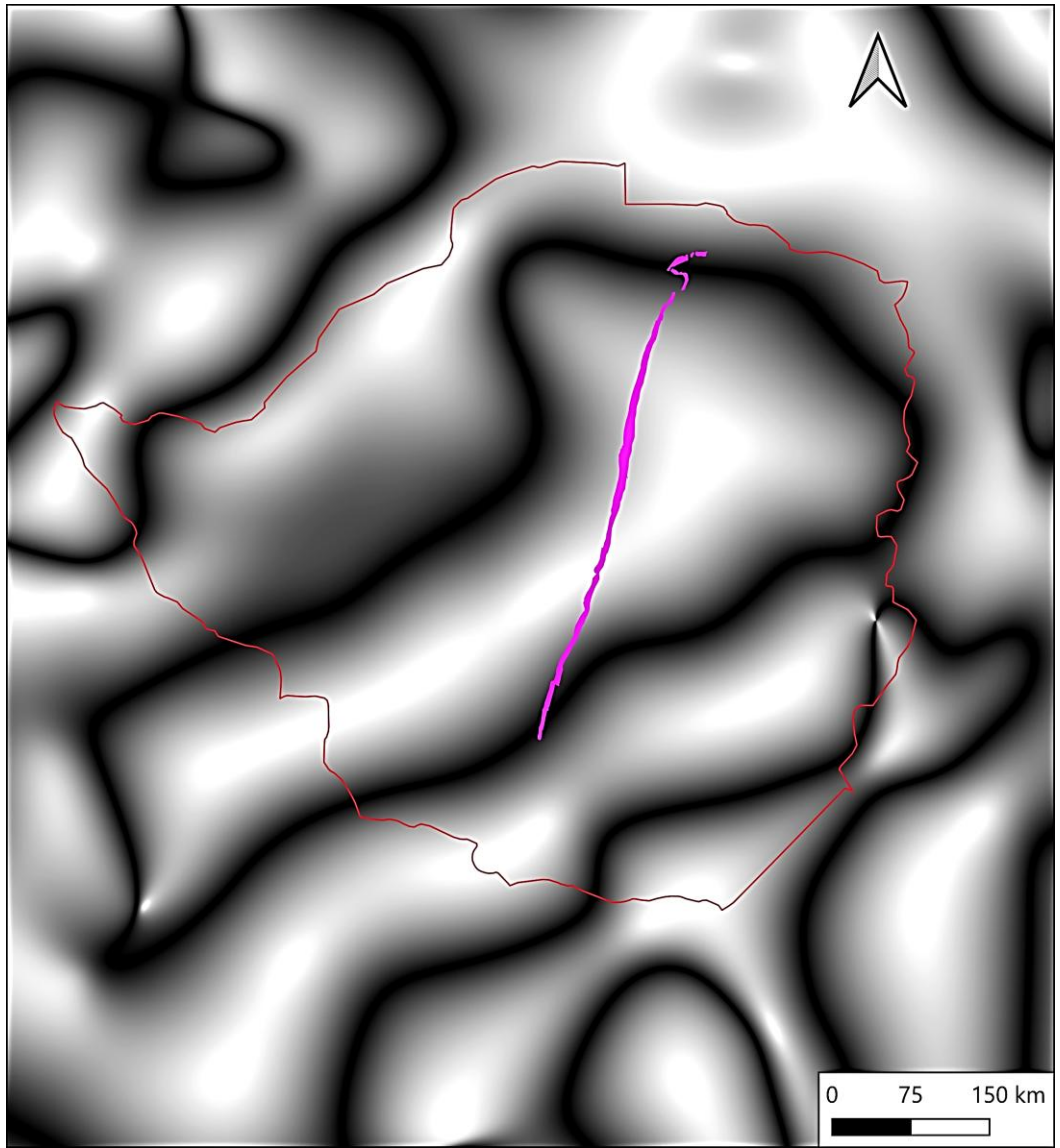


Gravity disturbance theta map (UC 50km + 30 km boundary)

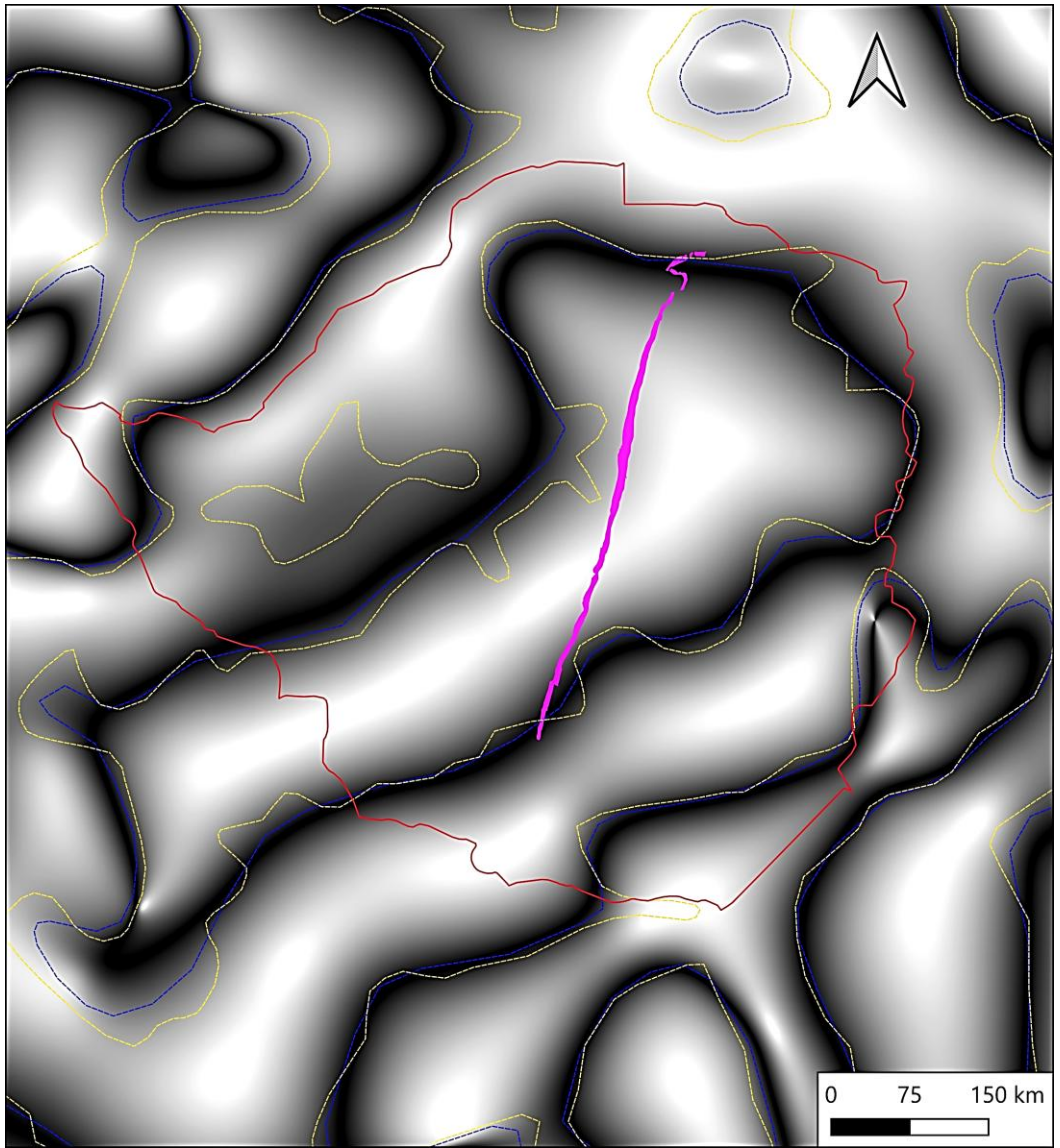


ZC lithospheric keel margin – edge-enhanced satellite gravity

Gravity disturbance theta map (UC 70km)

