Styles and Scales of Structural Inheritance throughout Continental Rifting

Examples from the Great South Basin, New Zealand

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LEVERHULME TRUST

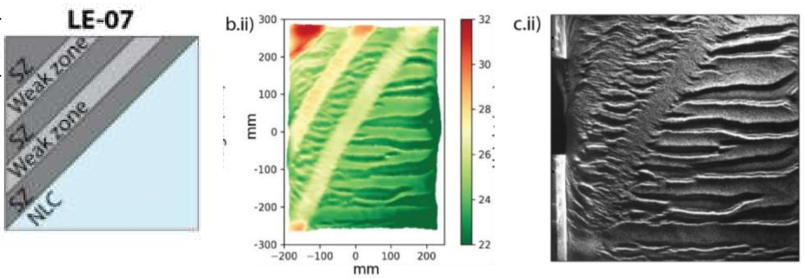
Schlumberger

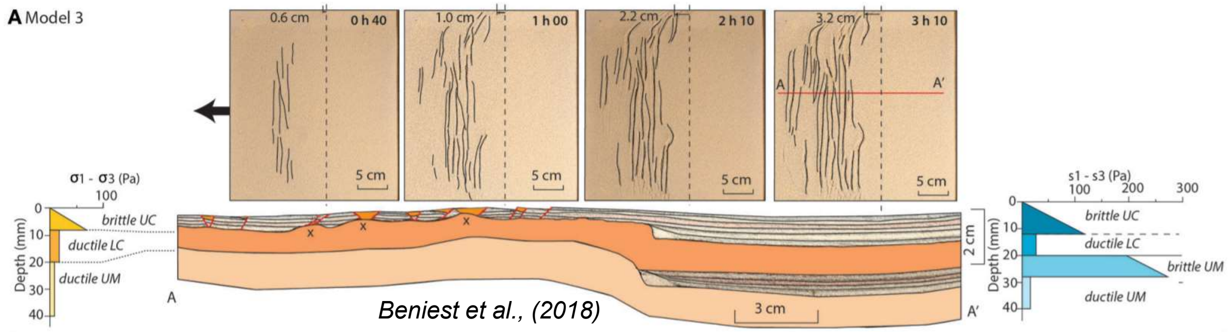
NEW ZEALAND PETROLEUM & MINERALS

Rationale

Continental crust comprises distinct crustal units and intruded magmatic material brought together throughout multiple tectonic events

Samsu et al., (2018)





Beniest et al., (2018)

- Crustal/lithospheric strength may influence the rift structural style and physiography
- Strain may initially localise in weaker areas of lithosphere, rather than at the boundaries between different domains

How do lateral crustal strength contrasts, along with prominent crustal boundaries, influence rift structural style and physiography?

- *The Great South Basin, New Zealand forms atop basement comprising multiple distinct terranes and magmatic intrusions.*
- *The extension direction during rifting is parallel to the terrane boundaries, such that all terranes experience extensional strain*

Geological evolution of Zealandia

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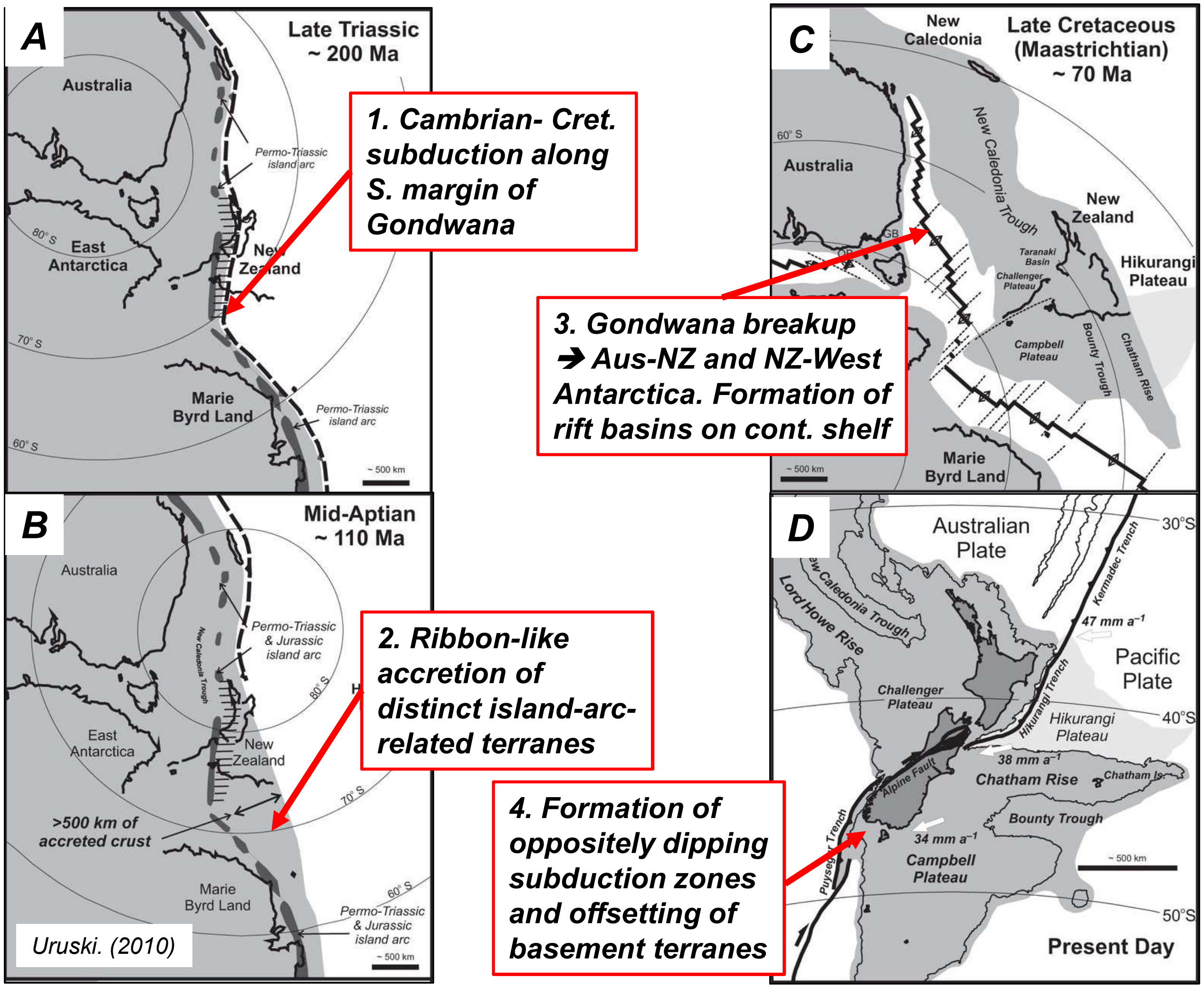
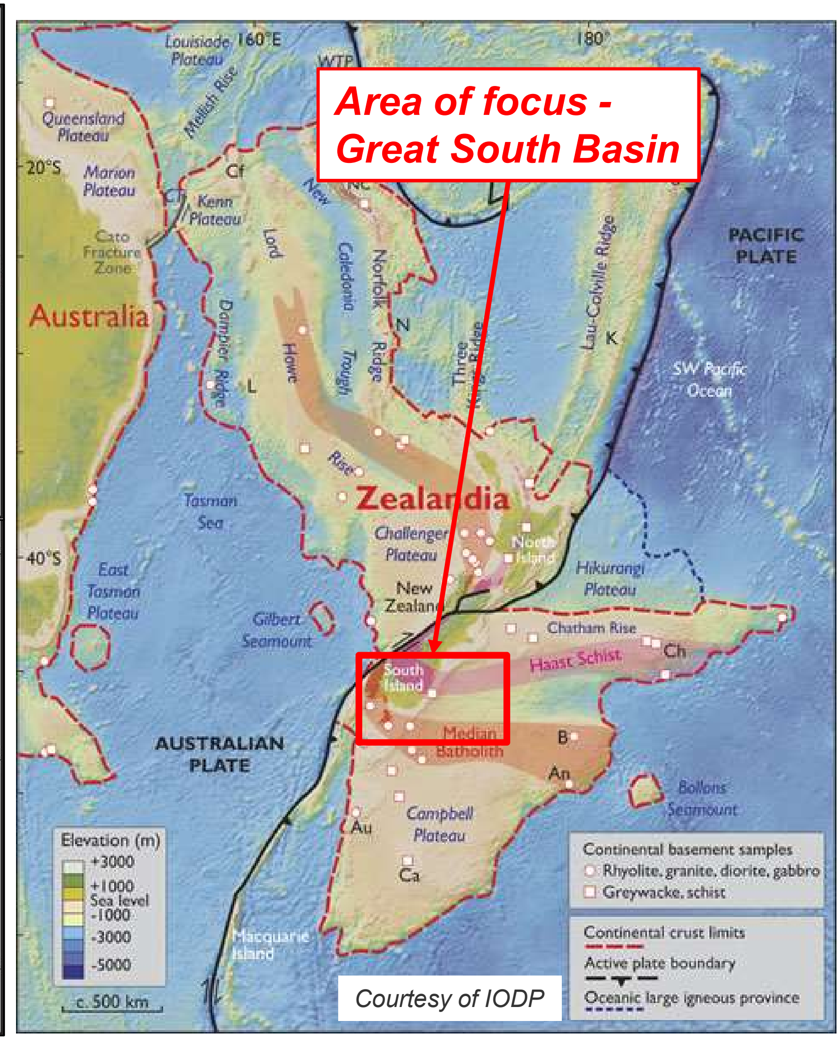


