European Geosciences Union

Imaging segmentation in early stage rifting using a joint inversion of Rayleigh waves from teleseisms and ambient noise in the northern East African Rift

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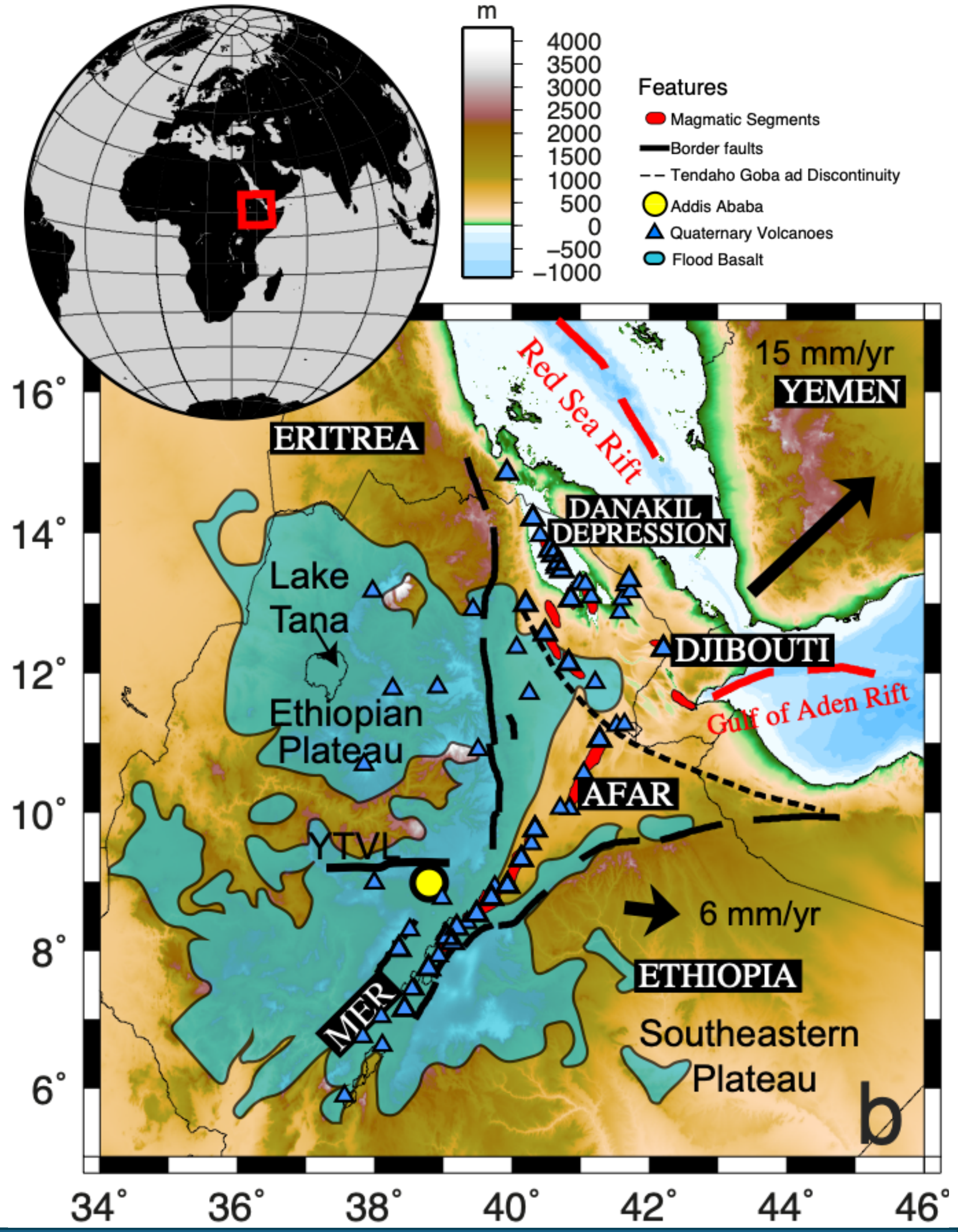
Aims

1. Investigate the controls on melt migration and storage in the mantle and crust.
2. Investigate whether melt is isolated to the rift or whether it can migrate off rift.

How will we do this?