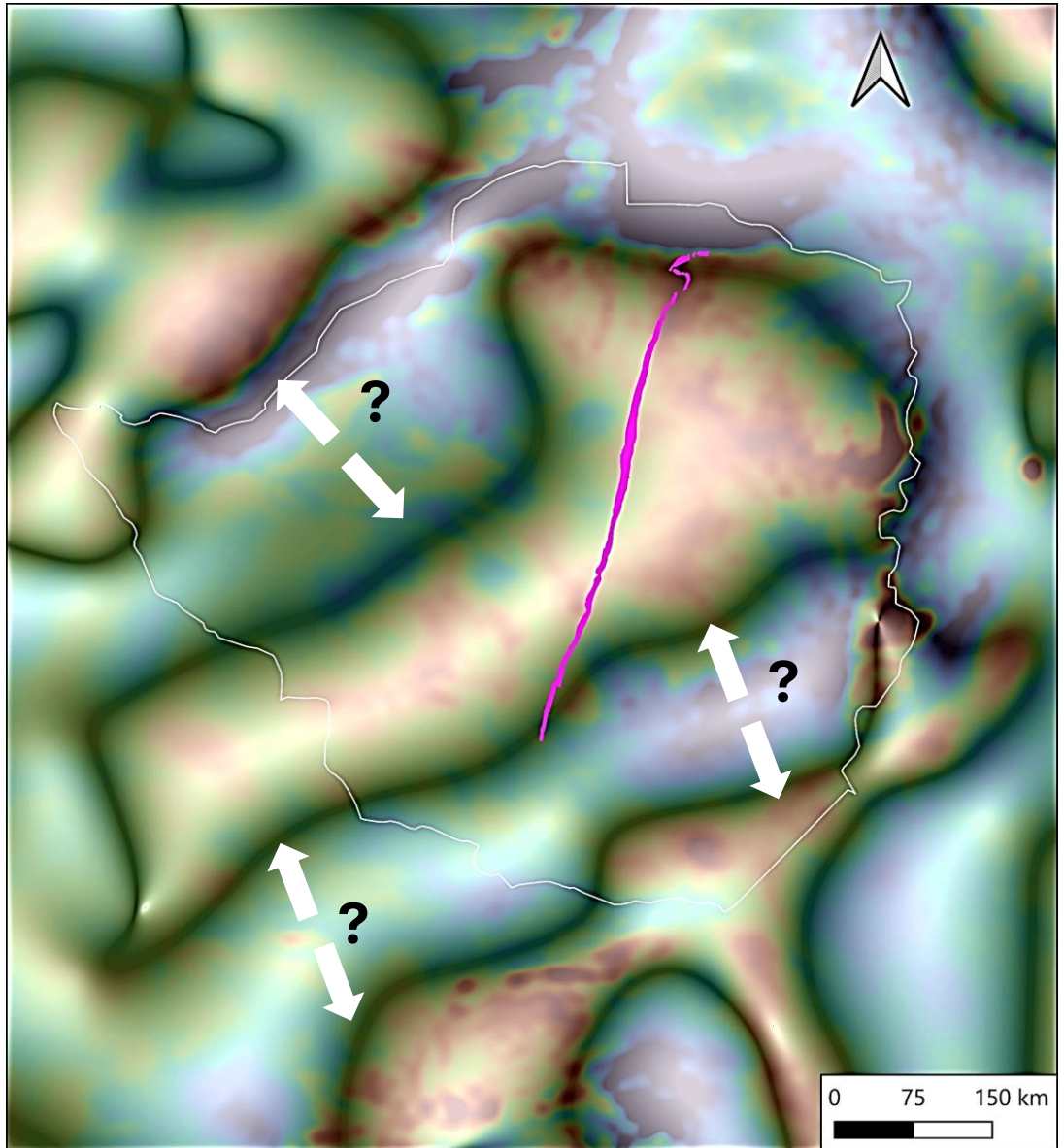


Gravity disturbance theta map (UC 70km + 30 + 50 km boundaries)

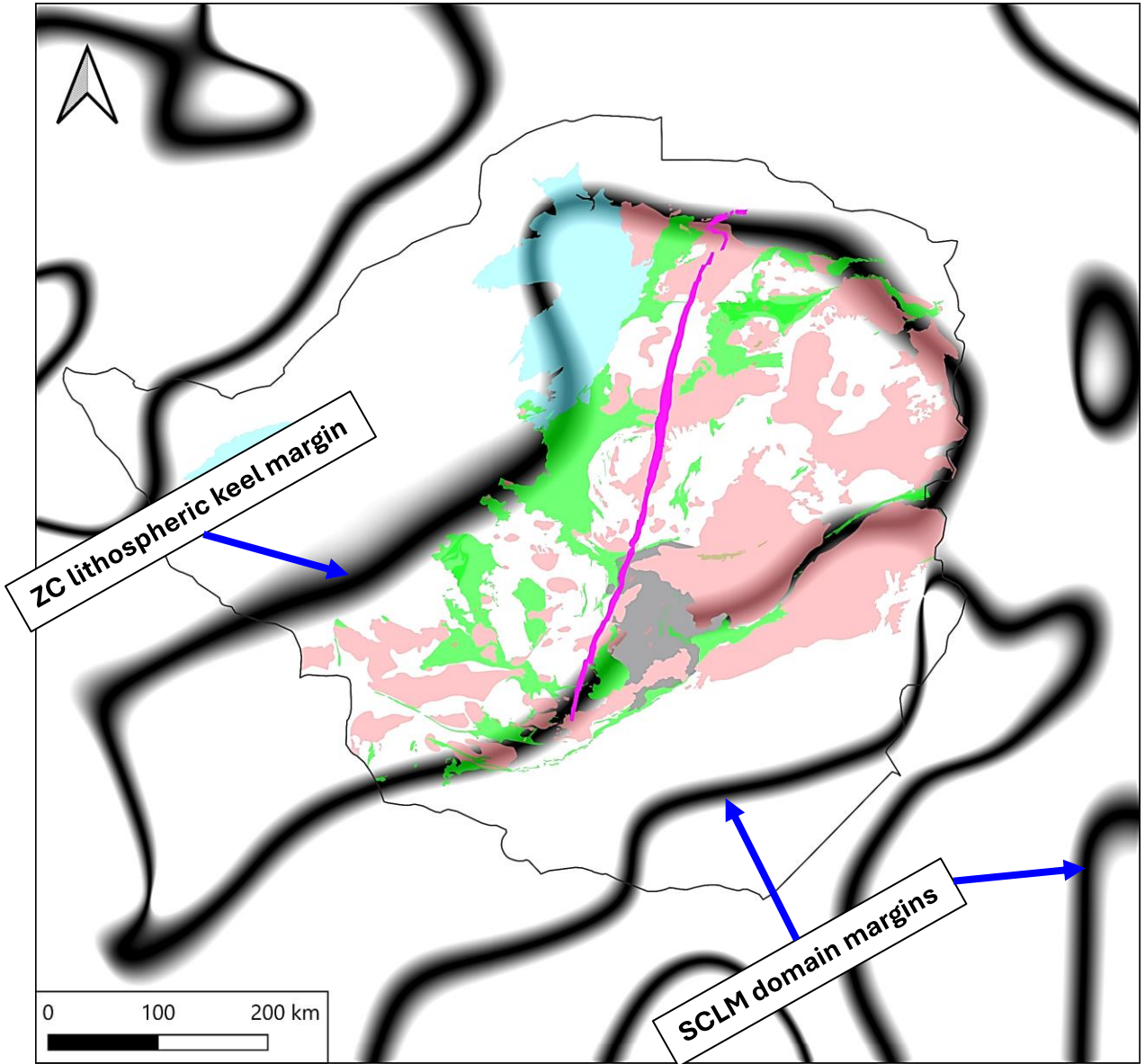


ZC lithospheric keel margin – edge-enhanced satellite gravity

Theta shade: gravity disturbance theta map (ca. 70 km depth slice) over gravity total field



Geology over gravity disturbance theta map (ca. 70 km depth slice)

