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# Crustal Thickness Estimates Beneath The Ethiopian Plateaus & Rift Using Receiver Function Analysis


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# Outline

# BACKGROUND & MOTIVATION

- The Northeast African rift system (NEARS) provides an exceptional setting to investigate a diverse range of geological natural processes, including rifting, partial melting, lithospheric uplift, and continental extension
- In NEARS: continental extension and deformation in both mechanical faulting and magmatic processes.
- It stretches from the top of Afar to the bottom of Turkana.

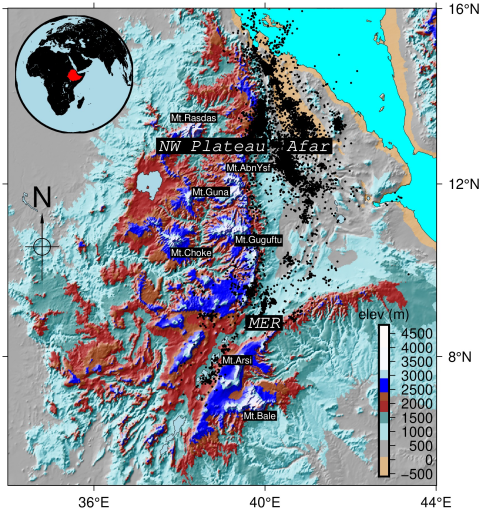
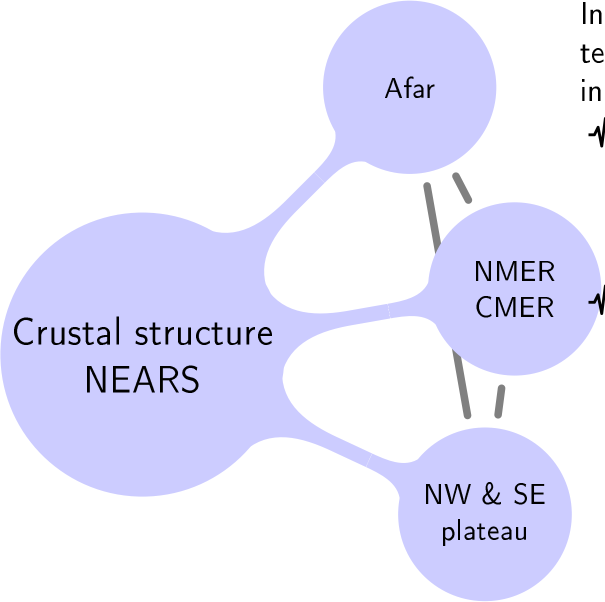


Figure: The Northeast African Rift System (NEARS).




In the context of crustal structure, tectonic processes play a significant role in its evolution.

- Tectonic stretching, driven by factors like:
  - mantle dynamics
  - magmatic intrusion
- Additionally, rifting, a consequence of tectonic stretching, leads to:
  - thermal softening and deformation
  - reduction in crustal strength

  which contribute to the formation of rift zones and continental separation.

A Summary of the findings of previous receiver function studies and gravity modeling to calculate the Moho depth in MER, Southeastern and Northwestern plateau.

| Location | Moho (km) RFs | Source | Moho (km) Gravity | Source |
|---|---|---|---|---|
| MER | 27–40 | Dugda et al. (2005); Keranen et al. (2009); Mackenzie et al. (2005) | ∼32–38 | Cornwell et al. (2006); Emishaw et al. (2017); Mickus et al. (2007); Tiberi et al. (2005); Mahatsente et al. (1999); Mammo (2013) |
| E plateau | 32-44 | Dugda et al. (2005); Stuart et al. (2006); Cornwell et al. (2010); Hammond et al. (2011); Hammond (2014); Mackenzie et al. (2005) | 34-38 | Mahatsente et al. (1999); Tessema and Antoine (2004); Cornwell et al. (2006); Mickus et al. (2007) |
| W plateau | 38–48 | Hammond et al. (2011); Stuart et al. (2006); Wang et al. (2021) | 38-51 | Mahatsente et al. (1999); Mammo (2013); Tessema and Antoine (2004); Cornwell et al. (2006); Woldetinsae and Gotze (2005); Mickus et al. (2007) |

## Crustal properties in NEARS

Further research needed

melting/thickness/Moho

Previous:seismic imaging tomography/RFs/MT/gravity

- Heavily intruded mafic crust and frozen magmatic segment in MER axis (Keranen et al., 2004; Daly et al., 2008; Ebinger and Casey, 2001).