- Use a joint inversion of Rayleigh waves from ambient noise and teleseisms.
- Image depths from 10 - 210 km.
- Perform the first surface wave tomography analysis using the Plateau YY network providing insight into plate structure of the western Ethiopian Plateau.
- Image a fast lid representative of Lithosphere-Asthenosphere-Boundary depths.
- Investigate radial anisotropy from ambient noise to determine storage of melt in the crust as sills and dykes.



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Data & Methods

- 270 stations from 1999 - 2017

Ambient noise

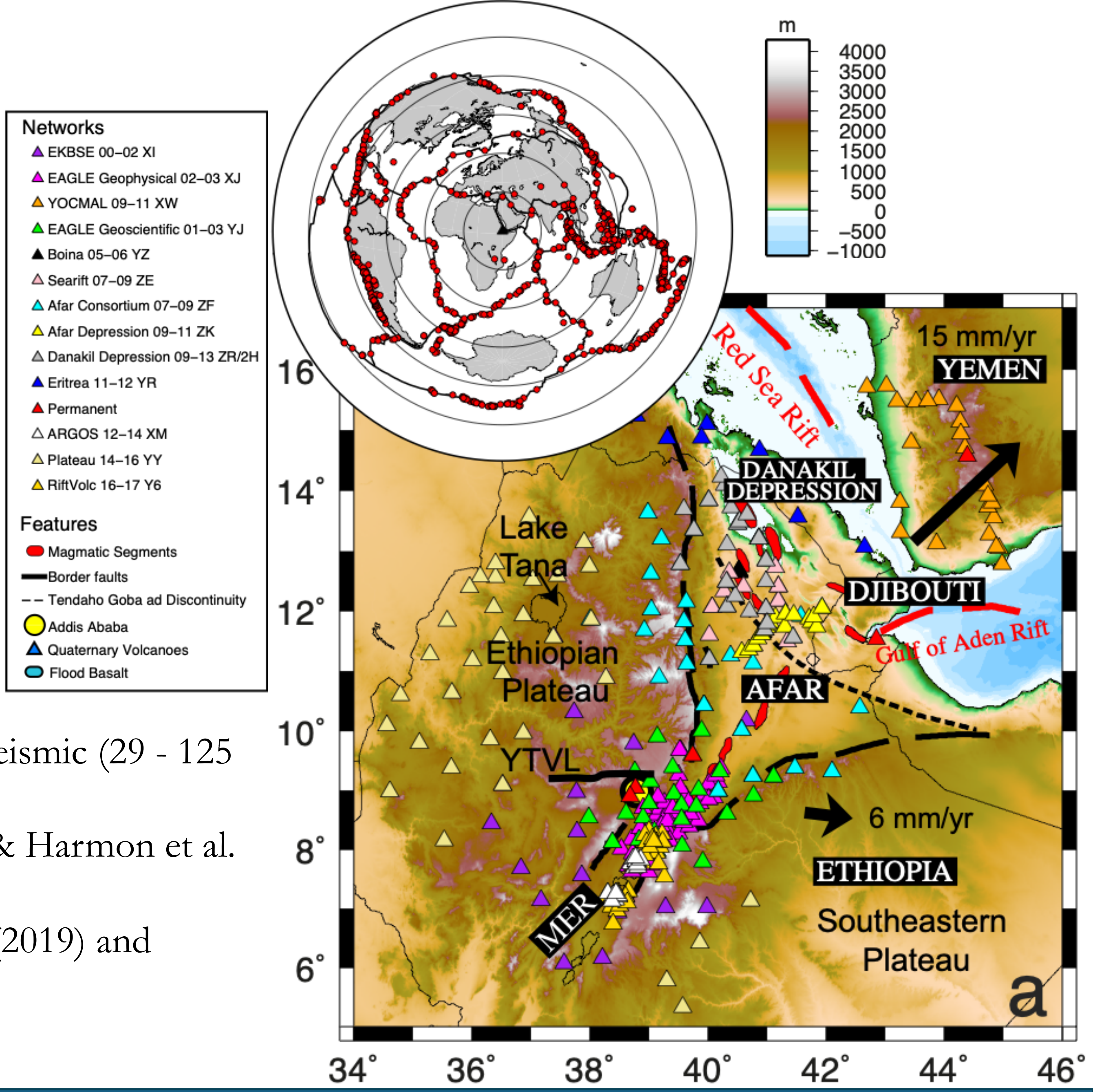
- 6716 cross correlations between station pairs
- Preprocessed using Harmon et al. 2007 and Bensen et al. 2007
- Periods from 8 – 33s