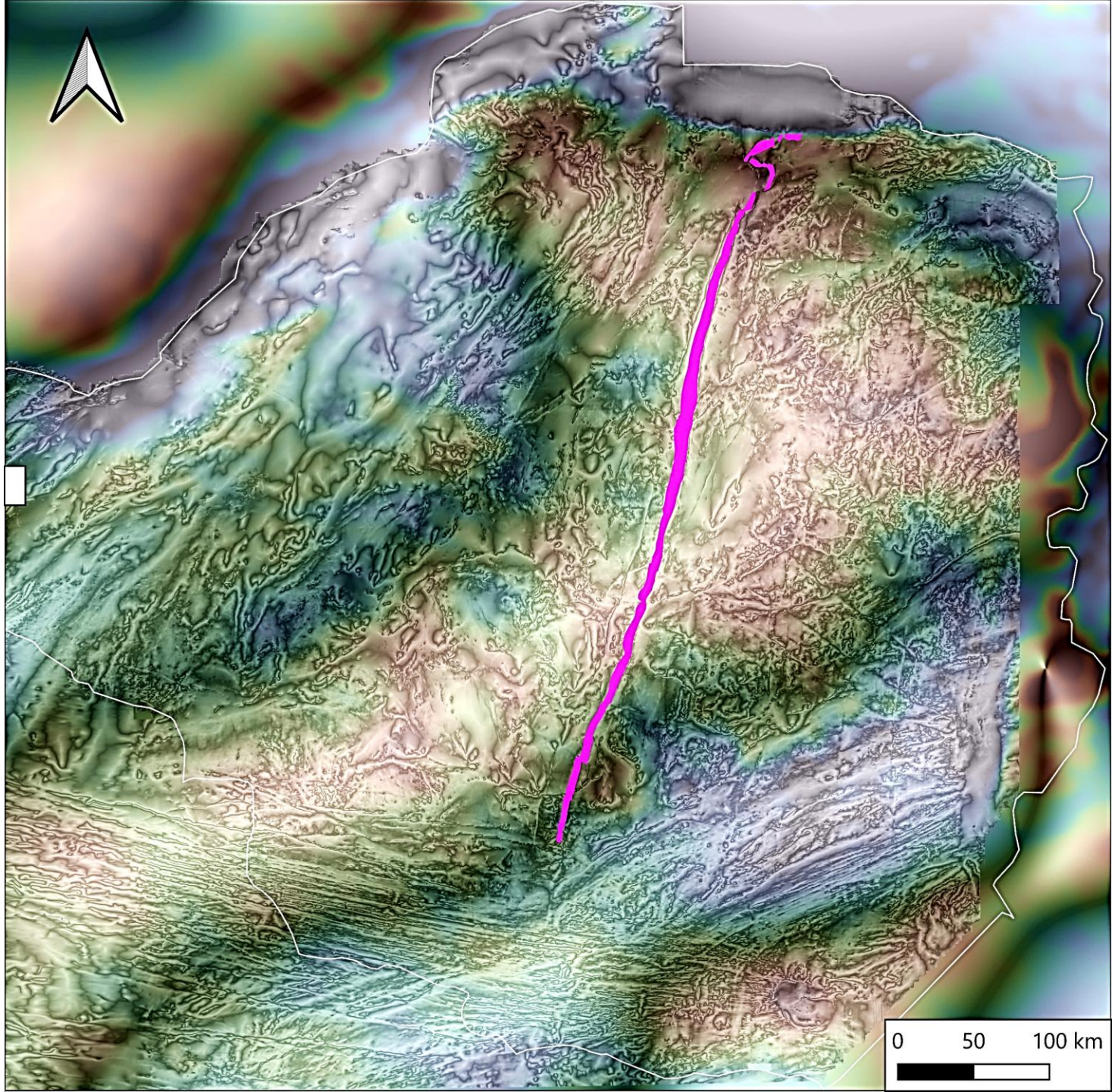


Relationship between near-surface & deep structures

Pseudogravity theta map over 70 km depth slice satellite gravity theta shade

- Pseudogravity theta map – near-surface features
- UC 70 km depth slice – SCLM domain margins

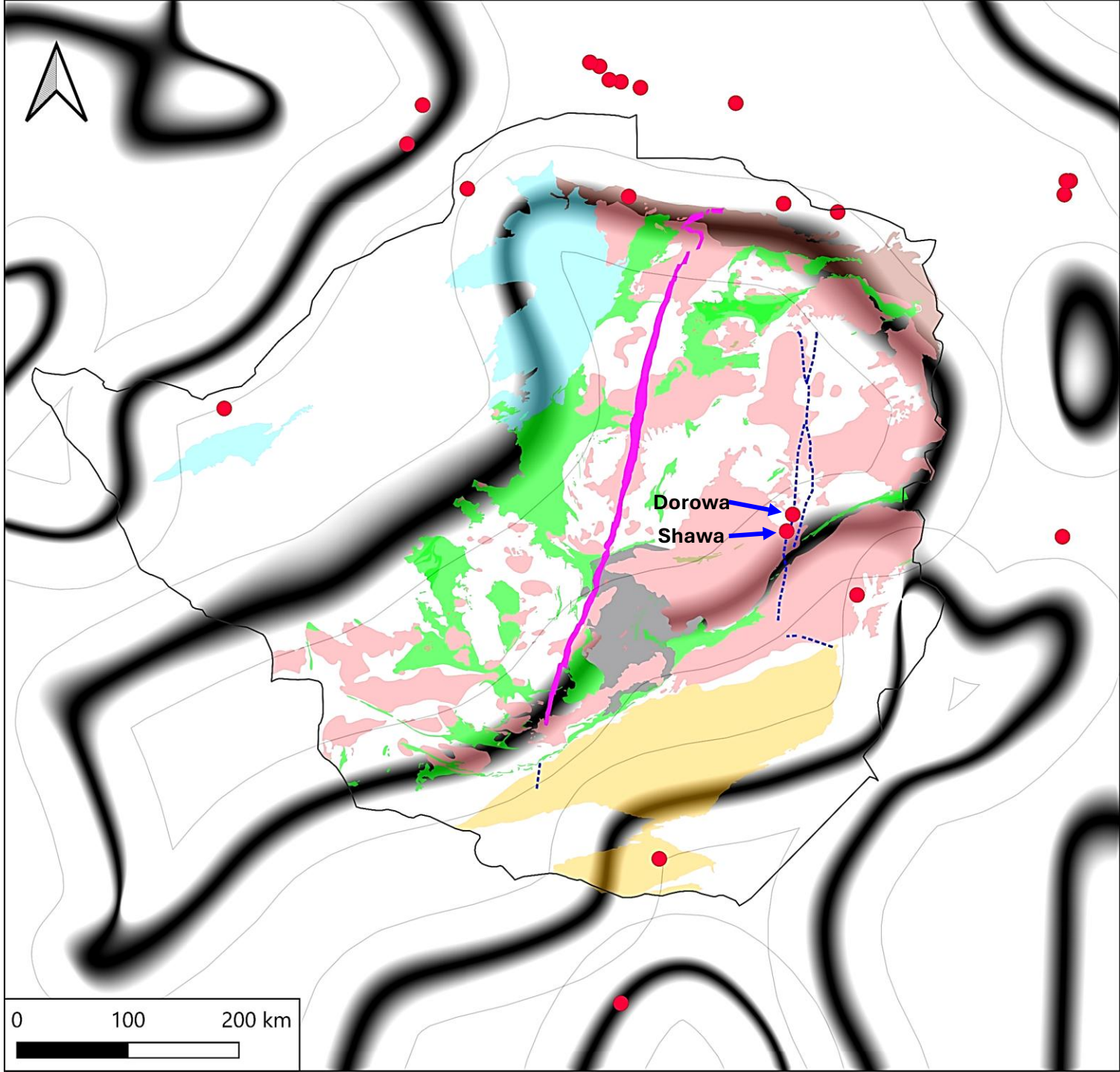
- Near-surface structures truncate deep lithospheric features (SCLM margins)
- To the south, both structures are broadly parallel – NMZ, Limpopo



Carbonatites and SCLM domain margins

Carbonatites (n = 22)	
Distance from margin	**% deposits**
0–20 km	18%
20–50 km	27%
50–100 km	27%
> 100 km	27%

- 45% of carbonatites occur within 50 km of the ZC lithospheric margin

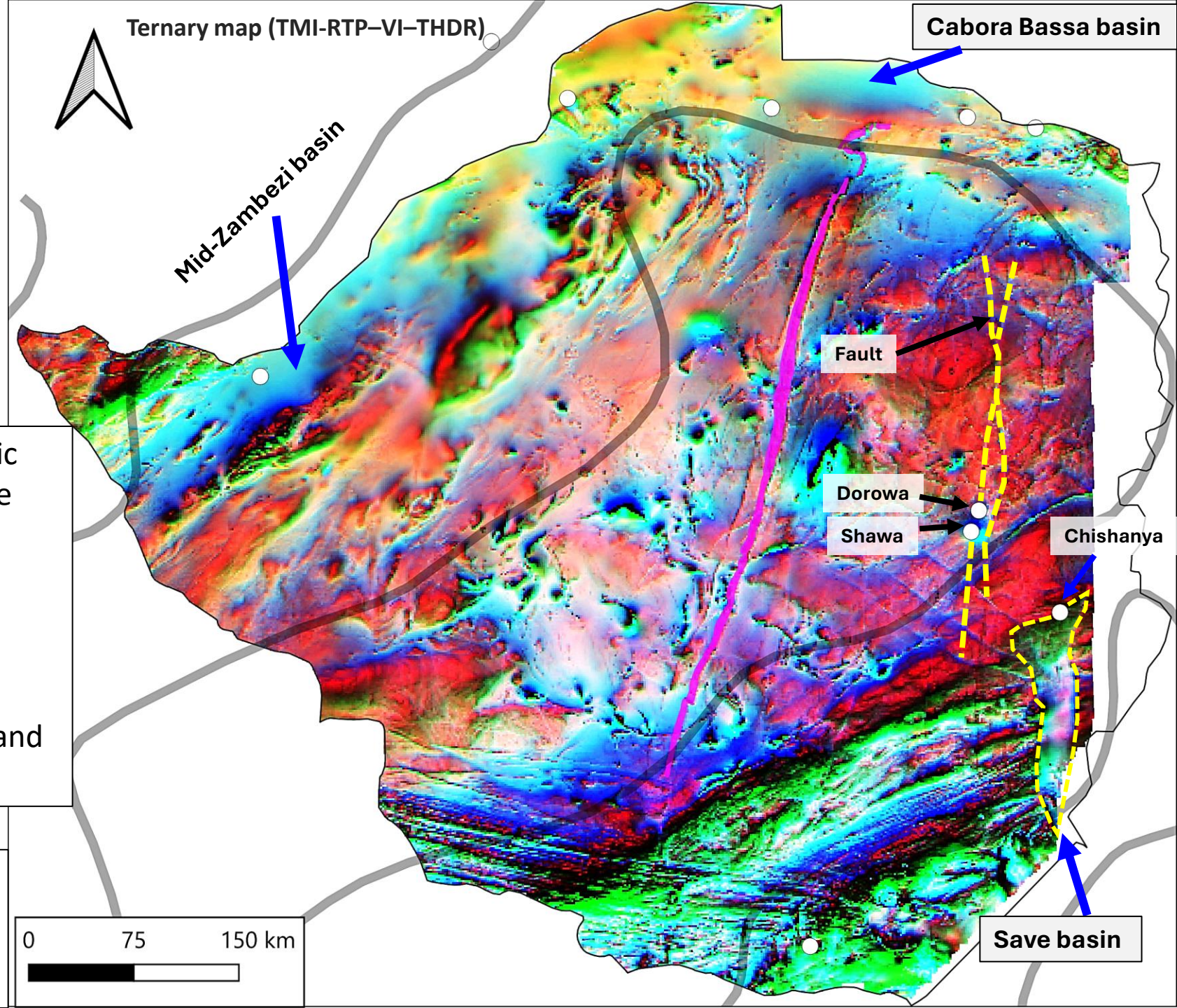


Carbonatites and crustal-scale structures

- Dorowa and Shawa on the ZC lithospheric keel margin transected by N–S transverse faults