1. Cambrian- Cret. subduction along S. margin of Gondwana

2. Ribbon-like accretion of distinct island-arc-related terranes

3. Gondwana breakup ➔ Aus-NZ and NZ-West Antarctica. Formation of rift basins on cont. shelf

4. Formation of oppositely dipping subduction zones and offsetting of basement terranes



Area of focus - Great South Basin

Courtesy of IODP

Basement beneath the Great South Basin

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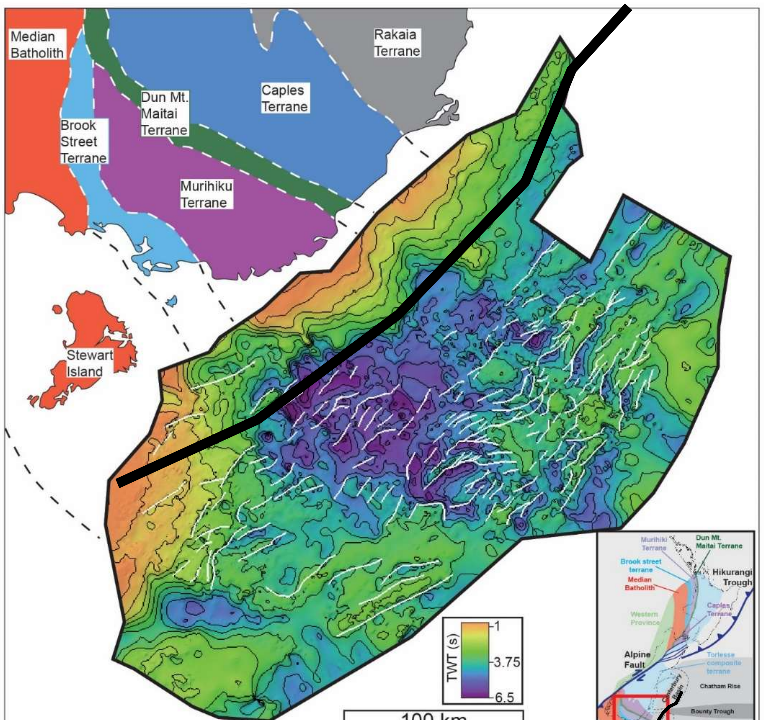
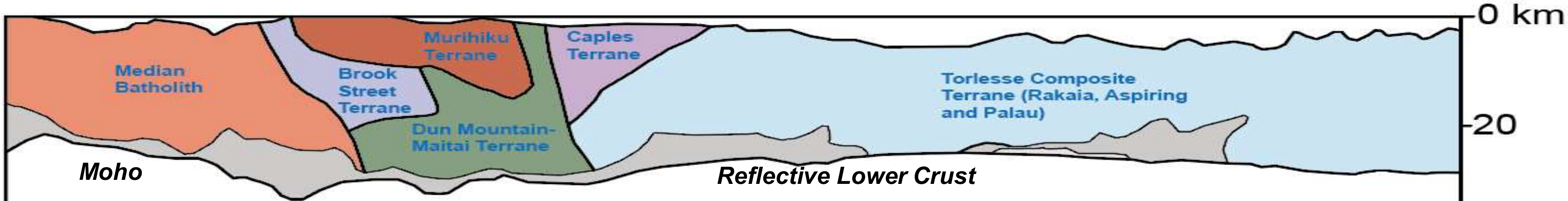


Phillips and McCaffrey (in prep.)

- *Distinct basement terranes of varying strength related to Island Arc system accreted to Gondwana margin*
  - ***Median Batholith*** *- Composite batholith consisting of multiple generations of granitic plutons*
  - ***Brook Street Terrane*** *– Volcanics and volcanogenic sediments*
  - ***Murihiku –*** *Sediments (relict forearc basin)*
  - ***Dun Mountain-Maitai Terrane*** *– Ophiolite complex (Dun Mt.) and mudstone (Maitai)*
  - ***Caples Terrane*** *– Volcanogenic sediments, becoming more schistose to NE*

Work in progress/Preliminary



SESI deep seismic line – After Mortimer et al., (2002)

Part I –
Influence of crustal-scale terrane boundaries

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Terrane boundaries controlling volcanism

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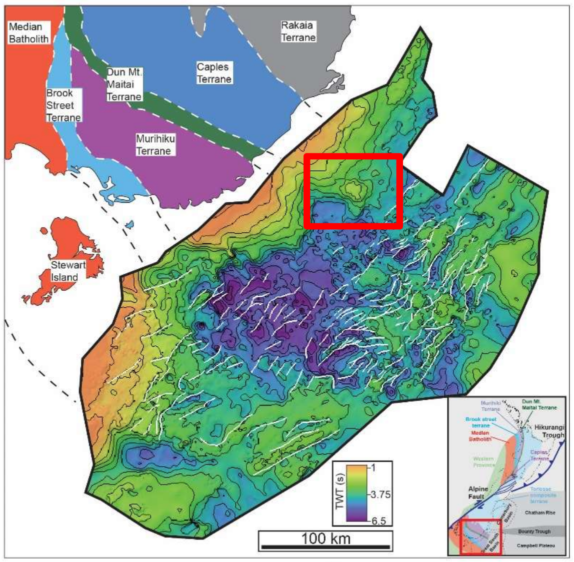
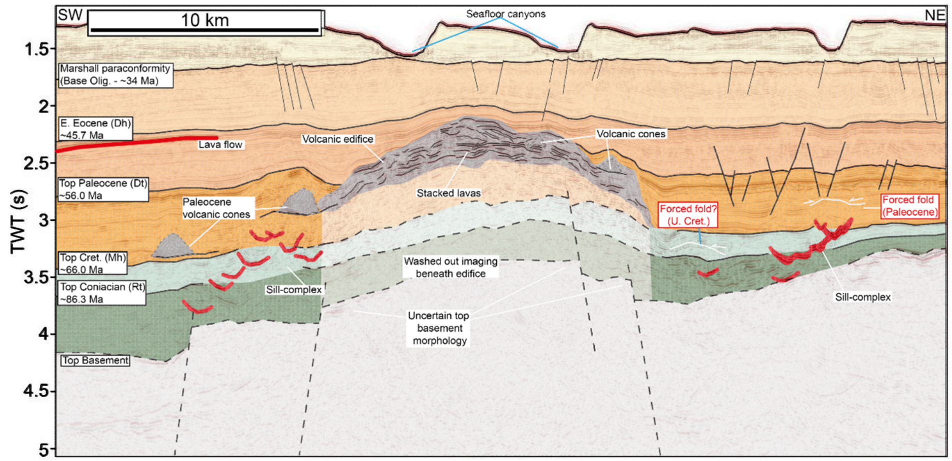
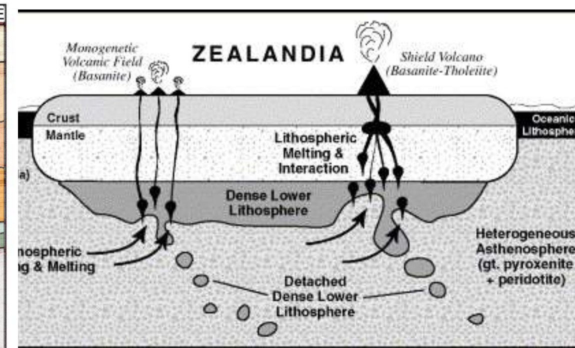
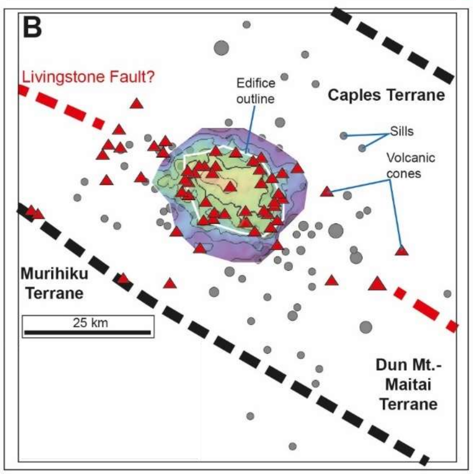


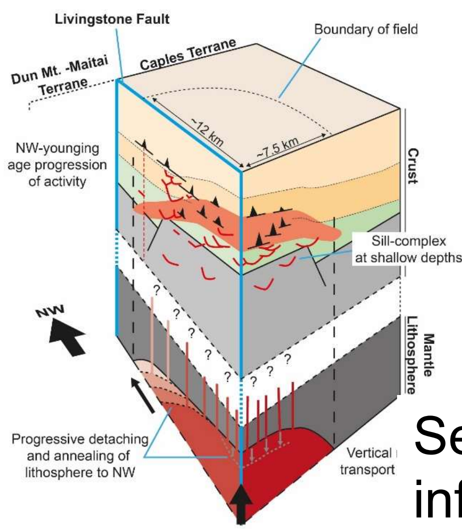


Phillips and Magee (subm.)



