ARCHIMEDES: A multi-methodical approach to decipher the extensional dynamics of the northern Lau Basin at 16°S

Anna Jegen[1], Anke Dannowski[1], Heidrun Kopp[1], Udo Barckhausen[2], Ingo Heyde[2], Michael Schnabel[2], Florian Schmid[3] , Philipp Brandl[1], Arvinder Sandhu[1], Reinhard Werner[1], Michael Riedel[1], Anouk Beniest[4] and Mark Hannington[5]

1 GEOMAR, Helmholtz Centre for Ocean Research, Kiel, Germany
2 BGR Federal Institute for Geosciences and Natural Resources, Hannover, Germany
3 K.U.M, Kiel, Germany
4 Vrije Universiteit Amsterdam, Amsterdam, Netherlands
5 University of Ottawa, Ottawa, Canada

GEOMAR

contact: ajegen@geomar.de

Introduction

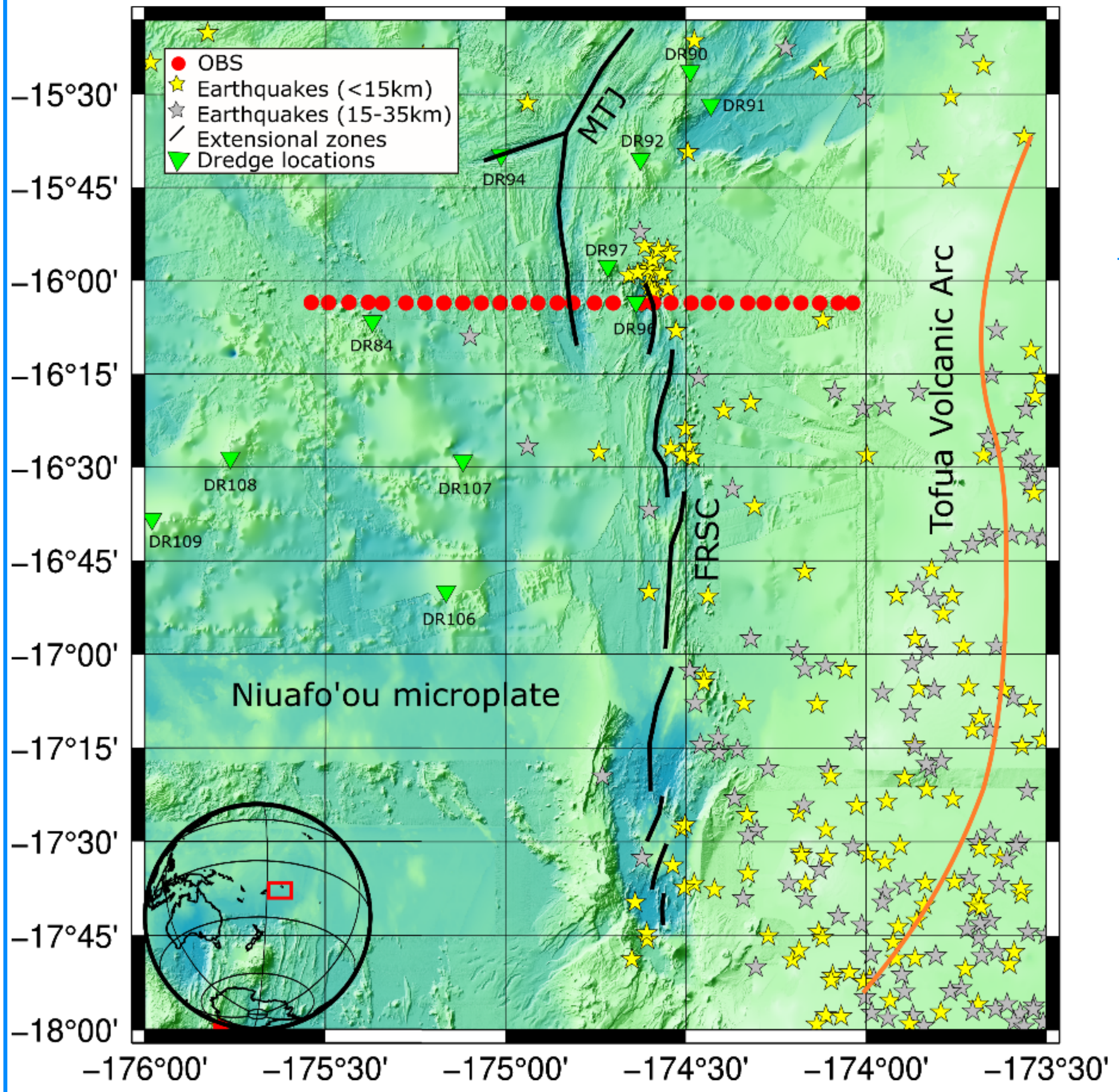

Figure 1: Bathymetric map of the larger study area, the discussed profile is marked in red, dredge locations in green. The crossed spreading centres are marked with FRSC (Fonualei Rift spreading centre) and MTJ (Mangatolu Triple Junction). Earthquake data is taken from Conder and Wiens 2011).

Objectives

(1) Determine the opening mechanisms at the FRSC1 & MTJ-S2.
(2) Determine whether crustal zonation influences the tectonic expression of the extensional zones.

Methods

(1) Refraction seismic data
- 185 km long transect
- 30 OBS with ~5 km spacing
- shot interval of 170 m

(2) Multi-channel seismics
- a 3.9 km long streamer with 312 channels
- shot interval of 50 m

(3) Magnetic data
- a towed marine magnetics SesSpyII gradiometer system

(4) Gravimetric data
- using the sea gravimeter system KSS32-M