- Carbonatites controlled by edges of and lineaments in Karoo rift basins:
  - Chishanya – edge of Save rift basin
  - Other carbonatites – Mid-Zambezi and Cabora Bassa basins

- Grey bold curves represent the ZC lithospheric keel margin and other SCLM domain margins
- Same for all figures to follow

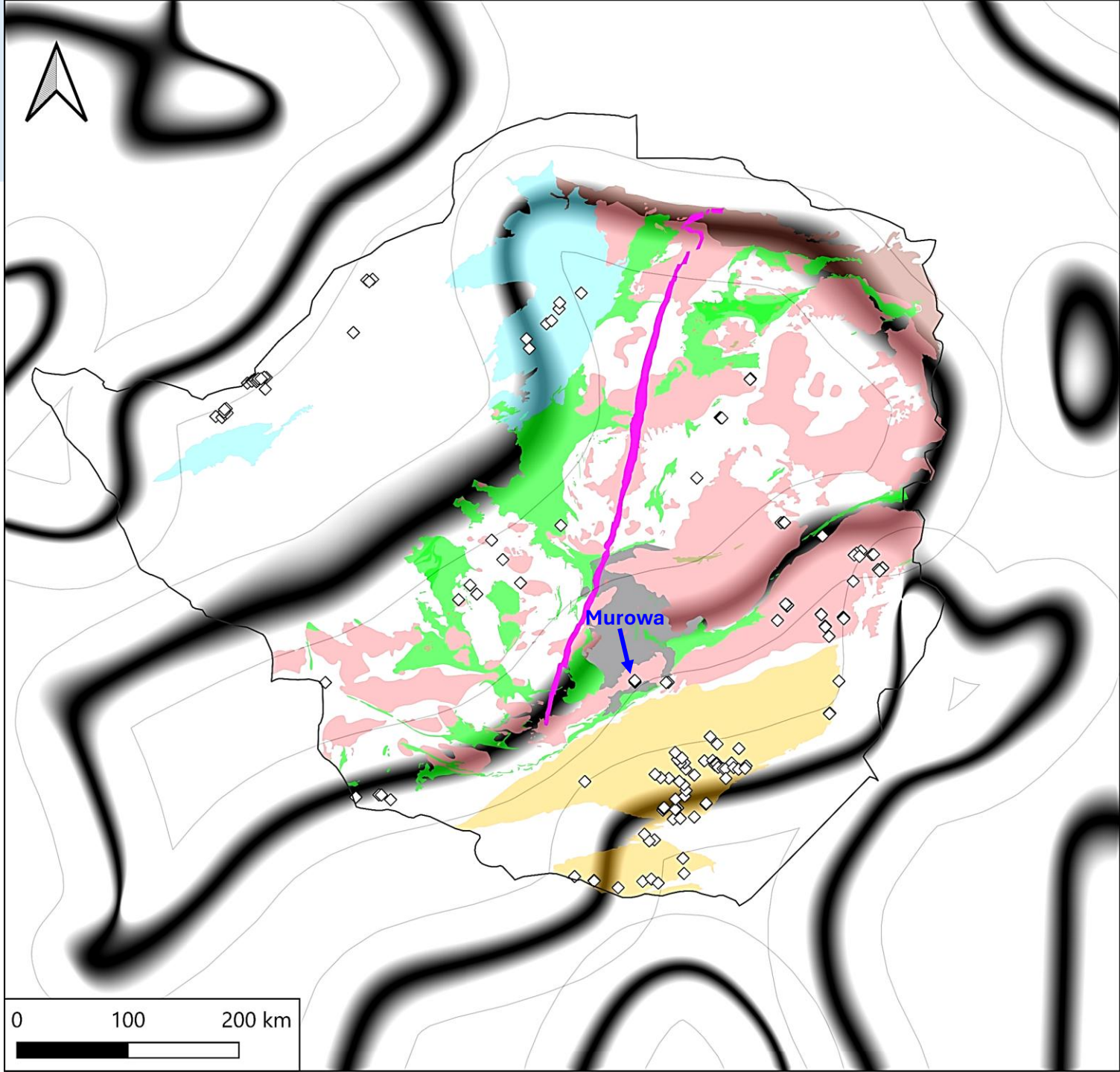


Diamondiferous kimberlites and SCLM domain margins

Kimberlites and diatremes (n = 151)	
Distance from margin	**% deposits**
0–20 km	23%
20–50 km	49%
50–100 km	24%
> 100 km	4%

- 72% of kimberlites occur within 50 km of the ZC lithospheric keel margin

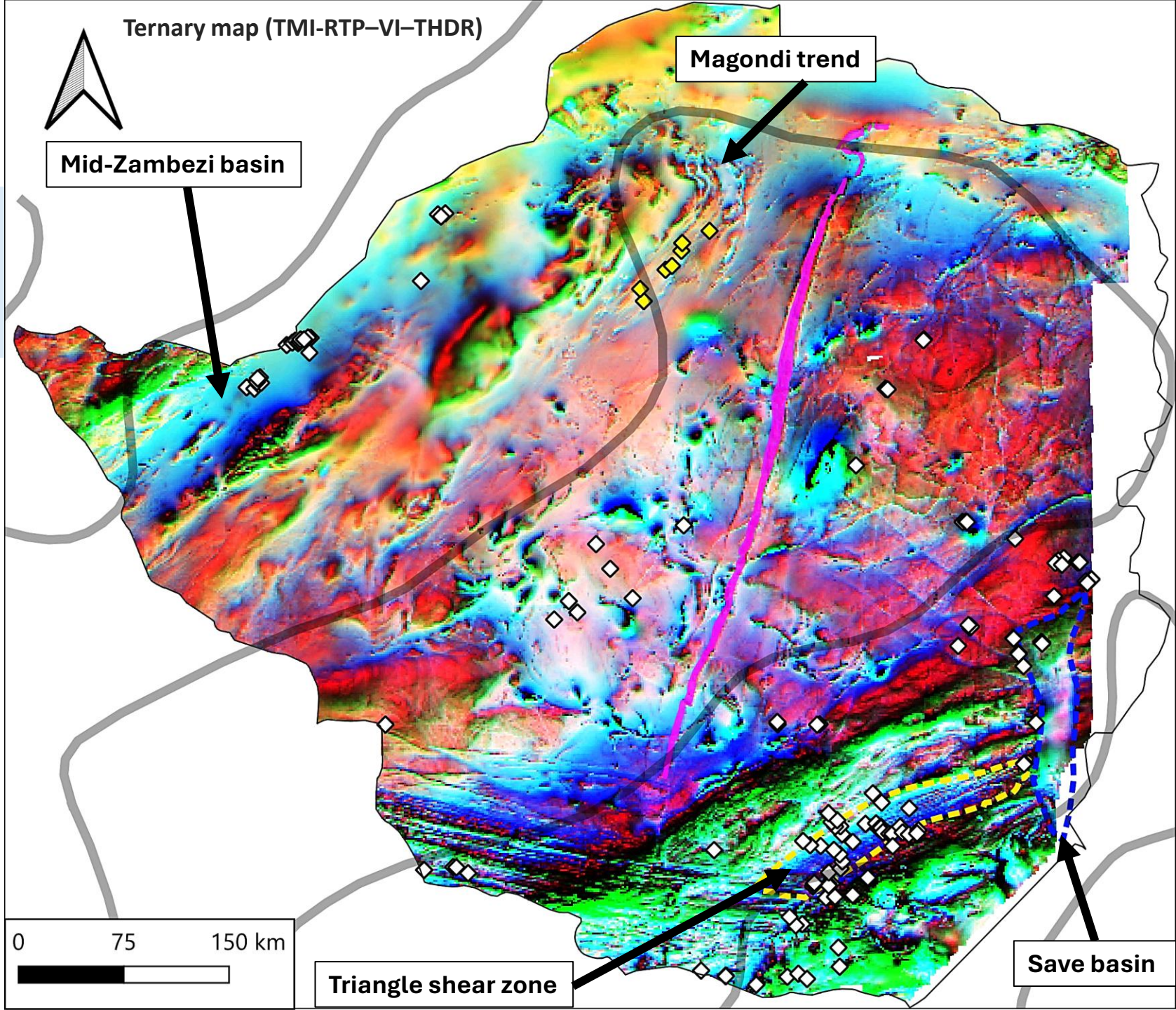
- Segments of the margins exhibiting complex geometries are highly endowed
- Areas around orogenic belts with protracted, repeated events
- Paleo-rift zones highly prospective?