Model for Cenozoic intraplate Volcanism across Zealandia (Hoernle et al., (2006)



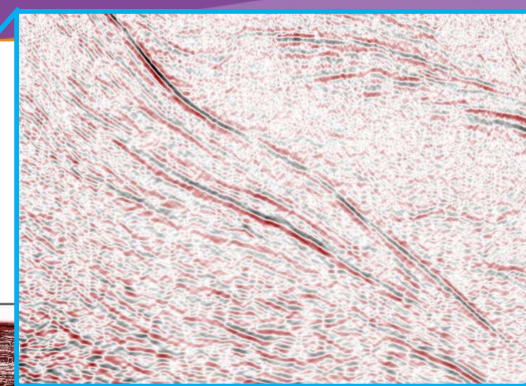


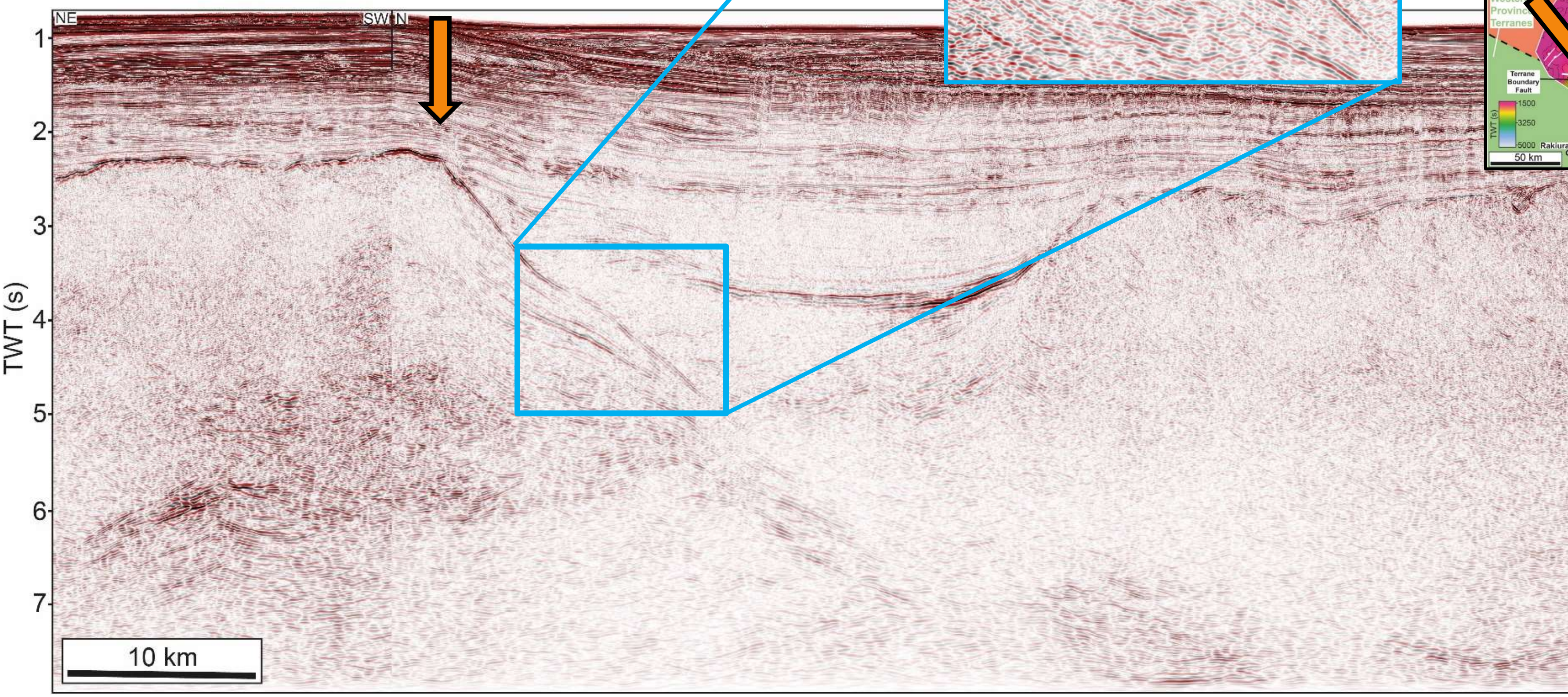
- *Expression of terrane boundary at base of lithosphere focusses detaching of lithospheric material, controlling the **location and lifespan** of the volcanic field*
- ***Terrane boundary acts as conduit for magma transiting the crust.***

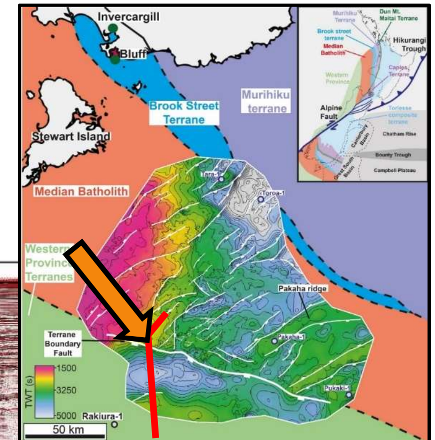
See ***Phillips and Magee (in review)*** for more information - https://eartharxiv.org/b94ds/

Reactivation of terrane boundaries

- *Southern Boundary of the Median Batholith Zone* ***reactivated as crustal-scale shear zone and fault***
- *Shear zone localises along margin of granitic body (Separation Point Batholith suite)*







Phillips and McCaffrey (2019) - **https://doi.org/10.1029/2019TC005772**

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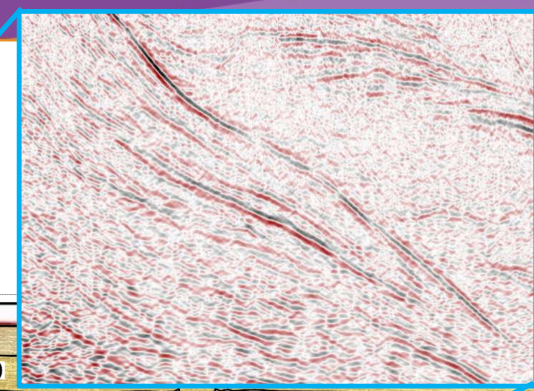
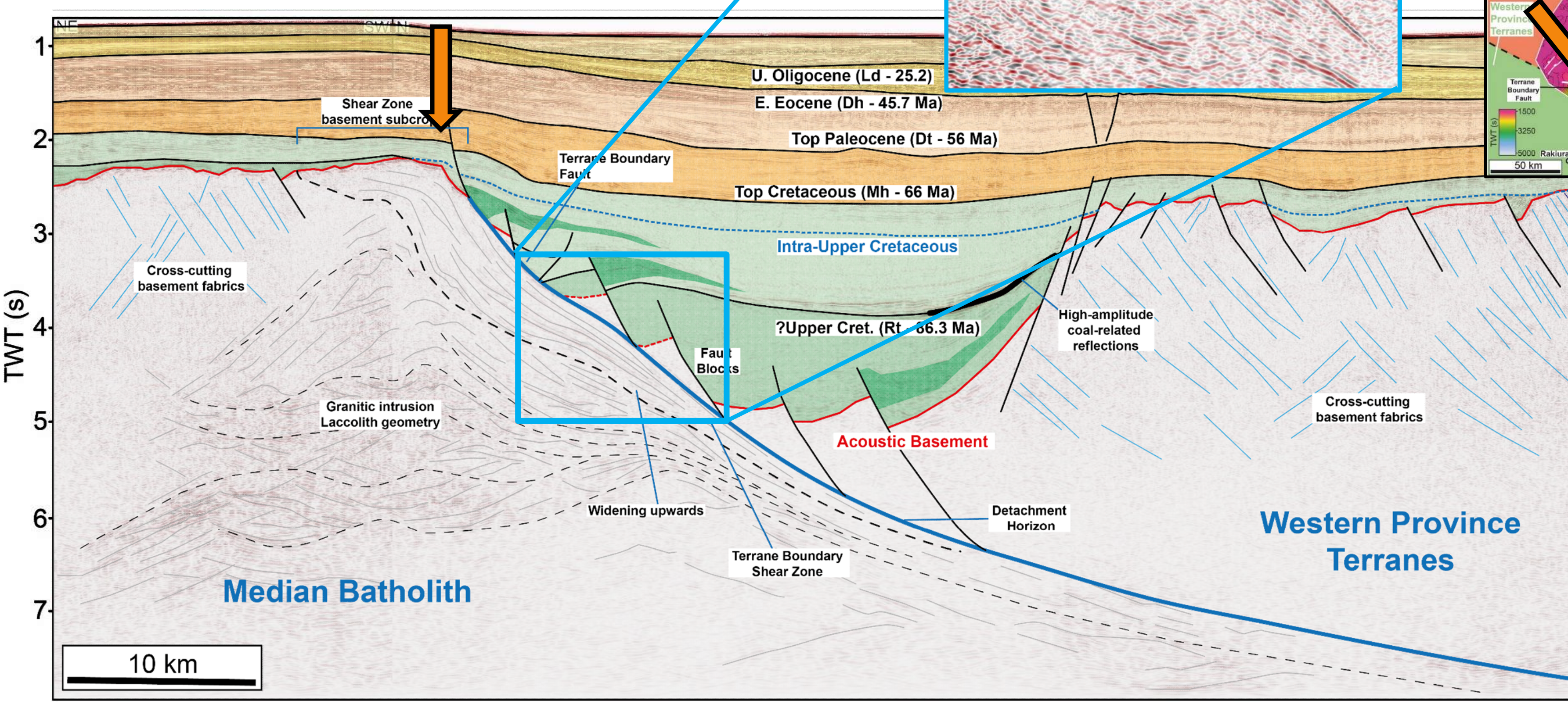
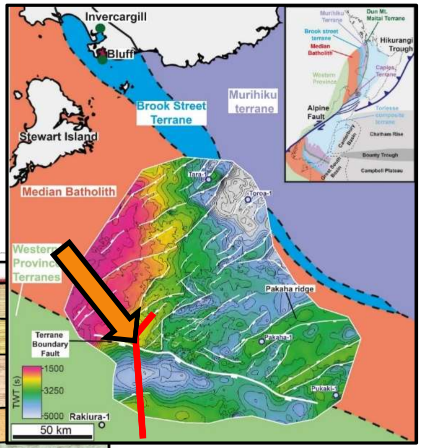
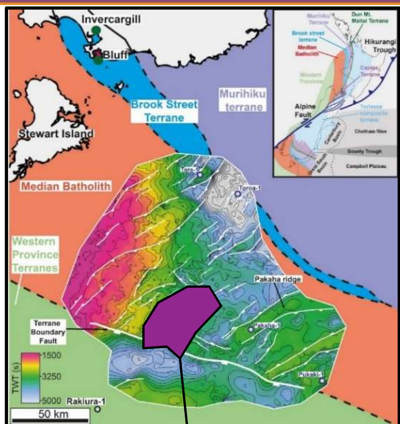