Geological setting

- The Lau basin is a young back-arc basin forming at the Indo-Australian-Pacific plate boundary.
- Its crust displays a geochemical zonation and varying crustal thickness, which depends on the arc offset and the thus conditioned coupling of the spreading centre's and the volcanic arc's melt supplies (Pearce et al., 1994; Hawkins and Taylor, 1995; Martinez and Taylor, 2002; Dunn and Martinez 2011).
- While a weak to no arc influence was determined for the MTJ-S2, coupled melt supplies were suggested for the FRSC1 (Keller et al., 2008, Escrig et al., 2012, Sleeper et al., 2016).
- A distinct feature of the northern Lau basin is an overlapping spreading centre (OLSC) that consists of the southern tip of the eastern axis of the Mangatolu Triple Junction (MTJ-S2) and the northern tip of the Fonualai Rift spreading centre (FRSC1).
- MTJ-S2 shows a patchy, narrow neovolcanic zone (Anderson et al., 2021) and is offset ~25 km from the FRSC1, which is characterised by an axial valley and a steady sized (15 km) volcanic zone (Sleeper and Martinez, 2016; Anderson et al., 2021).
- Despite comparable extension rates (MTJ-S: ~27-33mm/a, FRSC: ~8-22 mm/a), the observed seismicity varies strongly along the OLSC: clusters of earthquakes (EQ) at the FRSC1 and no seismicity at the MTJ-S2 (Conder and Wiens 2011).
- The formation of the crust between the MTJ-S2 & FRSC1 appears to be independent of the extensional zones (Dziewonski et al., 1981; Ekström et al., 2012; Sleeper and Martinez 2016).