Diamondiferous kimberlites
and crustal-scale structures

Kimberlites localized along:

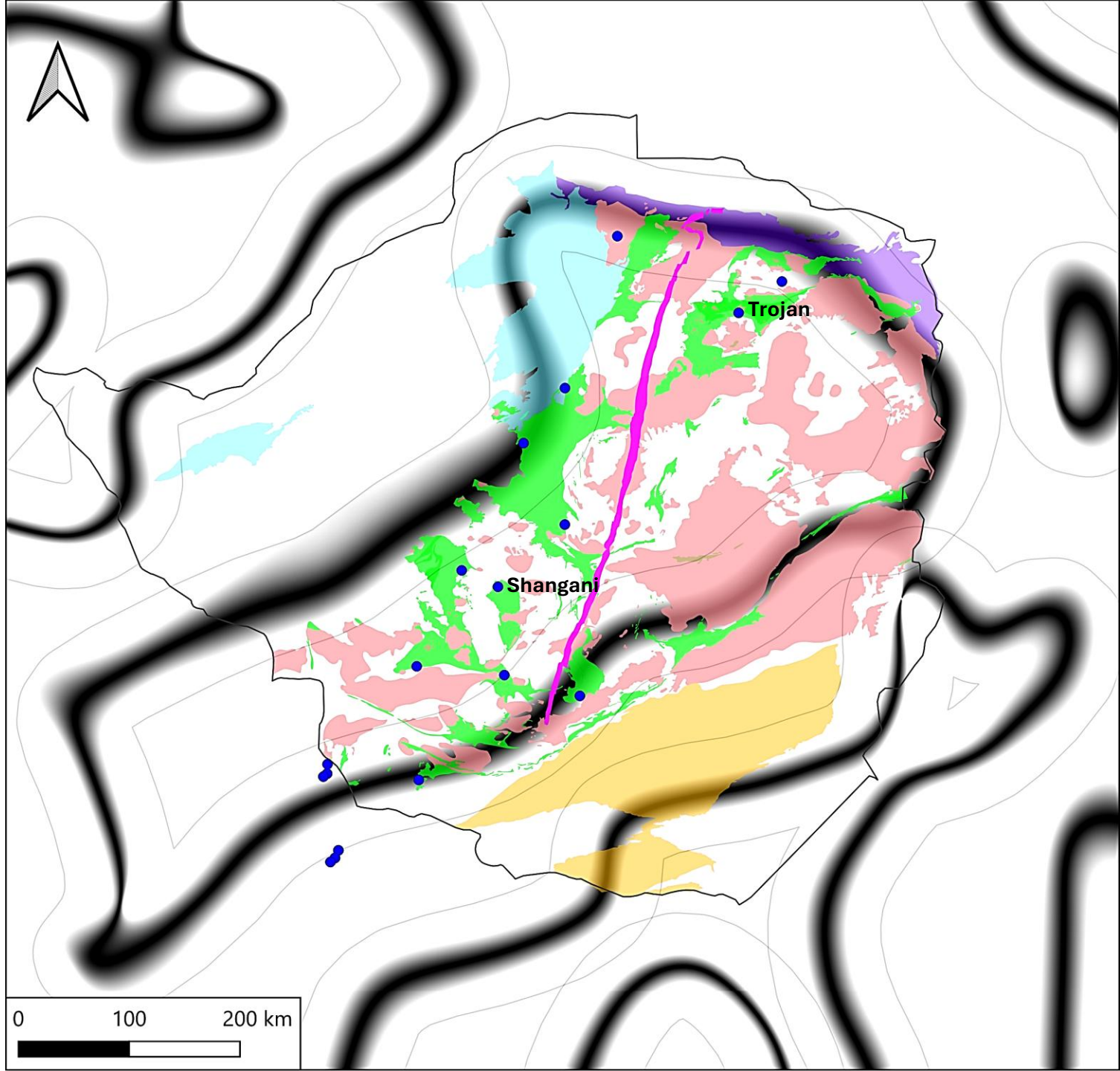
- ENE-trending Triangle shear zone
- Edge of the Save rift basin
- Region trend of the Magondi belt
- Lineaments in the Mid Zambezi rift basin



Komatiite-hosted magmatic Ni & ZC lithospheric keel margin

Magmatic Ni (n = 18)	
Distance from margin	**% deposits**
0–20 km	22%
20–50 km	39%
50–100 km	39%

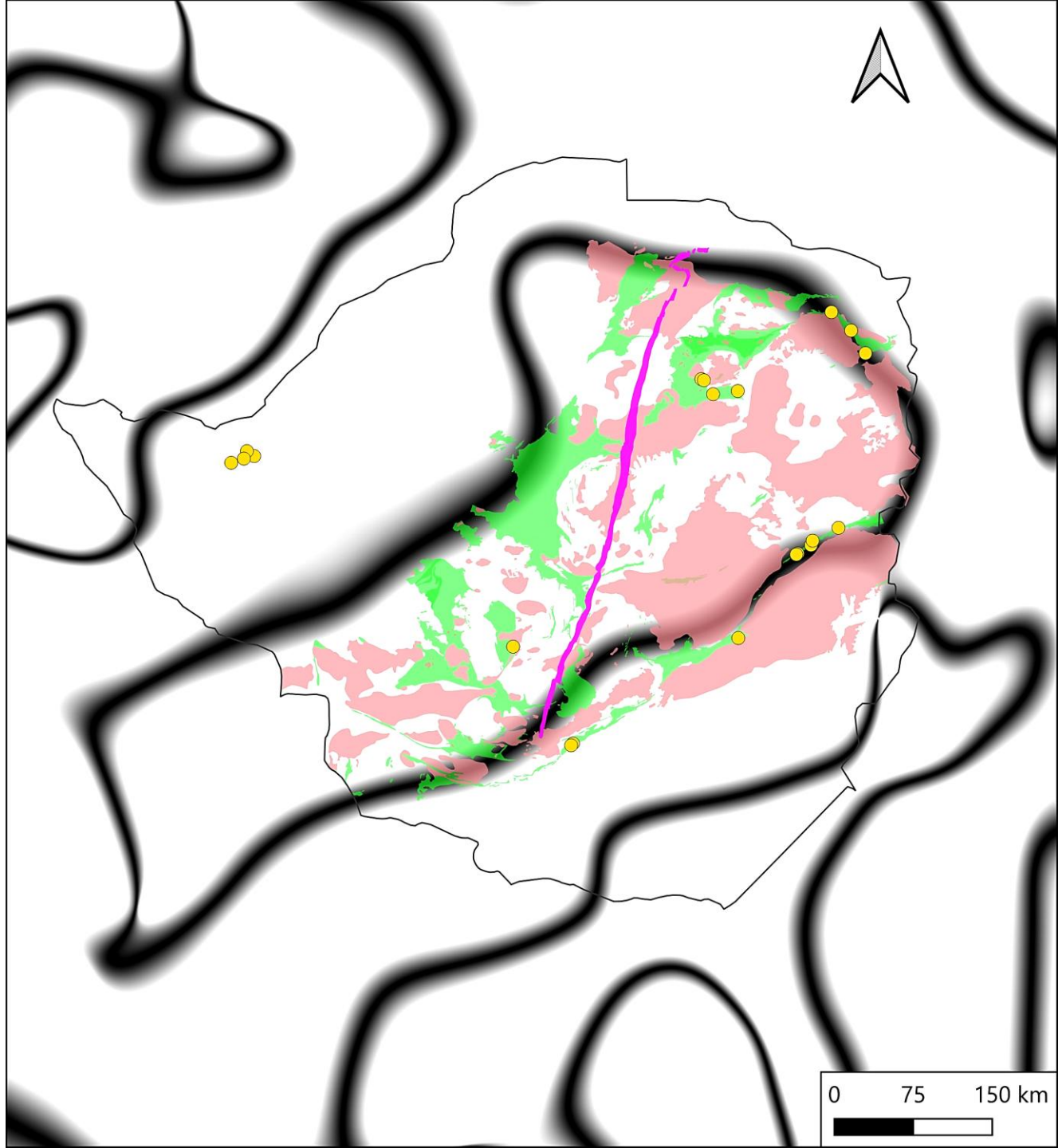
- 65% of magmatic Ni-Cu deposits occur within 50 km of the ZC lithospheric keel margin
- Although primarily controlled by greenstone belts, a few are localized along the lithospheric margin
- *Could this spatial relationship serve as a guide for exploration targeting?*



LCT pegmatites & ZC lithospheric keel margin

- Greenstone-hosted LCT pegmatites preferentially localized along edges of major Chilimanzi plutons
  - *Chibi, Masvingo, Mutoko*
- Some coinciding with the ZC lithospheric keel margin and other structures including:
  - The ZC-Limpopo belt terrane boundary
  - Mutare lineament