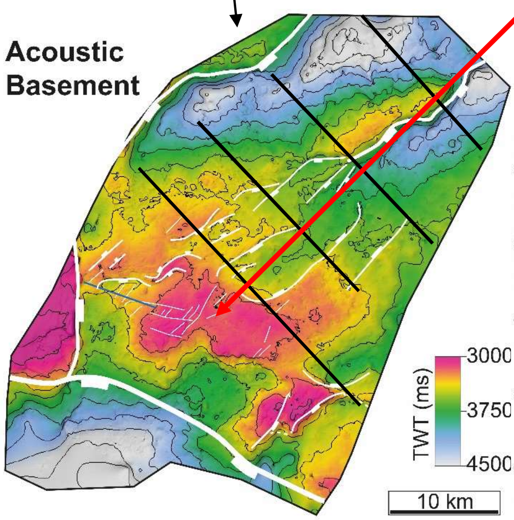


Phillips and McCaffrey (2019) - https://doi.org/10.1029/2019TC005772

Barriers to lateral fault propagation

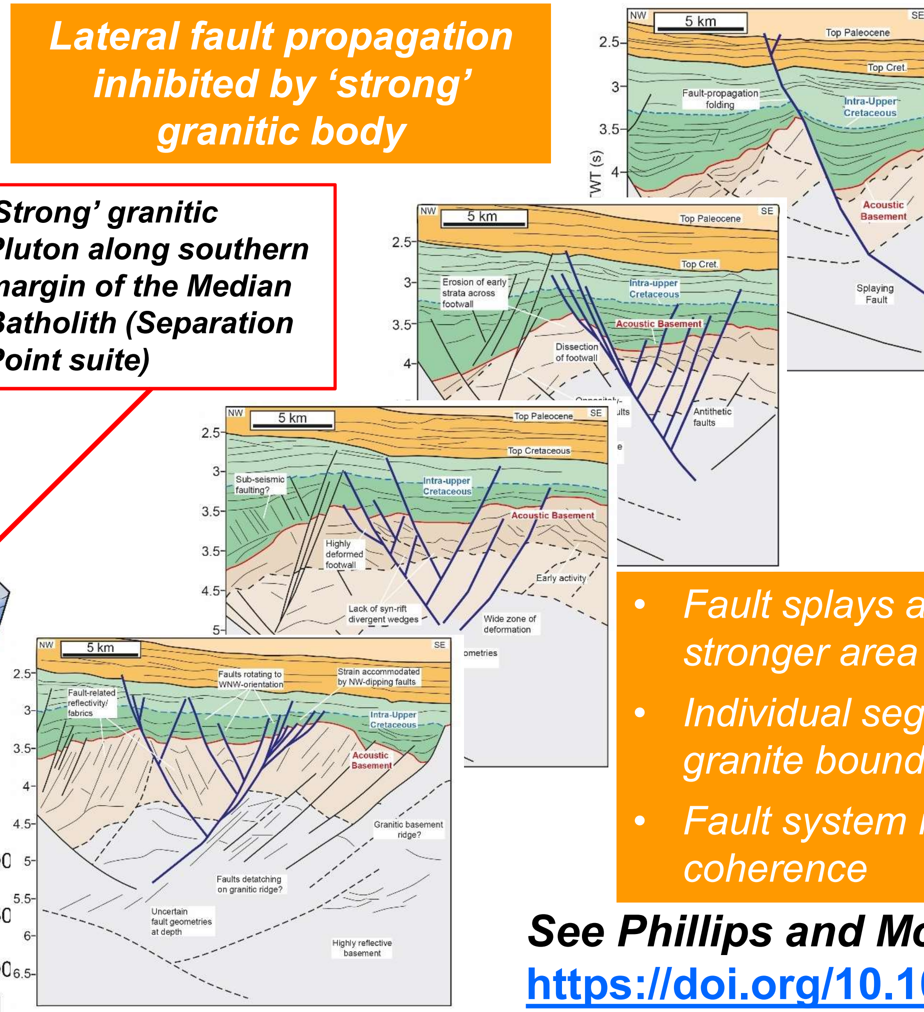


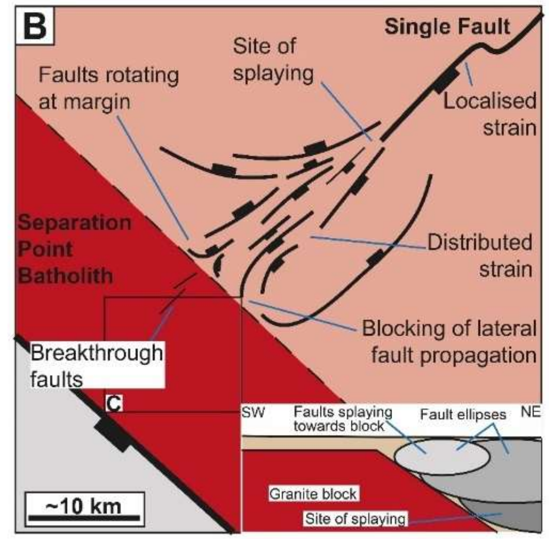
Acoustic Basement



Lateral fault propagation inhibited by 'strong' granitic body

'Strong' granitic Pluton along southern margin of the Median Batholith (Separation Point suite)





- *Fault splays and segments as it approaches stronger area i.e. the 'granitic batholith'*
- *Individual segments rotate and align with the granite boundary as they approach*
- *Fault system maintains geometric and kinematic coherence*

See Phillips and McCaffrey (2019) for details - **https://doi.org/10.1029/2019TC005772**