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Results

Reflection seismic and Parasound data

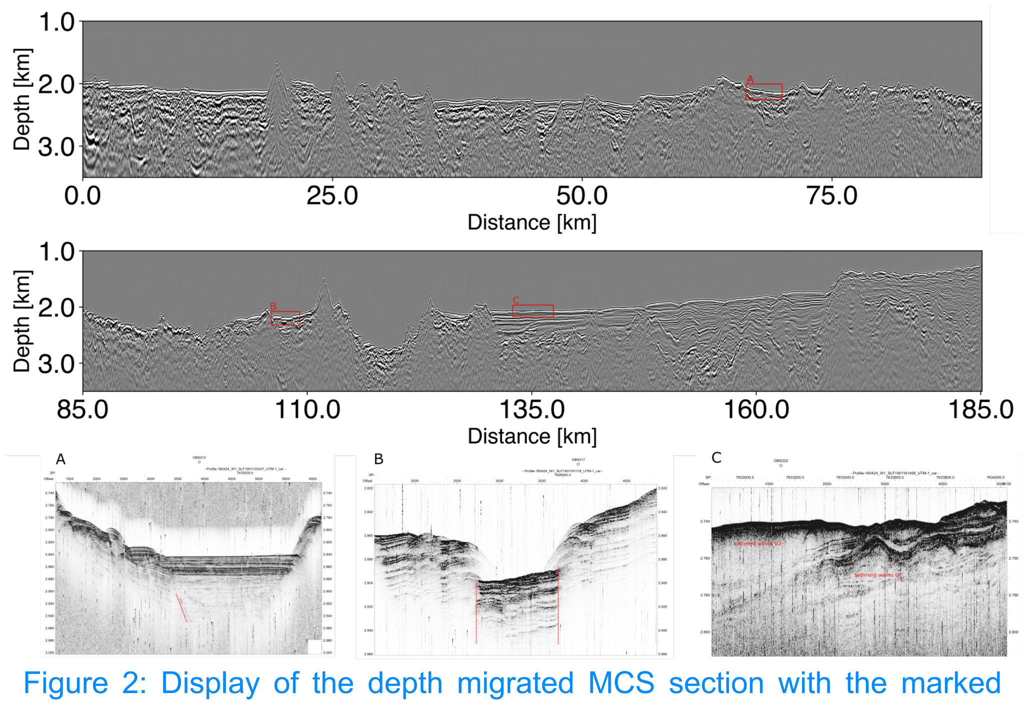


Figure 2: Display of the depth migrated MCS section with the marked locations of the Parasound excerpts shown in A-C.

- Recent tectonic activity is refined to the area of the OLSC.
- Numerous volcanic features, based on seafloor roughness, youngest features are located between 80-100 km.
- Wide spread, now inactive extensional features visible ⟶ previous wide rift phase

Potential field methods

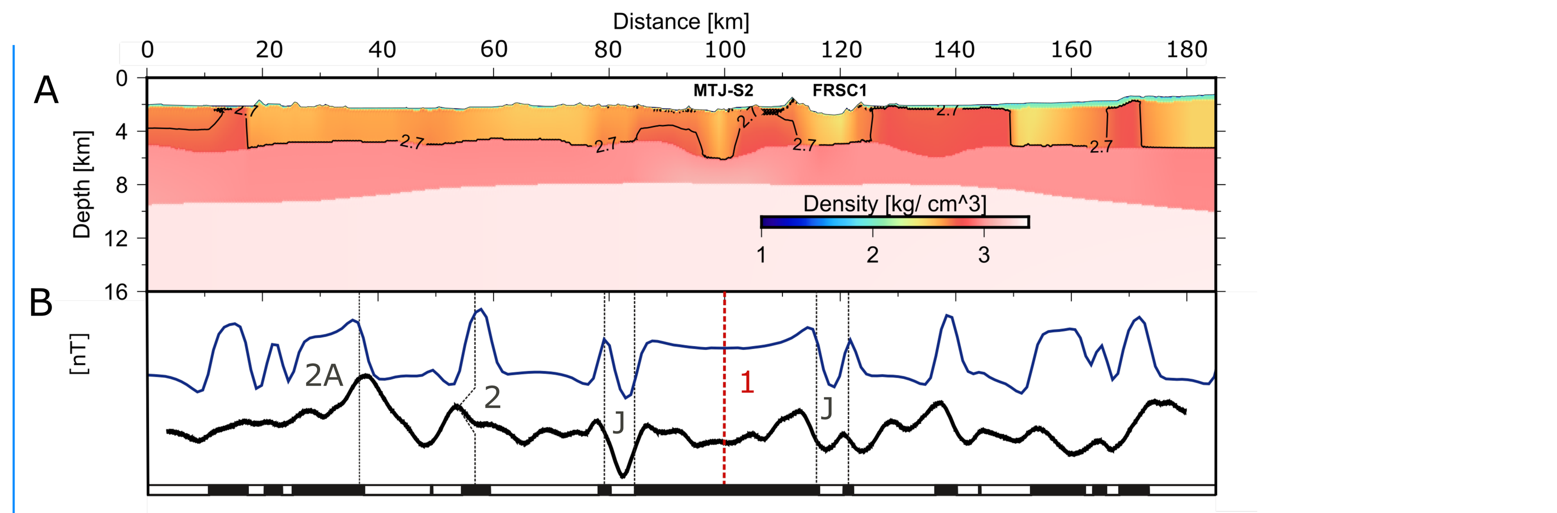


Figure 4: Crude density model derived by forward modelling (A) and B: Comparison of measured field strength (black line) and reference profile (blue). Identified anomalies are annotated and marked by dotted lines, grey for the first spreading phase and red for the second.