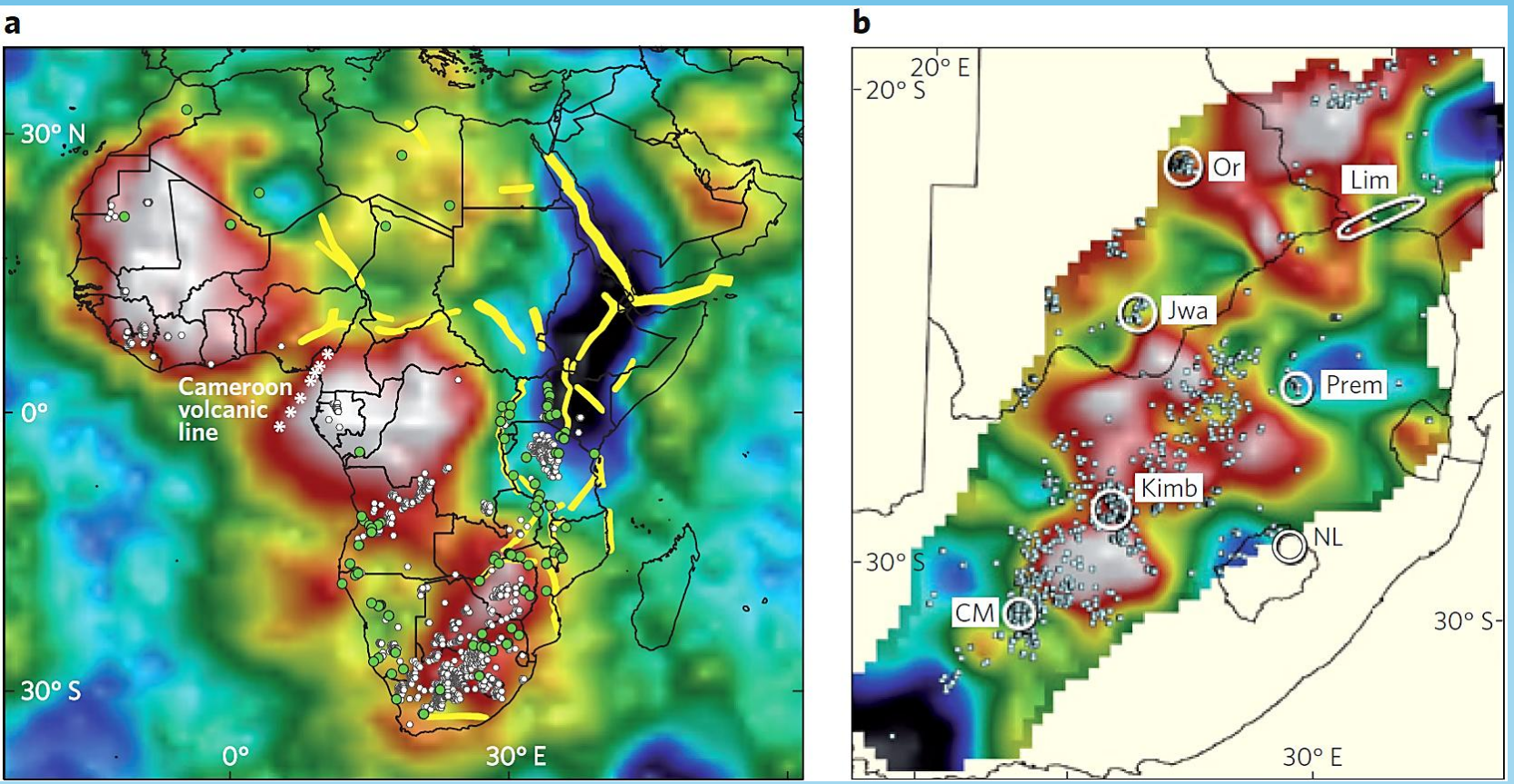
- *Could this spatial relationship serve as a guide for exploration targeting?*

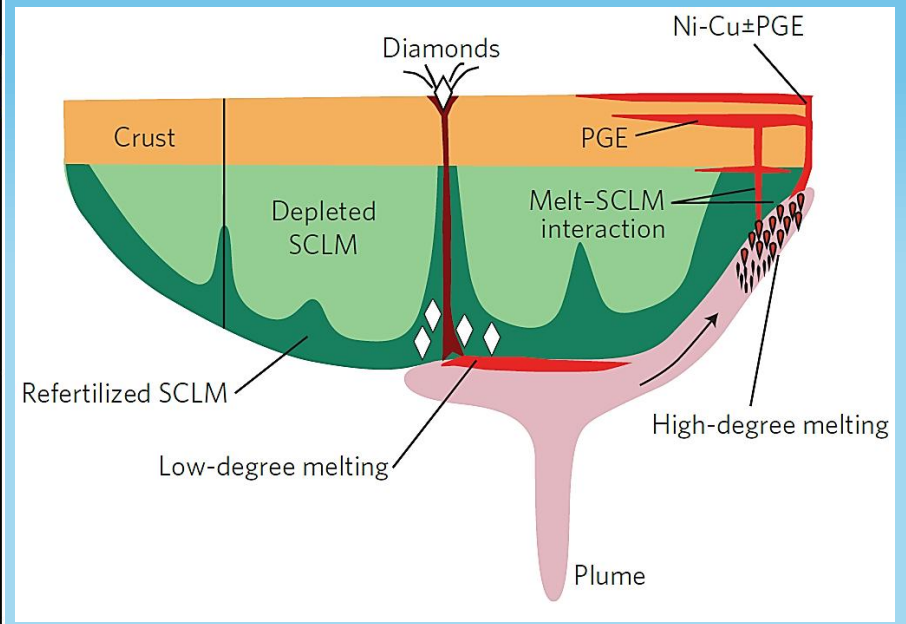


Comparison with previous studies

Begg et al. (2009), Econ. Geol; Griffin et al. (2013), Nat. Geosci

- Observation from this work consistent with previous studies
- Mantle-derived igneous rocks and associated mineral deposits are spatially associated with cratonic lithospheric margins
- The margins sometimes coincide with high seismic velocity lithospheric keel regions in seismic tomography





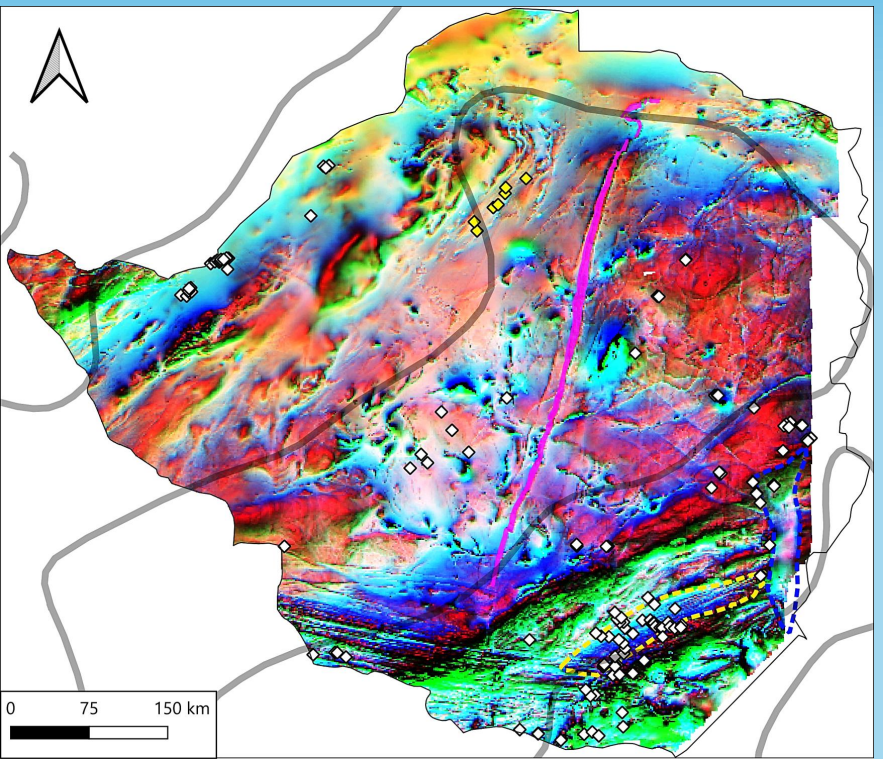
Griffin et al. (2013) Nat. Geosci.

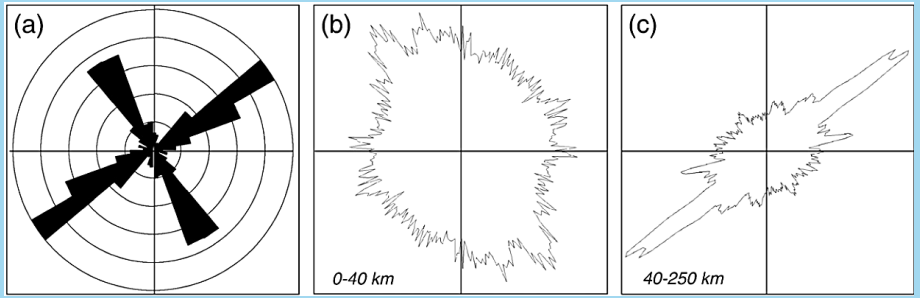
Comparison with previous studies

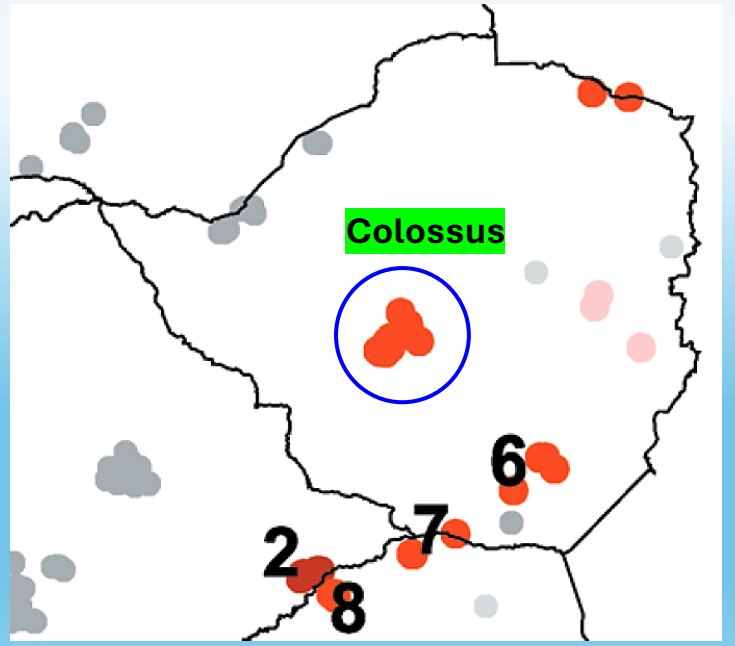
Jelsma et al. (2004) S. Afr. J. Geol.; Jelsma et al. (2009) Lithos