Part II – Rift structural styles across basement terranes of varying strength

Work in progress – Quantitative analyses unable to be completed

Regional rift physiography

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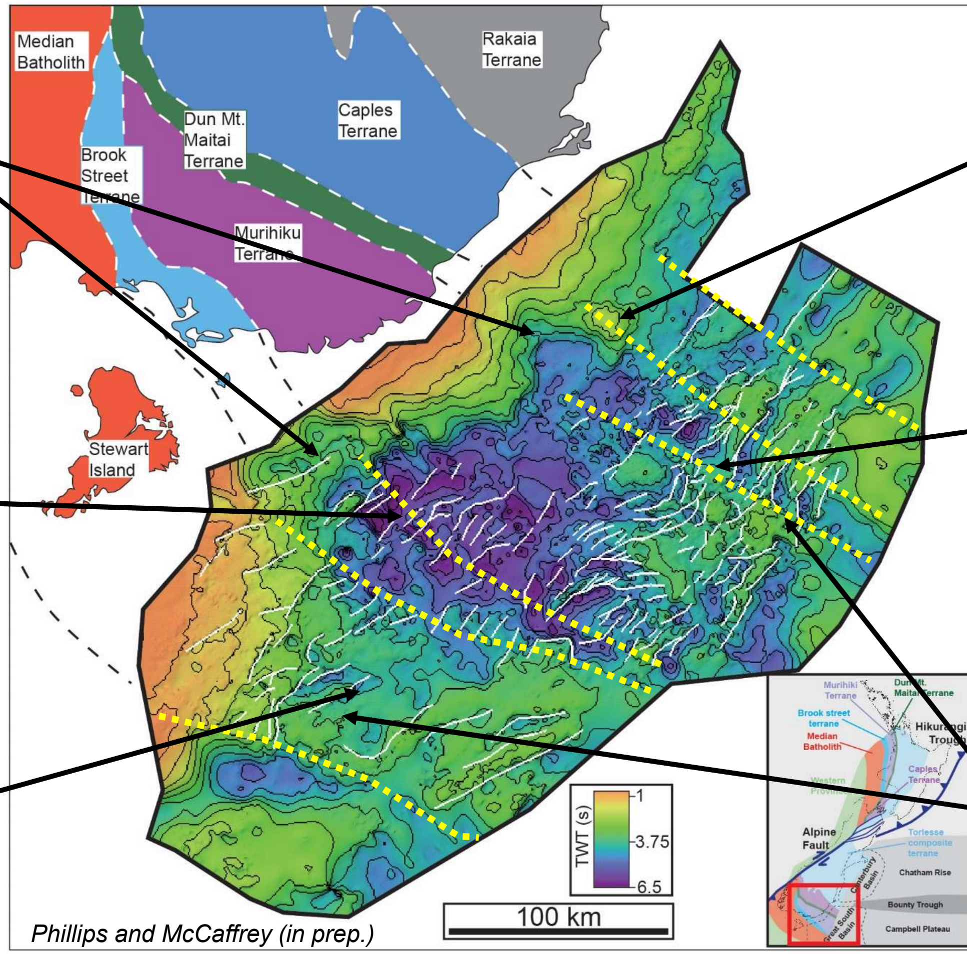
Shelf embayments
- Preferential erosion/extension of weaker terranes
- Increased activity along closely-spaced terrane boundaries

Depocentres
- Depocentres focussed along terrane boundaries
- Strain localises along terrane boundaries and/or weaker terranes

Shallow Median Batholith
- Buoyant/Less dense basement
- Stronger material experiences less rifting



Focussing of volcanism
- Exploiting of crustal-scale terrane boundary by magma transiting the crust
- Focussing of detaching lithospheric material from Lith-Asthen. Boundary
- ***See Phillips and Magee (2020)***

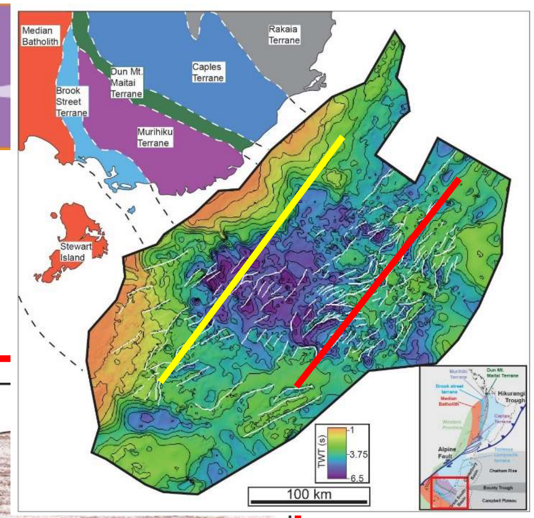
Fault rotations
- Faults rotate as they approach terrane boundaries due to local stress perturbations
- ***See Phillips and McCaffrey (2019)***

Fault terminations
- Faults laterally terminate as they approach stronger material/terrane boundaries
- ***See Phillips and McCaffrey (2019)***

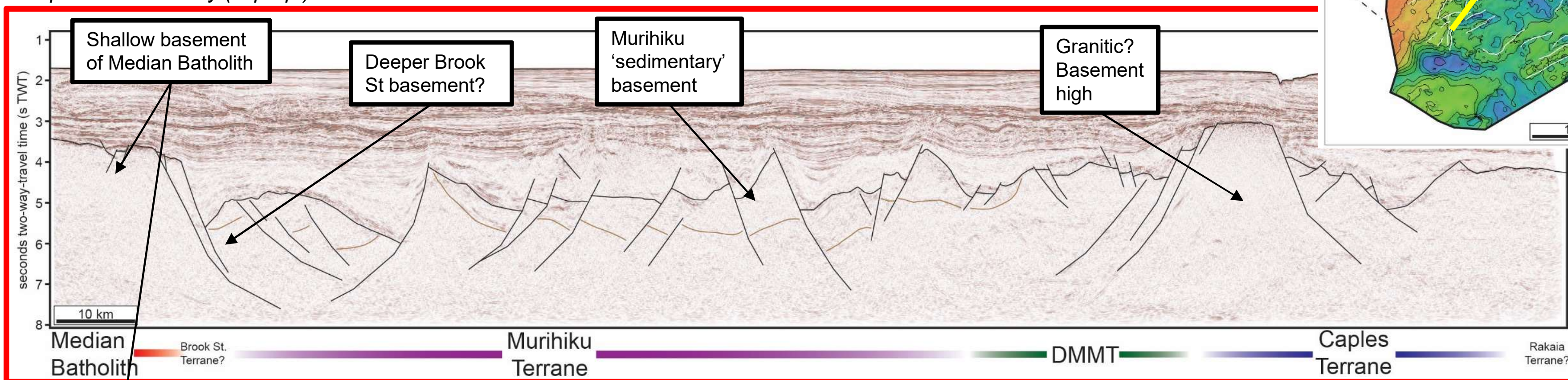
Work in progress/Preliminary

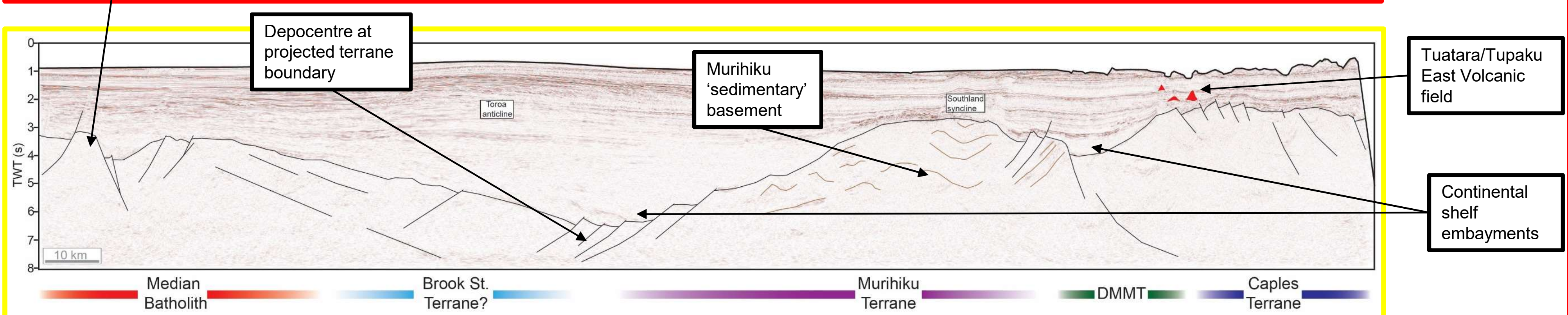
Regional rift physiography

- *Rift structural style varies across basement terranes*
- *Terrane boundaries often collocated with rift depocentres*



Phillips and McCaffrey (in prep.)