- High conductivity anomalies linked to hydrothermal fluids, young volcanism (Whaler and Hautot, 2006) and partial melt in subvolcanic plumbing system (Johnson, 2012; Desissa et al., 2013).

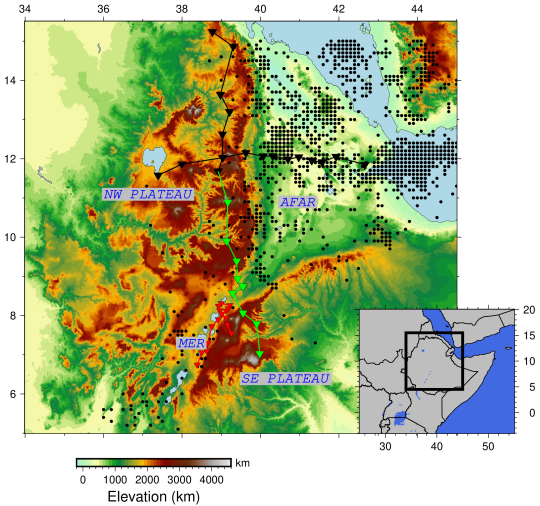



Figure: Temporary seismic stations used in the study (earthquakes b/n 1906 and 2021:http://www.isc.ac.uk/).

Black inverted triangles: NW plateau & Afar profiles (Archived)

Green inverted triangles: NW plateau, NMER and SE plateau stations (Archived)

Red inverted triangles are CMER stations (RiftVolc)

# Archival teleseismic data

- EAGLE, Afar Consortium, and RiftVolc
- RiftVolc, AFAR07 project, AFAR0911 project, Eritrea Seismic Project (ESP), and DORA project were integrated.
- Teleseismic earthquakes (30° and 90°) with Mb >6.0 sourced from the IRIS Data Management Center (IDMC).

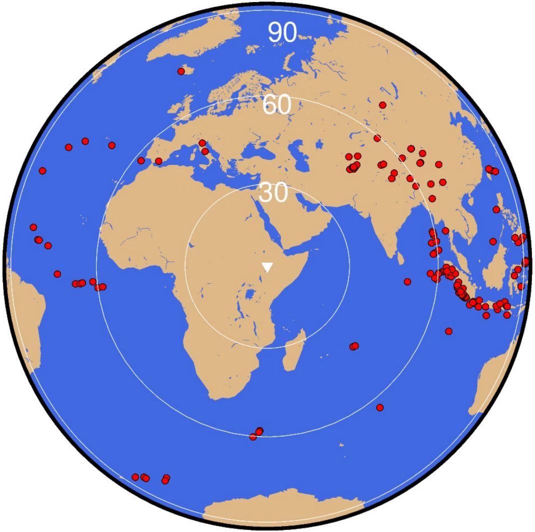



Figure: Locations of teleseismic earthquakes used in the analysis.

RF technique: was first introduced by Clayton and Wiggins (1976) and refined by Owens et al. (1984) and Ammon et al. (1990) employed to characterize the crustal structure.

- RF technique used with teleseismic earthquakes (> 6.0 magnitude, 30° to 90° epicentral distance) Langston (1979); Ammon (1991).

- RFs & Vs are computed using Gaussian parameter of 1.0 and water level of 0.01 starting from ak135 $V_{inintial}$

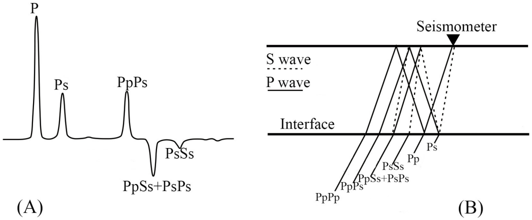



Figure: Formation of a radial receiver function through a single layer above a half space. (A) P wave, Ps converted wave, and reverberations. (B) Model indicating wave conversions at an interface.