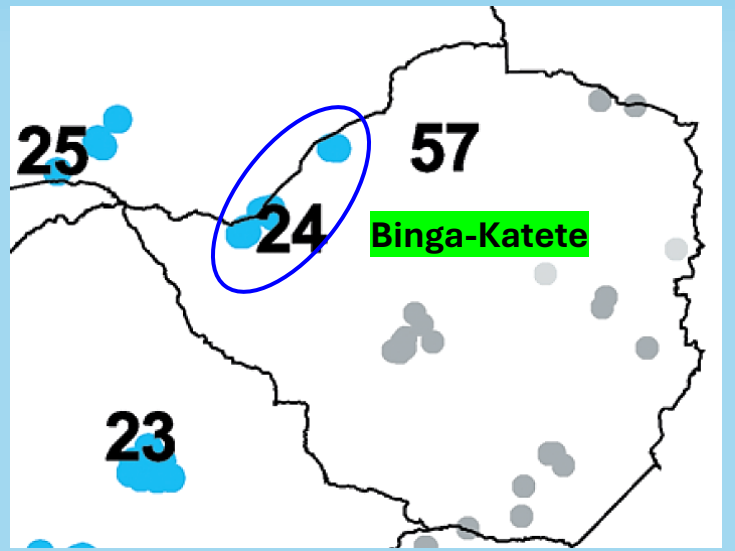
Preferential distribution along transcontinental corridors

- Kimberlite clusters in Zim are controlled by prominent ***NE*** trending regional lineaments
  - Pre-205 Ma Colossus cluster – NE trend (040°)
  - Paleozoic-Mesozoic Mwenezi and River Ranch clusters – ENE trend (065°)
  - Ca. 90 Ma Binga-Katete and Magondi clusters – NE trend
- These NE lineaments broadly mimic the orientation of crustal-scale & deep ZC lithospheric margin from satellite gravity data







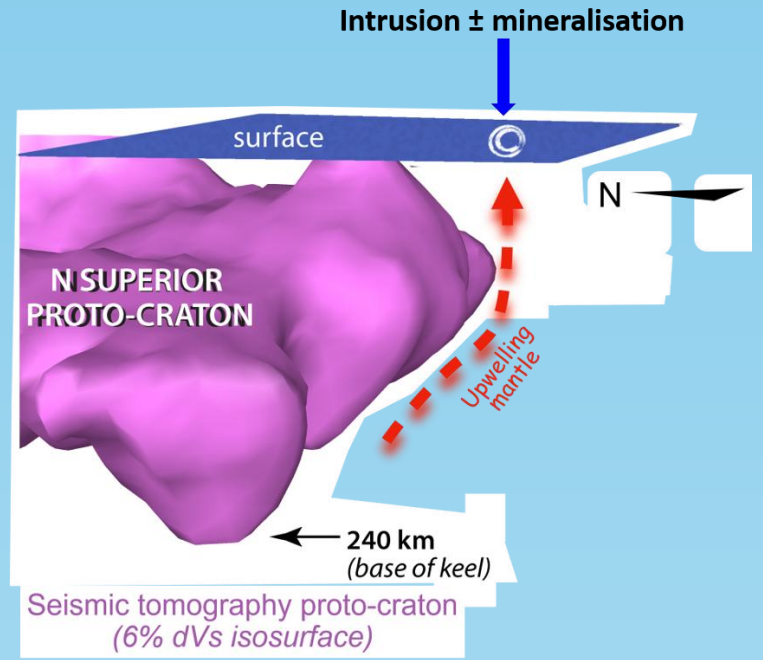


Is proximity to lithospheric margins an obvious predictor of prospectivity?

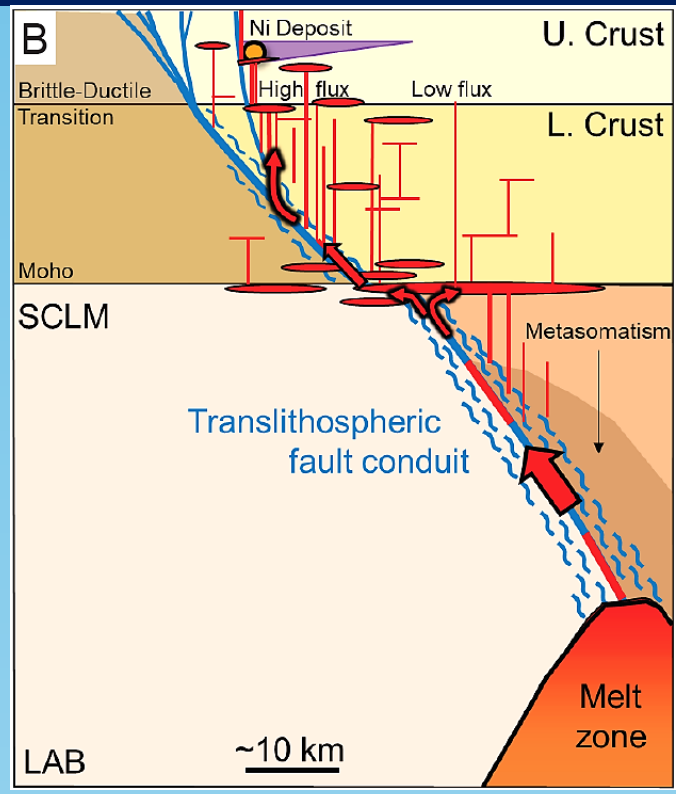
Influence of geometry of SCLM features on location of intrusions

- ***How far intrusions (± deposits) occur from a SCLM structural feature is a function of***:
  (1) subsurface geometry of lithospheric margin:
  - Steep margins – intrusions fall directly on or very close to the margin
  - Shallow margins – intrusions form farther away from the margin
  - Complex geometries – variable spatial variations

  (2) Age of deposits:
  - Young deposits may show obvious spatial relationships with margins
  - Older ones may show cryptic relationships – subsequent modification of the margins post deposit formation



Provided by Lyal Harris



Hayward (2024) Econ. Geol.

- For kimberlites (case of the ZC), the following areas seem highly prospective:
  - Areas close to complex margin geometries
  - Areas showing evidence of rifting(?) – southern and northwestern ZC
  - Areas recording repeated orogenic activity - repeated refertilisation of mantle domain margins

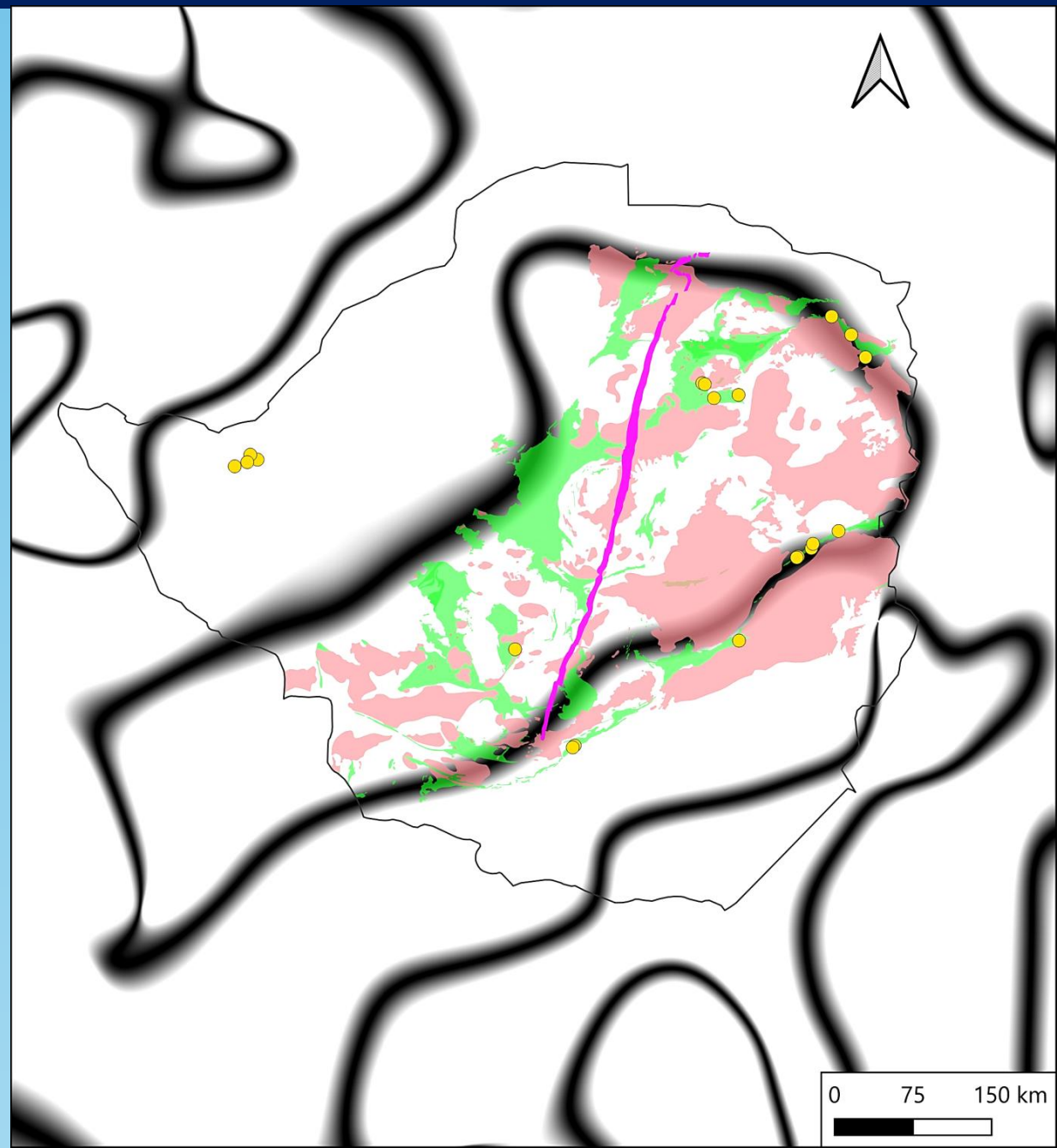
Is proximity to lithospheric margins an obvious predictor of prospectivity?