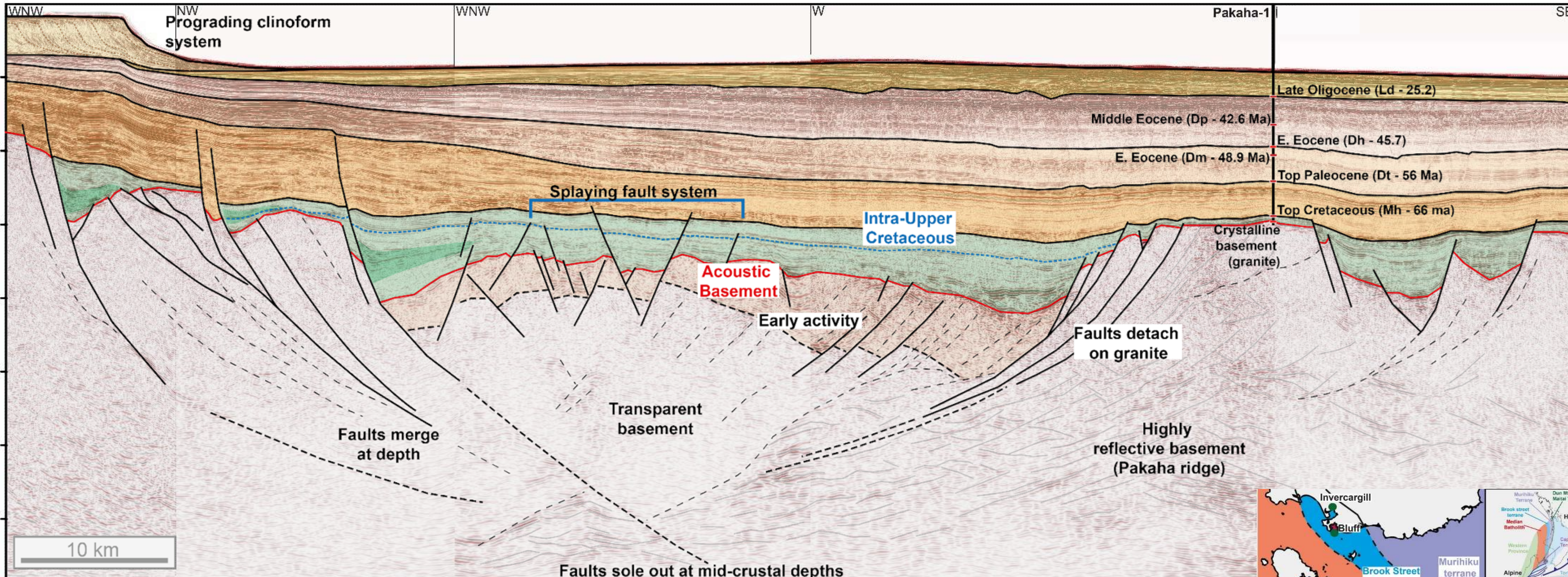




Work in progress/Prelimminary

What are the prevailing structural styles associated with different basement terranes?

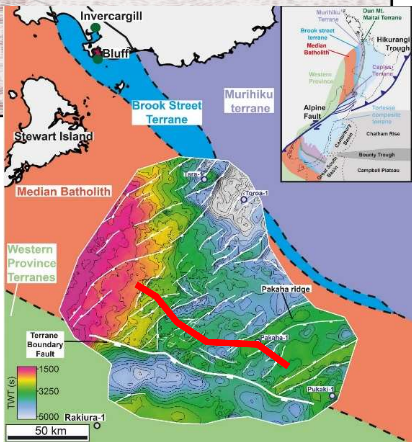
‘Strong’ case - Median Batholith



Phillips and McCaffrey (2019)

Major faults *- ~9 (~31 total)*
Total heave *- ~10 km, ~1 km per fault (~0.33 km on all faults)*
Average throw *- ~0.3-0.4 s TWT*
Beta Factor *- ~1.11*

- *Strain localised on irregularly spaced major faults*
- *Low β, dominated by minor faults?*
- ***Location of major faults governed by granite-cored basement highs?***



Work in progress/Preliminary

‘Normal’ case - Dun Mt.-Maitai terrane

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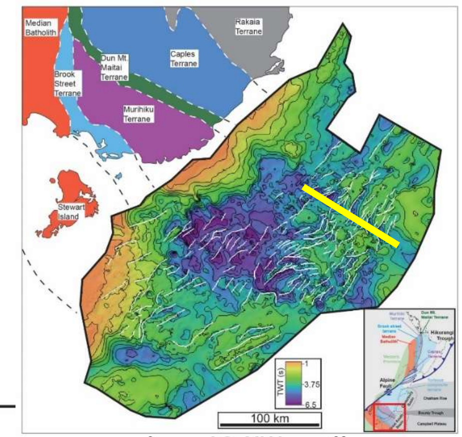
Faults *- ~8 (~0.079 faults per km)*

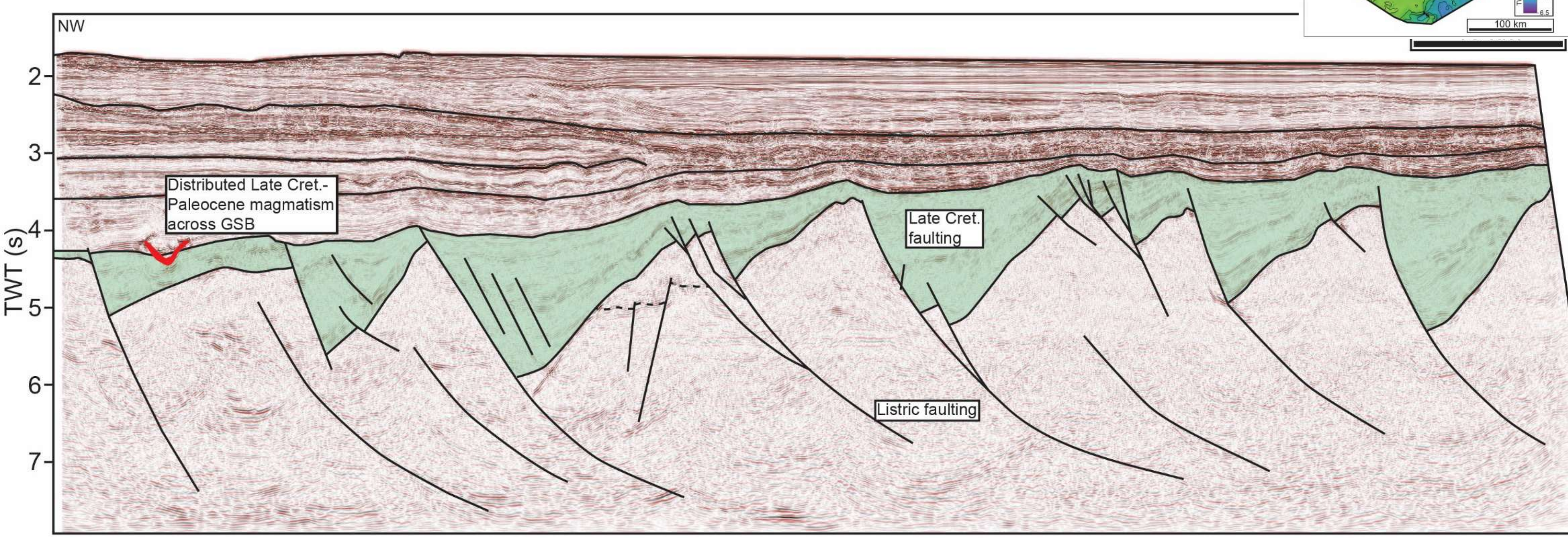
Total heave *- ~25 km, ~3 km per fault*

Average throw *- ~1-1.5 s TWT*

Beta Factor *- ~1.32*

- *Regularly spaced, SE-dipping faults*
- *Listric fault geometry, indicating mid-crustal detachment (Uruski, 2010)*
- *High displacement faults*
- *Relatively high β factor*





Phillips and McCaffrey (in prep.)

Work in progress/Preliminary

‘Weak’ case - Murihiku Terrane

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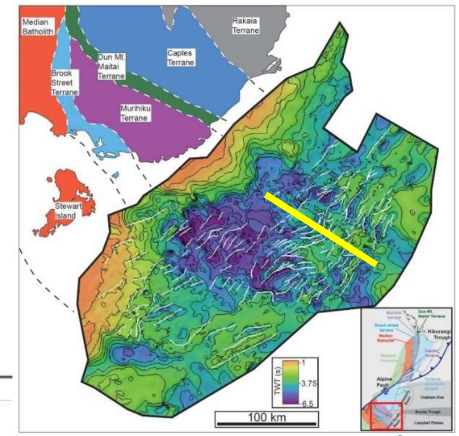
Major faults *- ~12 (28 total) (~0.08 (0.19)) faults per km)*

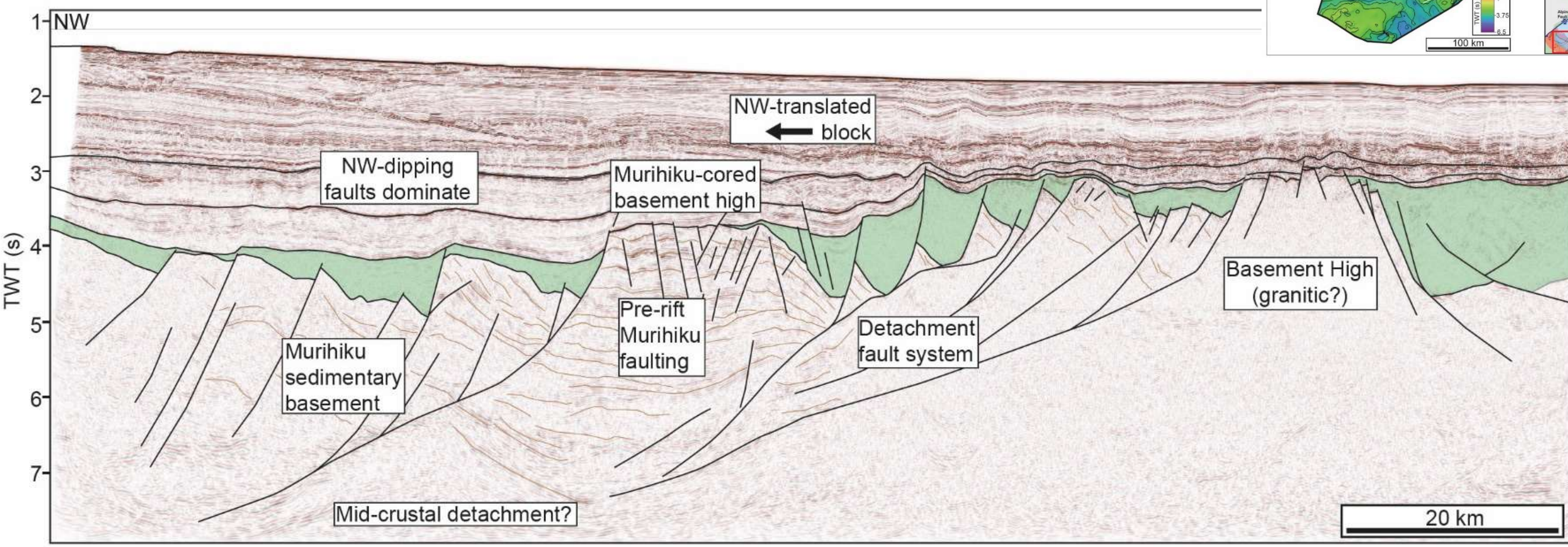
Total heave *- ~30 km, ~2.5 km per fault*