- FRSC1 displays wide basement cross-cutting density anomaly and no identifiable magnetic anomaly ⟶ amagmatic extension, rifting
- MTJ-S2 displays decreased upper crustal densities and a wide zone of increased lower crustal densities.
- MTJ-S2 shows Chron 1 anomaly ⟶ magmatically active
- Older anomalies are tectonically overprinted ⟶ likely during wide rift phase (MCS, Fig. 2)
- Age of deformed anomalies decreases with arc proximity

Petrology

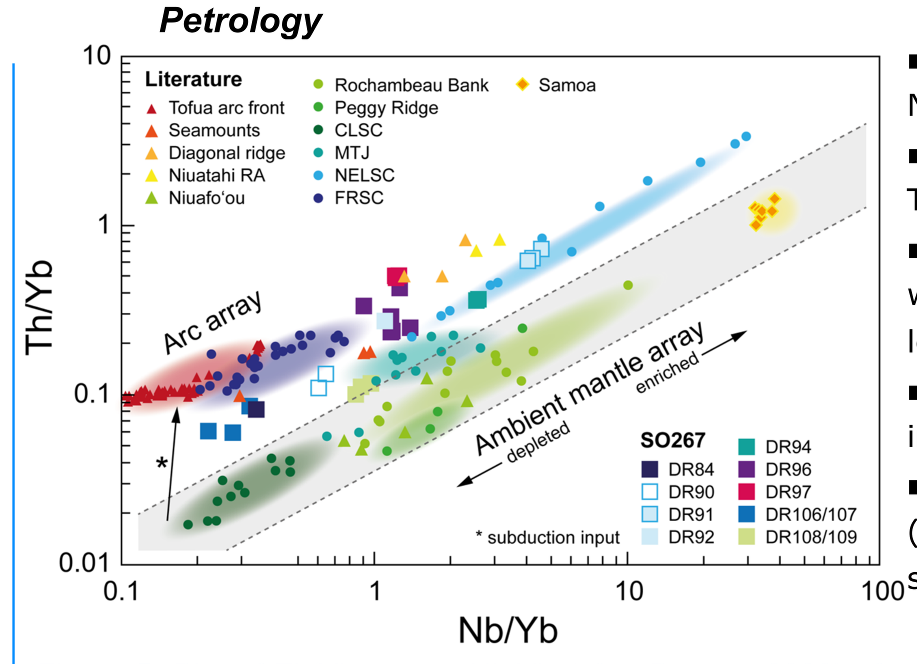
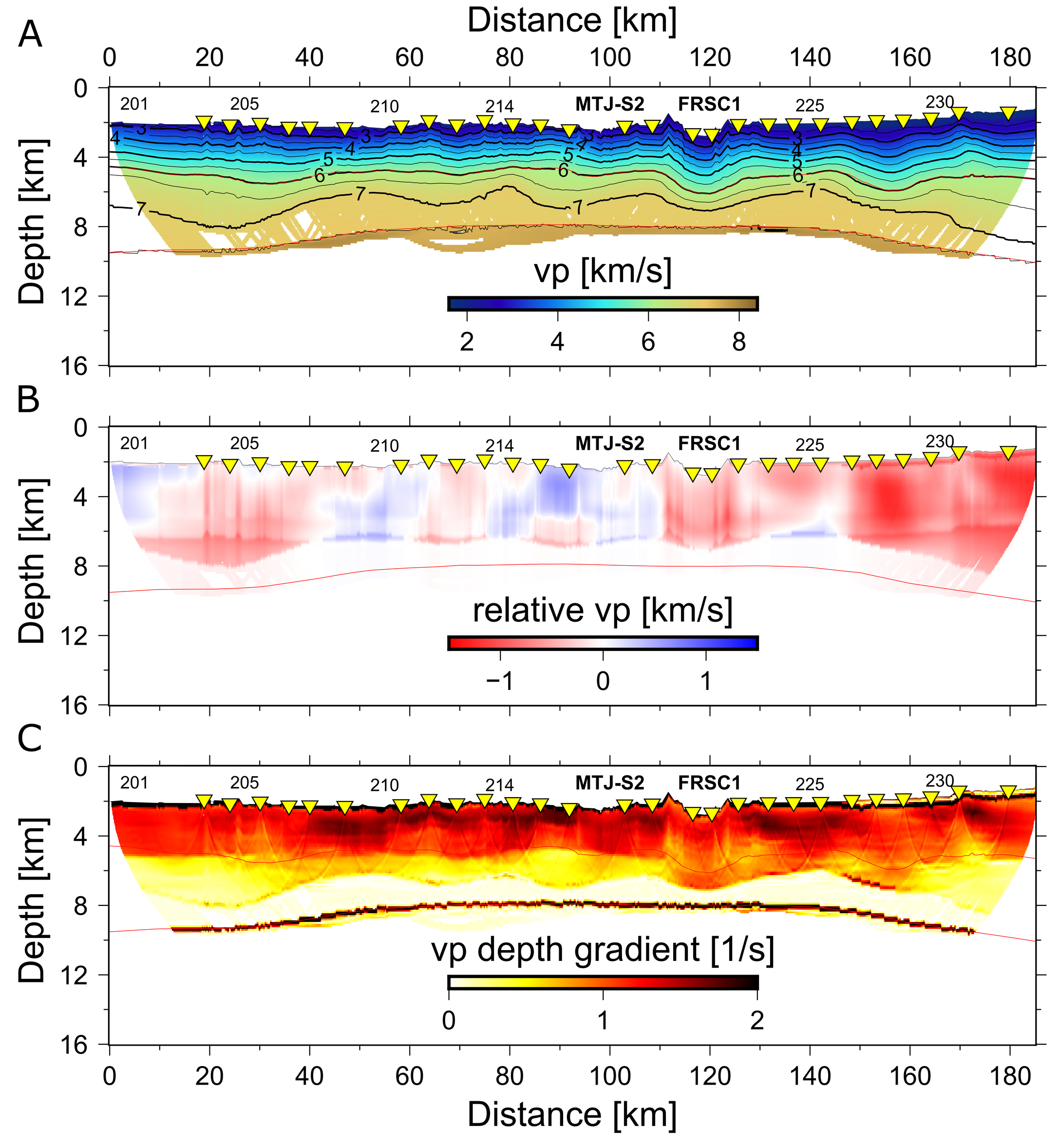