Teleseisms

- 1053 Teleseismic events located
- Magnitude >5.5
- Preprocessed using Harmon et al. 2007 and Bensen et al. 2007
- Periods from 20 – 125 s

Joint inversion

- Combine ambient noise phase velocities (8 – 26 s) with teleseismic (29 - 125 s) to generate phase velocity maps.
- Linear least squares inversion using DISPER80 (Saito 1988 & Harmon et al. 2008) to invert phase velocity maps for shear velocity.
- Input model based on average velocities of Chambers et al. (2019) and Gallacher et al. (2016) discretized at 5km intervals.
- Shear velocity produced from 10 – 210 km depth.



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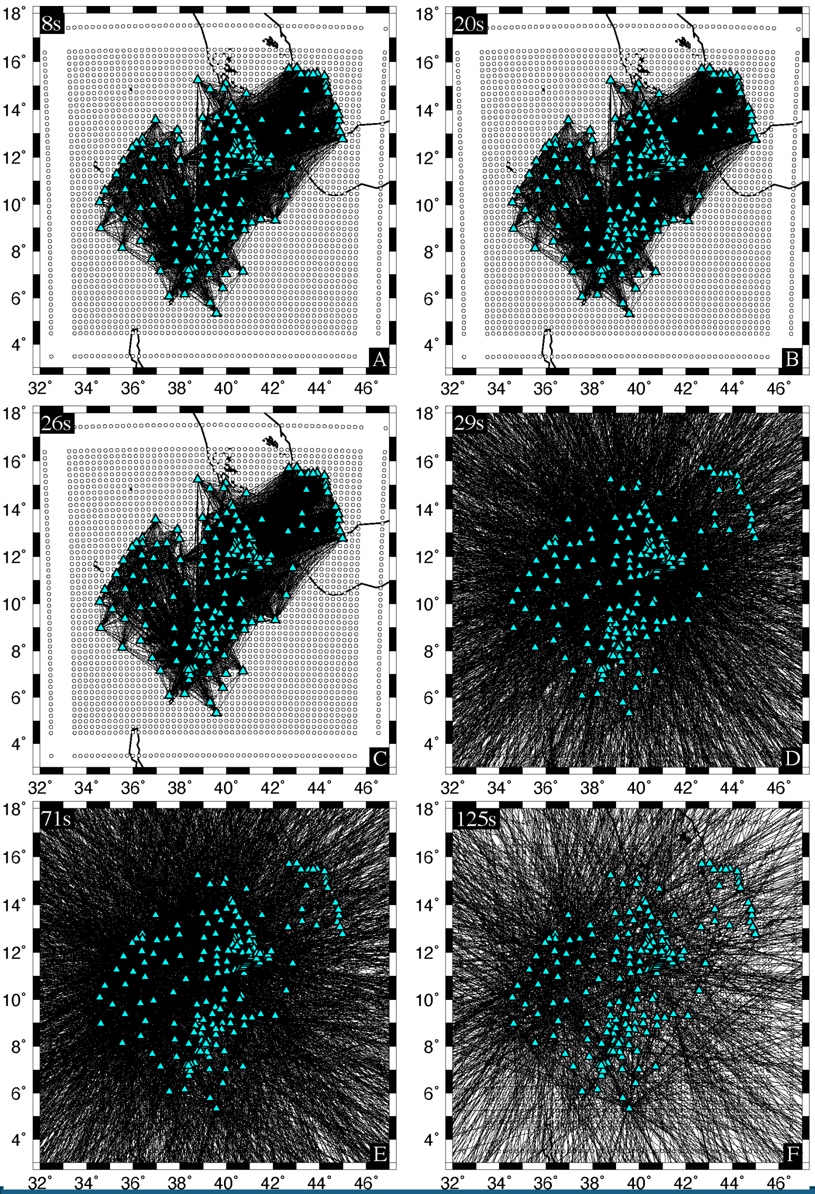
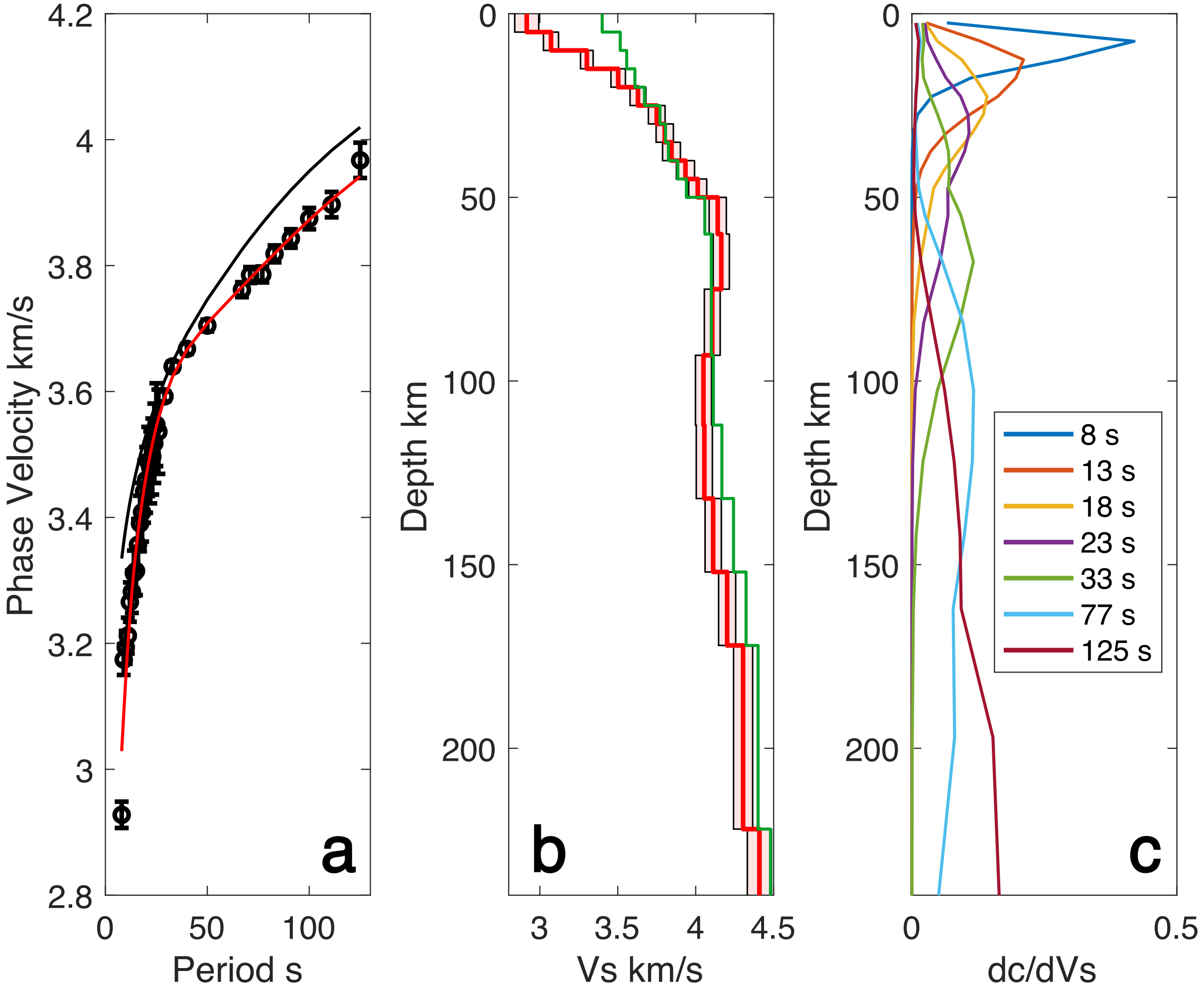
Data & Methods



Ray paths show we have good coverage for all periods. Ray paths for 8, 20 and 26s for ambient noise (a – c) and 29, 71 and 125s for teleseisms (d – f). Nodal grid at 0.25 ° spacing. Blue triangles indicate stations.



(a) Average 1-D phase velocity with 3σ error bars (circles), starting model (black line) and best fit shear velocity model dispersion overlain (red line). (b) Best fit shear velocity model for the study area (red line) and formal 2σ error bounds (thin black lines and shaded area). Green line is initial starting model using the average shear velocity from Chambers et al., (2019) and Gallacher et al., (2016). (c) Sensitivity kernels for Rayleigh waves at selected periods.