Average throw *- ~0.6 s TWT*

Beta Factor *- ~1.26*

- *NW-dipping faults west of the basement high*
- *Basement characterised by sedimentary reflectivity*
- *Detaching faults ➔ exploiting mid-crustal detachment/internal Murihiku horizon*
- *Unfaulted granite- and Murihiku-cored basement highs*



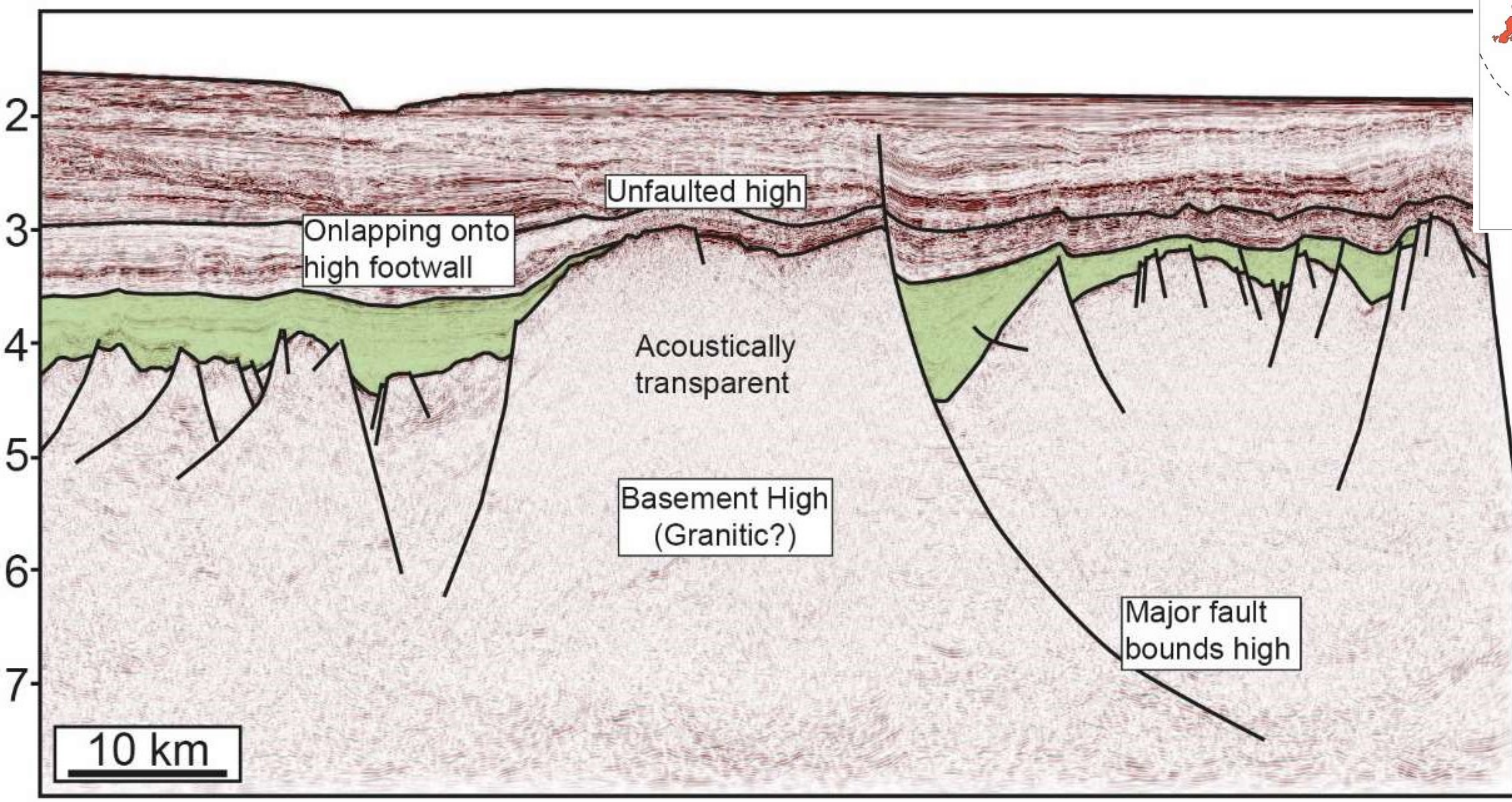


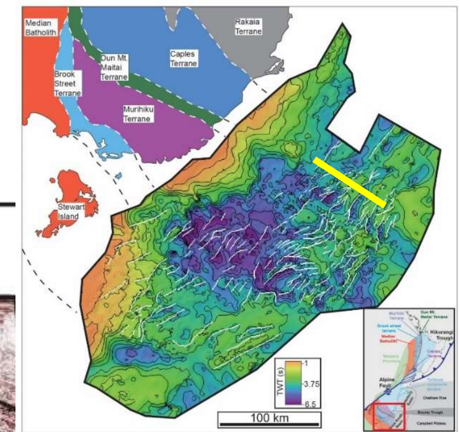
Phillips and McCaffrey (in prep.)

Work in progress/Preliminary

Role of granitic basement highs

- *Unfaulted during Late Cretaceous extension*
- *Acoustically-transparent – granite-cored nature?*
- *Partition areas of dominantly NW- and SE-dipping faults*





Phillips and McCaffrey (in prep.)

Work in progress/Preliminary

Basement highs – Rift anchors?

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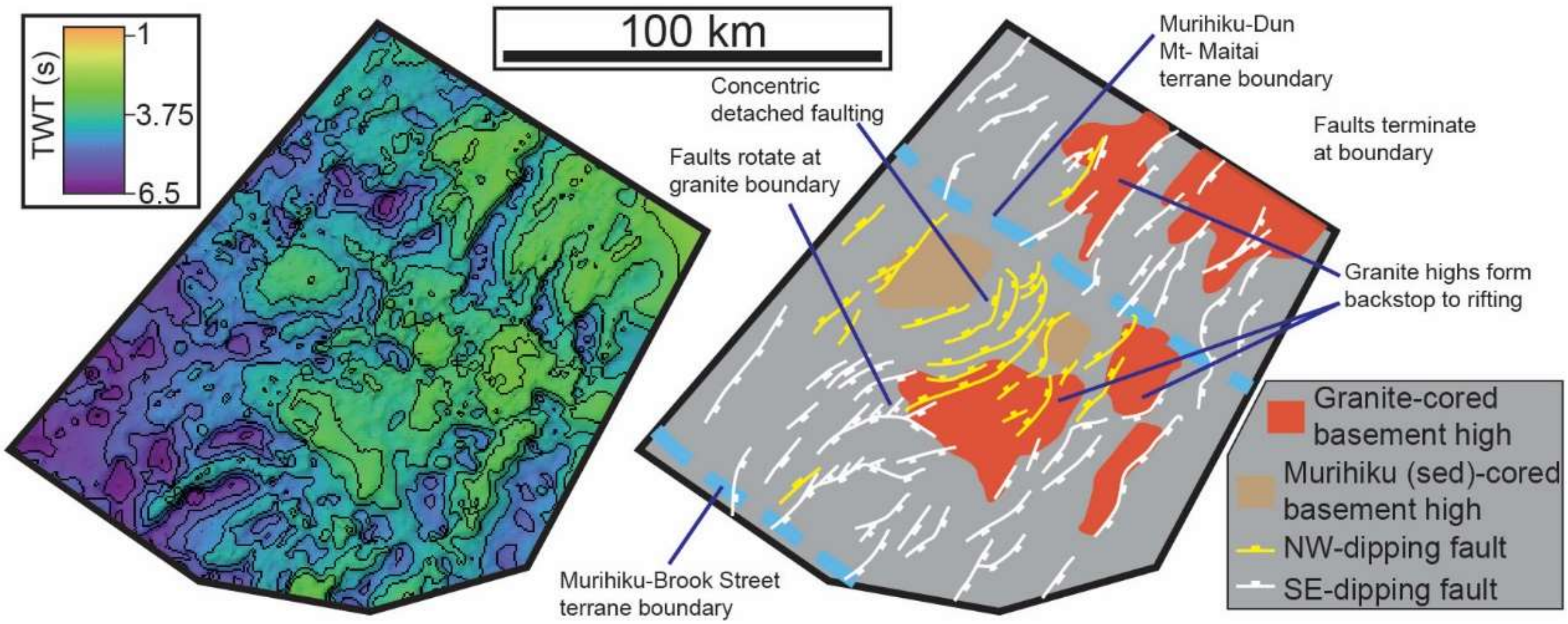