Figure 5: Plot of Th/Yb versus Nb/Yb (after Pearce, 2008) of selected datasets from the northern Lau Basin–Tofua arc area. Data sources: Tofua arc front – Beier et al. (2017); North-East Lau Spreading Center (NELSC), Seamounts at the NELSC propagator, Niuatahi Rear-Arc (RA) volcano, and the Diagonal Ridge – Haase et al. (in review); Peggy Ridge, Rochambeau Bank and rifts, Niuafo'ou intraplate, and the Mangatolu Triple Junction (MTJ) – Tian et al. (2011); Fonualei Rift and Spreading Center (FRSC) – Keller et al. (2008); Caulfield et al. (2012), Escrig et al. (2012); SO267 – Sandhu et al. (in prep.).

- Varying mantle enrichment, visible in the Nb/Yb ratio.
- Variable subduction input, visible in the Th/Yb ratio.
- Trend of decreasing subduction influence with increasing arc offset (compare dredge locations Fig. 1).
- FRSC shows stronger subduction influence than MTJ.
- The crossed volcanic chain at 20-40 km (MCS, Fig. 2), shows a surprisingly strong subduction influence.

Refraction and wide-angle reflection tomography



- Moho depth increases towards the eastern and western end of profile.
- Moho depth is stable under OLSC ⟶ Crust thinnest under FRSC1 due to bathymetric low.

- Two zones of decreased relative vp (20-40 km;110-180 km).
- MTJ-S2: increased relative vp in upper crust and decreased vp in lower crust.
- FRSC1: overall vp decrease.