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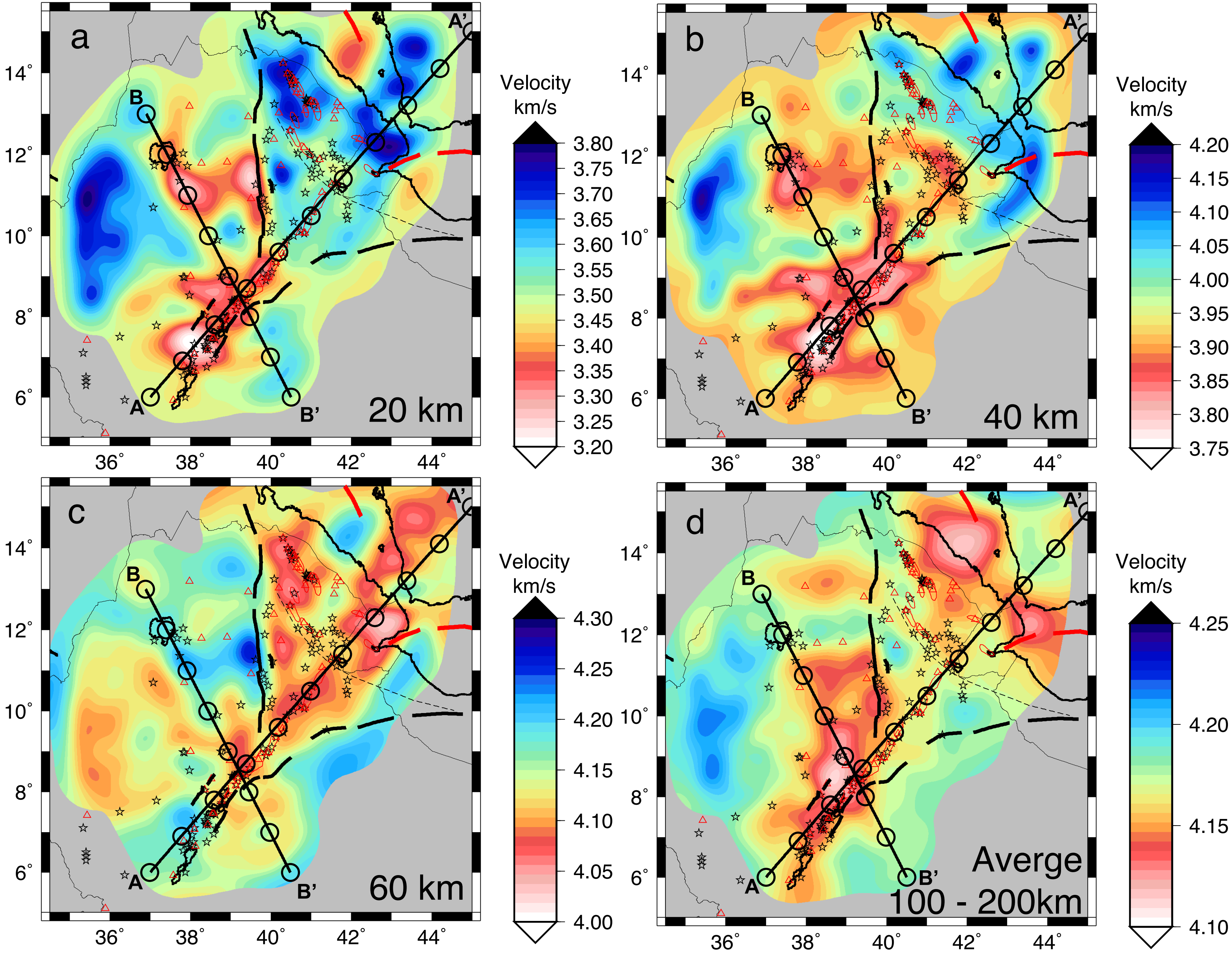
Shear velocities

<u>Lithospheric depths (10 – 80 km)</u>

- Large lateral variations in velocity.
- Slowest velocities beneath the Main Ethiopian Rift.
- Further slow velocities beneath eastern Ethiopian Plateau (southeast of Lake Tana and east beneath border faults).
- Afar and western Ethiopian Plateau some of fastest velocities.