**CPS application advantages:**

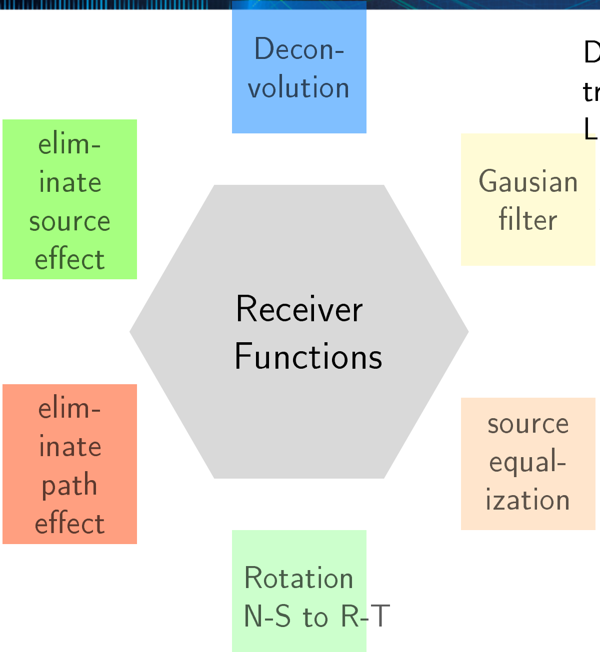
Advanced tools

adaptability

simplicity

inversion of ORF

calculation of SRF




Deconvolution generated radial and transversal RFs (Ammon, 1991; Langston, 1979). **Displacement**

$$Disp_V(t) = Inst(t) * Srs(t) * Erth_V(t) \quad (1)$$

$$Disp_R(t) = Inst(t) * Srs(t) * Erth_R(t) \quad (2)$$

$$Disp_T(t) = Inst(t) * Srs(t) * Erth_T(t) \quad (3)$$

$$Erth_R(\omega) = \frac{Disp_R(\omega)}{Disp_V(\omega)} \quad (4)$$

$$Erth_T(\omega) = \frac{Disp_T(\omega)}{Disp_V(\omega)} \quad (5)$$

## Results and Discussion

- ORFs & SRFs were computed at 17 stations (77%–92% fit).
- RFs show P waves and converted/reverberated phases.
- Stations on SE Plateau have similar Vs to ASSE.

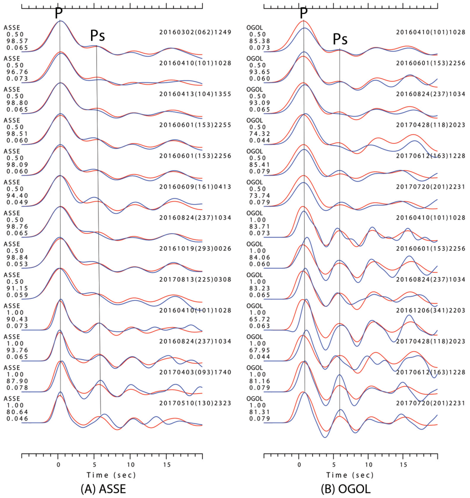



Figure: Largest (ASSE) and smallest (OGOL) fit models

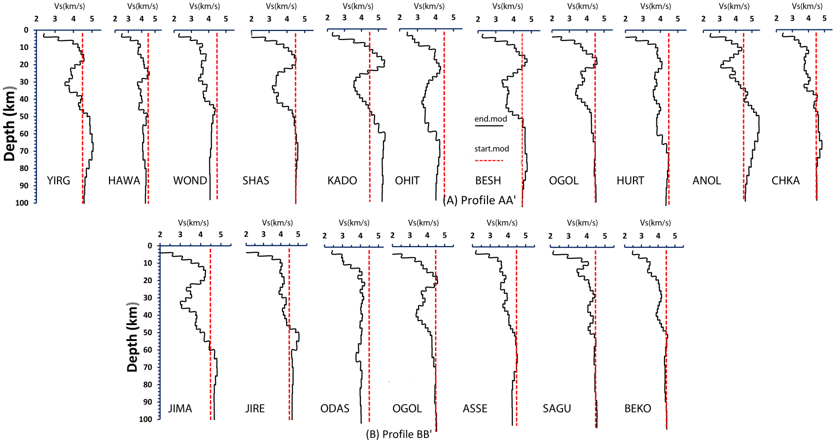



Figure: (A) shows the 1D velocity model for the along-rift profile AA', which is located along the eastern margin of the central main Ethiopian rift profile. (B) is the 1D velocity model for the across-rift profile, which includes the rift side (JIMA, JIRE, ODAS, and OGOL) and plateau side (ASSE, SAGU, and BEKO) stations.