- Anomalies represent disturbances in ambient crustal stratification.
- Anomalies corelate with heavily faulted or volcanically overprinted seafloor.
- FRSC1 shows stronger & more extensive anomaly than MTJ-S2

Figure 3: Display of A: the final vp tomography result, in which both the mid-crustal boundary and the Moho are marked in red. B: Relative vp distribution, calculated with the 1D profile taken from 105.2 km. C: Calculated depth gradient of the vp distribution, mid-crustal boundary and moho marked in red.

Interpretation

Crustal zonation and spreading history

- The crust underlying the profile was not formed at the OLSC, but at arc proximal a paleo-spreading centre (P-SC).
- With ongoing spreading, P-SC progressively moved away from the arc ⟶ translation of arc-like crust (Fig. 5, DR 106/107)
- Transition to formation of more MORB-like crust, currently visible at ~110 km (Fig. 3B).
- Anomalies formed at the P-SC deformed during wide rift (Fig. 2).
- Crust is currently being magmatically overprinted at the MTJ-S2 and tectonically overprinted at the FRSC1 (Fig. 4).

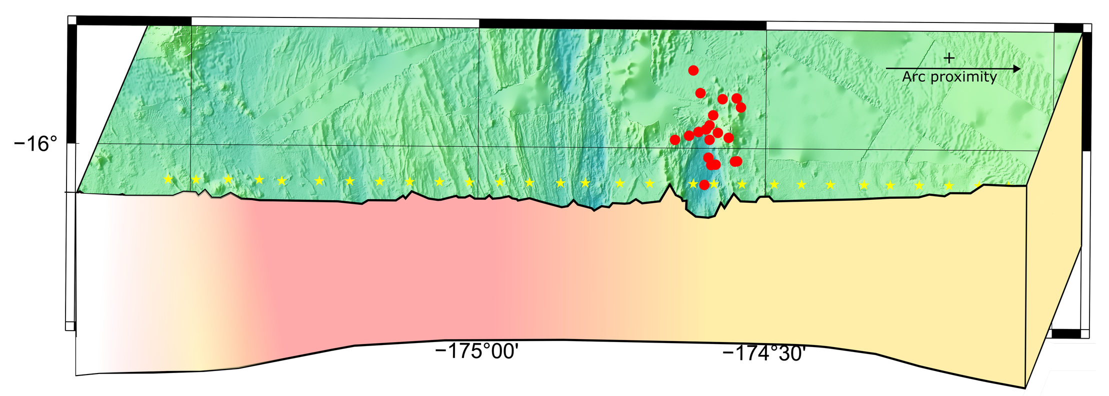


Figure 6: Schematic overview of the interpreted crustal zonation under the profile. Yellow marks old crust that was formed when the melt source of the corresponding paleo-spreading centre (P-SC) was coupled with the volcanic arc, pink colour marks crust that was formed after the P-SC's melt source decoupled from the volcanic arc's. Superimposed are OBS (yellow star) and EQ (red dot) locations.

Opening mechanisms of the FRSC1& MTJ-S2

- FRSC1 is rifting, excessive faulting is lowering the density and the bulk modulus, causing the decreased vp, density and the disturbance in the ambient crustal stratification (Fig. 2,3,4).
- The MTJ-S2 is in an early-spreading state or rifting with a large magmatic budget, forming the Chron 1 anomaly and the observed ragged seafloor (Fig. 2,4).

- At the FRSC1 increased or decreased densities directly translate into a vp decrease or increase respectively (Fig. 3,4).
- Considering the amplitude of the relative vp anomalies at the FRSC1, the anomalies are likely strenghtend by an increase in the bulk modulus in the upper crust and decrease in the lower crust.

- The FRSC1 and MTJ-S2 propagated into geochemically zoned crust
- Geochemical zonation and the different underlying mantle regimes (Haase et al., in review) influence the lithosphere's response to stress.

Conclusions

- Older, more evolved arc-like crust with low viscosity mantle (Dunn and Martinez 2011) reacts more brittle to the imposed trans tensional stress: ⟶ rifting at the FRSC1

- Younger, more fertile MORB-like crust with a more viscous mantle (Dunn and Martinez 2011) has a more elastic stress response: ⟶ early stage spreading or magm. rifting at the MTJ-S2

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