Styles and Scales of Structural Inheritance throughout Continental Rifting

Examples from the Great South Basin, New Zealand

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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

1. Cambrian-Cretaceous subduction along the southern 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 the continental shelf

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

Area of focus - Great South Basin

Uruski (2010)

Courtesy of IODP
Basement beneath the Great South Basin

- 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

SES1 deep seismic line – After Mortimer et al., (2002)
Part I –
Influence of crustal-scale terrane boundaries
Terrane boundaries controlling volcanism

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)

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Barriers to lateral fault propagation

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

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

Work in progress – Quantitative analyses unable to be completed
Regional rift physiography

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

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

Phillips and McCaffrey (in prep.)
Regional rift physiography

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

Phillips and McCaffrey (in prep.)
What are the prevailing structural styles associated with different basement terranes?
**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 $\beta$, dominated by minor faults?
- Location of major faults governed by granite-cored basement highs?
**‘Normal’ case - Dun Mt.-Maitai terrane**

- **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

**Work in progress/Preliminary**

- 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.)*
‘Weak’ case - Murihiku Terrane

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.)
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.)
• 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
Global comparisons

Tanganyika Rift

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

Gulf of Corinth

Taylor et al., (2011)
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

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