## Slow velocity:

- From 2–3 km/s at 2–6 km depth corresponds to layered sediments and volcanic layers.
- The low Vs of the upper crust extends deeper within the CMER highly beneath volcanic centres compared to outside of it.
- Slow velocity zones observed beneath caldera rims.

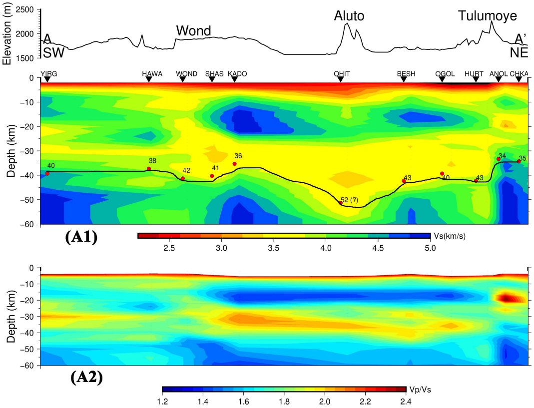



Figure: 2D vertical slice along the eastern margin of the central Main Ethiopian Rift (A1) and corresponding Vp/Vs ratio values (A2). Blue indicates low Vp/Vs, and red indicates high Vp/Vs ratio.

# S-wave Velocity Structure of the Eastern Plateau

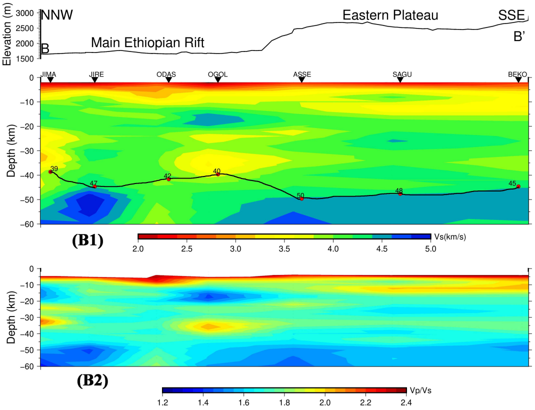



Figure: (B1) 2D vertical slice of rift profile BB' from JIMA to BEKO. Red: slower velocity, blue: faster velocity. (B2) Vp/Vs values for rift and plateau side. Blue: low Vp/Vs, red: high Vp/Vs ratio.

- Vs beneath SE Plateau is remarkably homogeneous, with distinct increase at ∼45 km.
- Limited crustal heterogeneity beneath SE plateau suggests a stable continental crust with little magmatic modification.
- The strong velocity contrast between the Eastern Plateau and the rift indicates an asymmetry in the rifting process, unlike the conjugate side.

# Velocity Models of Afar

- Under rift axis fast Vs (>4 km/s) at shallow depths (6–14 km), slower Vs (<3.2 km/s) in lower crust (15–25 km).
- Magmatic segment, representing current extension locus.
- Mid-crust showed a Vp/Vs ∼2.0 along the rift axis.
- Deep crustal earthquakes interpreted as magma or fluid-related.
- High Vp/Vs (∼2.0) at ∼20–25 km depth beneath magmatic segment.

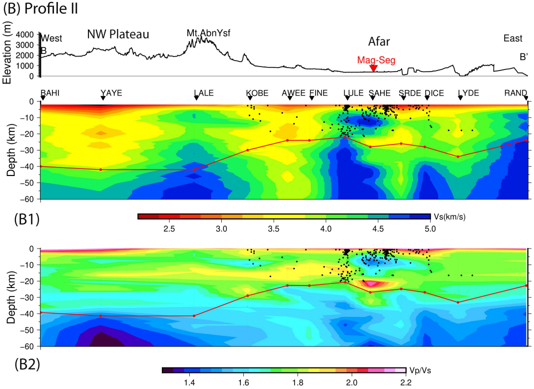



Figure: (B) shows a 2D vertical slice of Afar profile II. Earthquakes Zwaan et al. (2020).