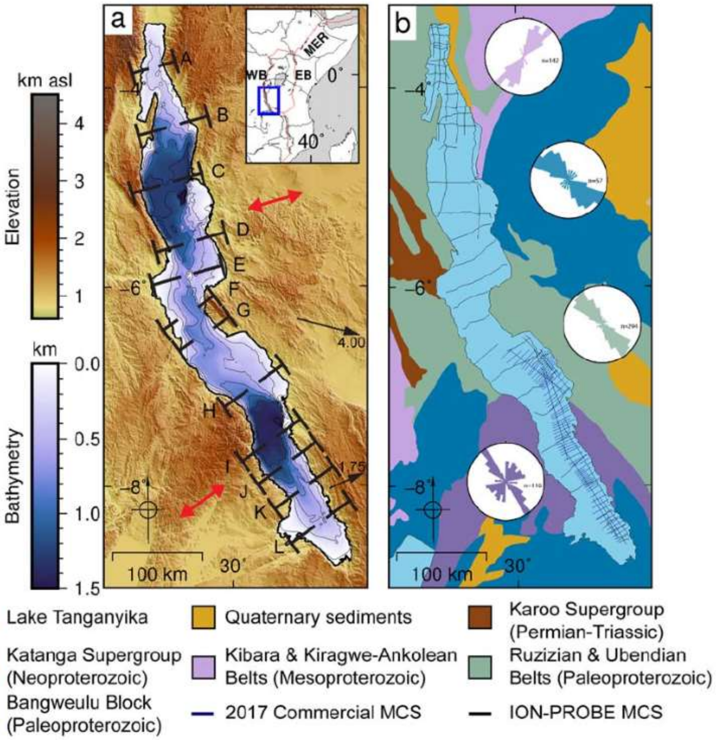
Phillips and McCaffrey (in prep.)

- *Terrane boundaries delineated by **fault terminations, fault rotations,** and **areas of changing fault polarity***
- *Relatively 'strong' granitic bodies are resistant to extension and form fixed **anchors** during rifting*
- *Faults localise along both or one of the margins of these granite-cored **anchors,** governing the dip polarity of faults on that side*
- *Sedimentary-cored (Murihiku) highs are transported along detaching fault systems*

Work in progress/Preliminary

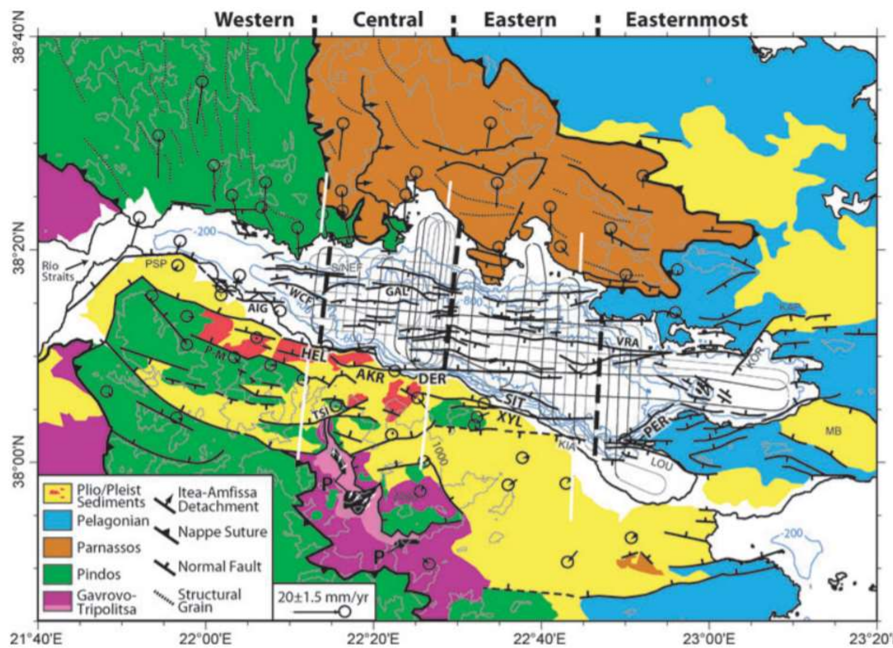
Global comparisons

Tanganyika Rift



Wright et al., (2020)

Gulf of Corinth

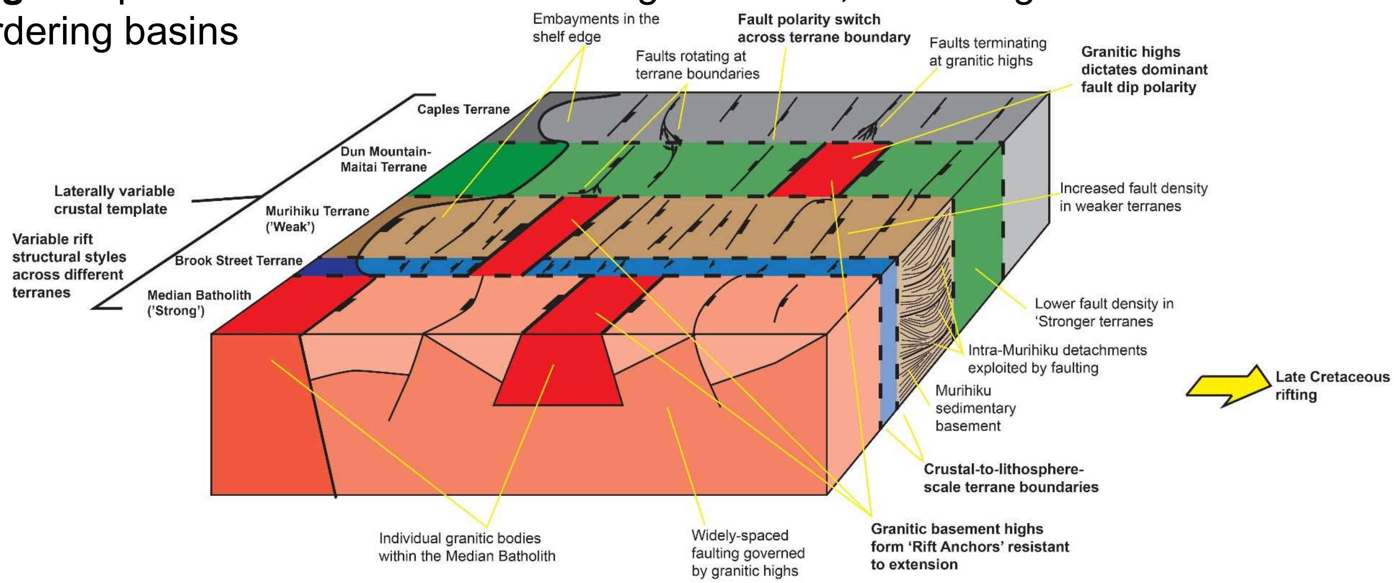


Taylor et al., (2011)

- *Rifting across a laterally variable and heterogeneous basement*
- *Extension direction often (sub-) parallel to the boundaries between basement terranes.*

Summary

- Terrane boundaries may **reactivate** during earlier phases of extension, but **partition and segment** the rift system during the main rift phase
- Stronger areas of crustal material and terranes(i.e. granitic batholiths) are typically **resistant to faulting** and undergo seemingly less extension
- **Weaker** terranes experience larger strains and extension, characterised by the development of **high-displacement, listric** faults
- **Basement highs** represent **"Rift Anchors"** during extension, remaining unfaulted and determining the fault polarity in bordering basins



Phillips and McCaffrey (in prep.)

References

Phillips and Magee (in Review) - Structural controls on the location, geometry, and longevity of an intraplate volcanic system - The Tuatara Volcanic Field, Great South Basin, New Zealand - https://eartharxiv.org/b94ds/

Phillips and McCaffrey (2019) - Terrane Boundary Reactivation, Barriers to Lateral Fault Propagation and Reactivated Fabrics: Rifting Across the Median Batholith Zone, Great South Basin, New Zealand - https://doi.org/10.1029/2019TC005772

Samsu et al., https://eartharxiv.org/afd7w/

Beniest et al., (2018) - https://doi.org/10.3389/feart.2018.00148

Uruski, 2010 - https://doi.org/10.1016/j.marpetgeo.2010.05.010

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