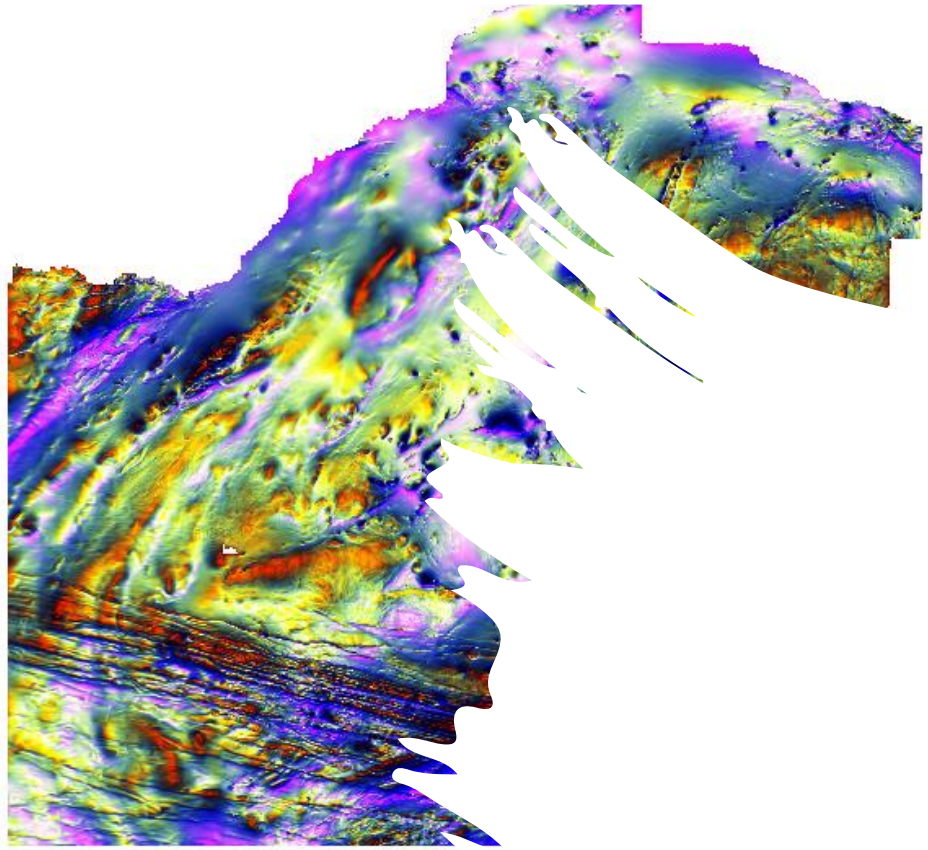
What does present-day lithospheric architecture tell us?

- *Craton interiors*: better preservation of older lithospheric architecture
- *Craton margins*: extensive reworking and modification
- *Orogenic margins*: polyphase accretionary histories
- *Younger deposits*: clearer lithospheric-margin associations
- *Upper-crustal structures*: important localising pathways

Proximity ≠ prospectivity?

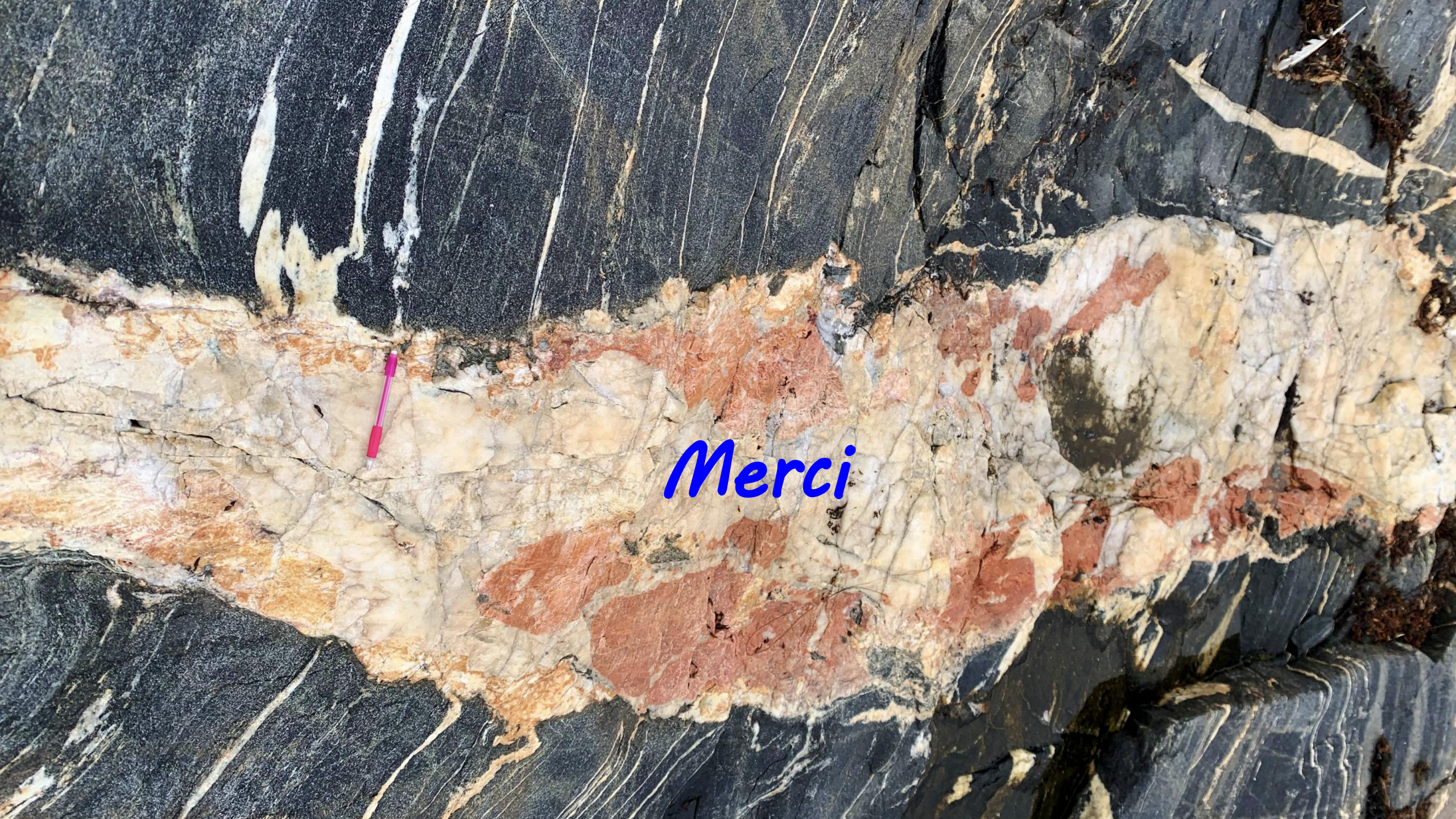
1. How far from the margin is too far?
2. Does closer always mean better? Should proximity drive exploration priority?
3. Are all lithospheric margins equally endowed?





Concluding remarks

- Satellite gravity reveals first-order SCLM architecture, including the ZC lithospheric keel margin
- Most carbonatites, kimberlites and magmatic Ni-Cu cluster near SCLM domain margins but proximity alone does not predict prospectivity
- Lithospheric architecture provides the framework but upper-crustal structures help localise mineralisation
- Present-day lithospheric geometry reflects cumulative tectonic modification, particularly along craton margins bounded by orogenic belts
- Satellite gravity remains an underutilized tool for regional lithospheric-scale targeting
- Machine learning offers a way to disentangle the relative contribution of depth levels and structural features


Merci