## 2D Vs and Vp/Vs Models

- NW plateau: High-velocity material at 12-22 km depth with >4.3 km/s.
- Large area with low-velocity material (<3.4 km/s) beneath NW plateau.
- NMER: high Vs (>4.6 km/s) is localized throughout mid-to-lower crusts
- Beneath NMER: Low Vs & high Vp/Vs is observed at deepest layers.
- Our observation supports previous findings

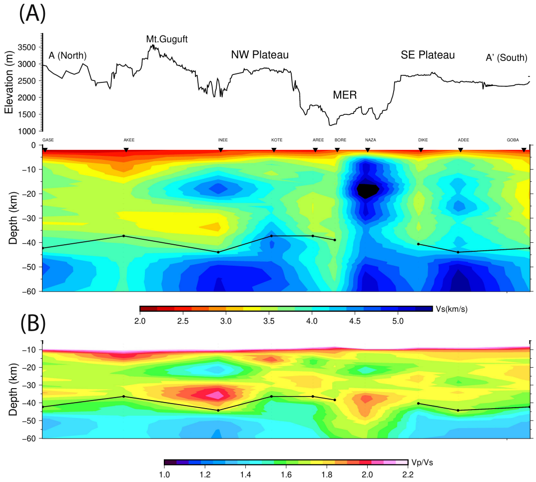
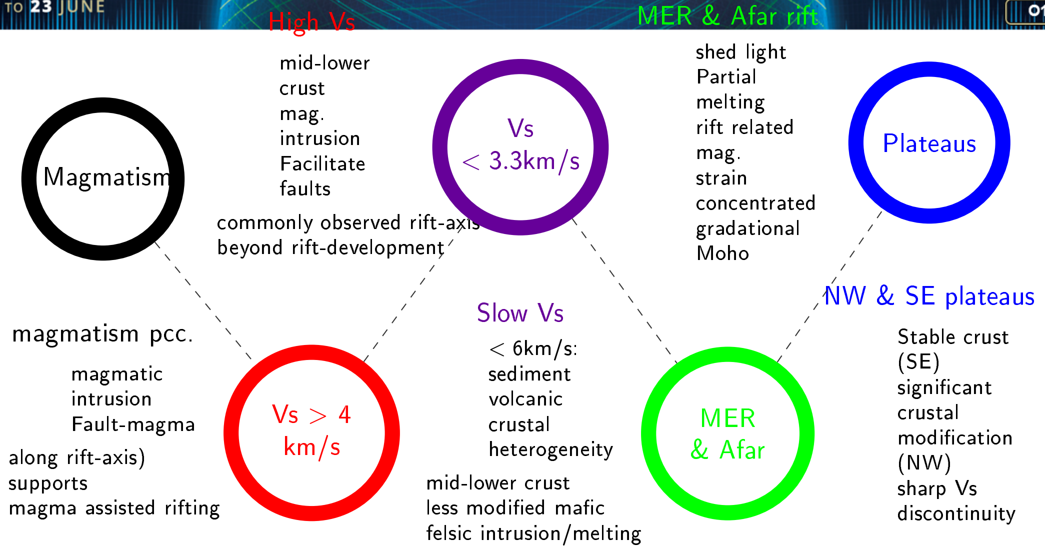



Figure: 2D Vs & Vp/Vs model obtained from 1D results using Delaunay triangulation.


Magmatism
High Vs
mid-lower crust mag. intrusion Facilitate faults
commonly observed rift-axis beyond rift-development
Vs < 3.3km/s
MER & Afar rift
shed light Partial melting rift related mag. strain concentrated gradational Moho
Plateaus
magmatism pcc.
magmatic intrusion Fault-magma
along rift-axis) supports magma assisted rifting
Vs > 4 km/s
Slow Vs
< 6km/s: sediment volcanic crustal heterogeneity
mid-lower crust less modified mafic felsic intrusion/melting
MER & Afar
NW & SE plateaus
Stable crust (SE) significant crustal modification (NW) sharp Vs discontinuity

# CONCLUSIONS

- This study analyzed teleseismic data to investigate the crustal structure of Ethiopia and Eritrea.
- The uppermost crust exhibits low Vs, indicating sedimentary and/or volcanic layers
- Partial melt in the lower crust is more widespread and plays a significant role in the active rifting.
- High Vs materials are observed under the rift axis of Afar and MER.
- Faster Vs is observed beneath the upper-to-mid crust of the NW plateau.
- In contrast, SE Plateau shows a more homogeneous and faster $V_s$.
- Crust thickness varies: $36 - 44$ km in NW plateau, $38 - 42$ km in SE plateau.
- Crustal thinning that support magma-assisted rifting hypothesis.

# THANK YOU!

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