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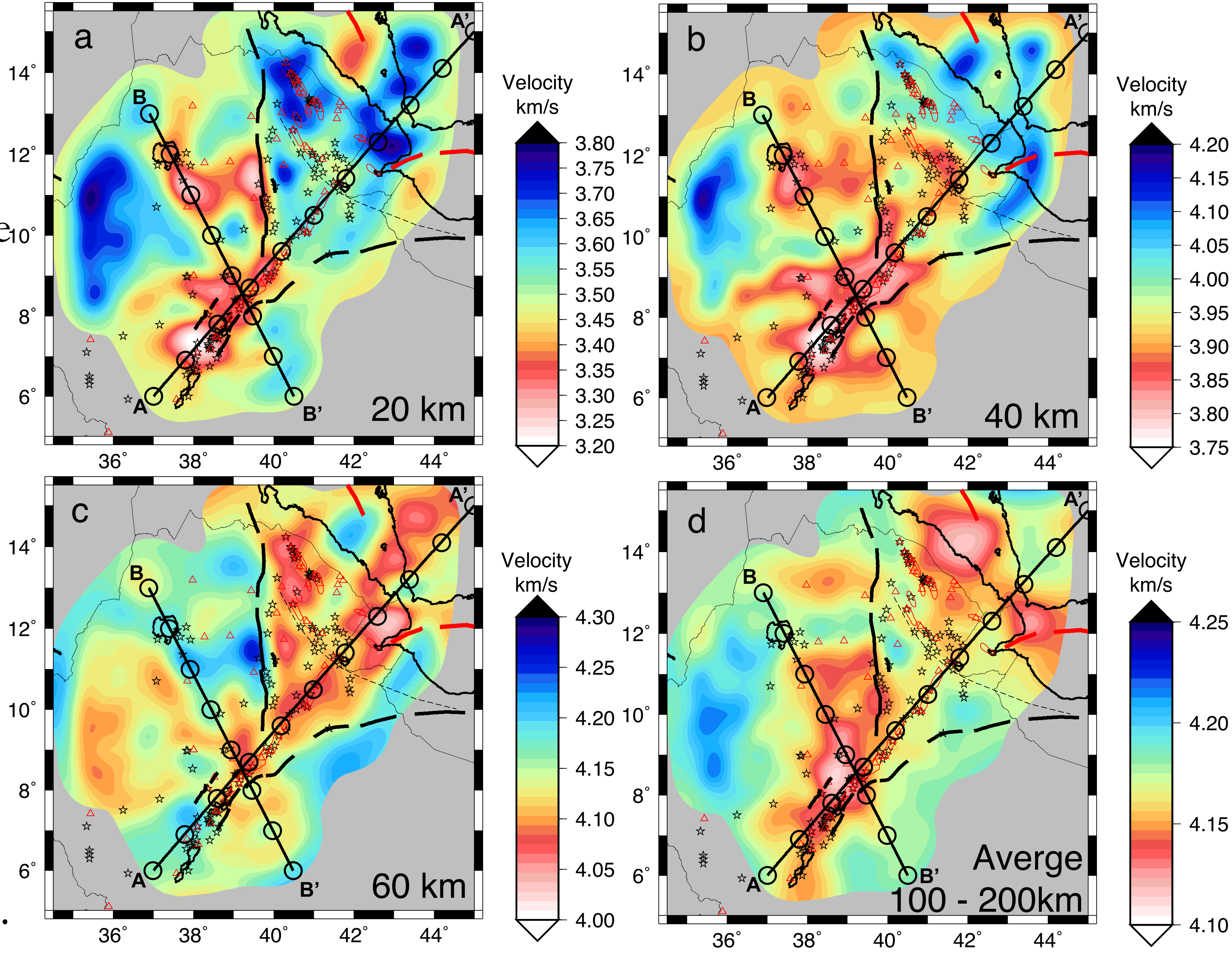
Shear velocities

Asthenospheric depths (>80 km)

- Slowest anomalies are within the MER and in surrounding plateau.
- Largest slow velocity anomaly offset from central rift axis.
- Multiple segmented slow velocity regions (<4.15 km/s).

Broad Observations

- Slowest anomalies in crust are offset from the asthenosphere.
- In Afar slow velocities beneath magmatic segments correlate to slow velocities in asthenosphere.



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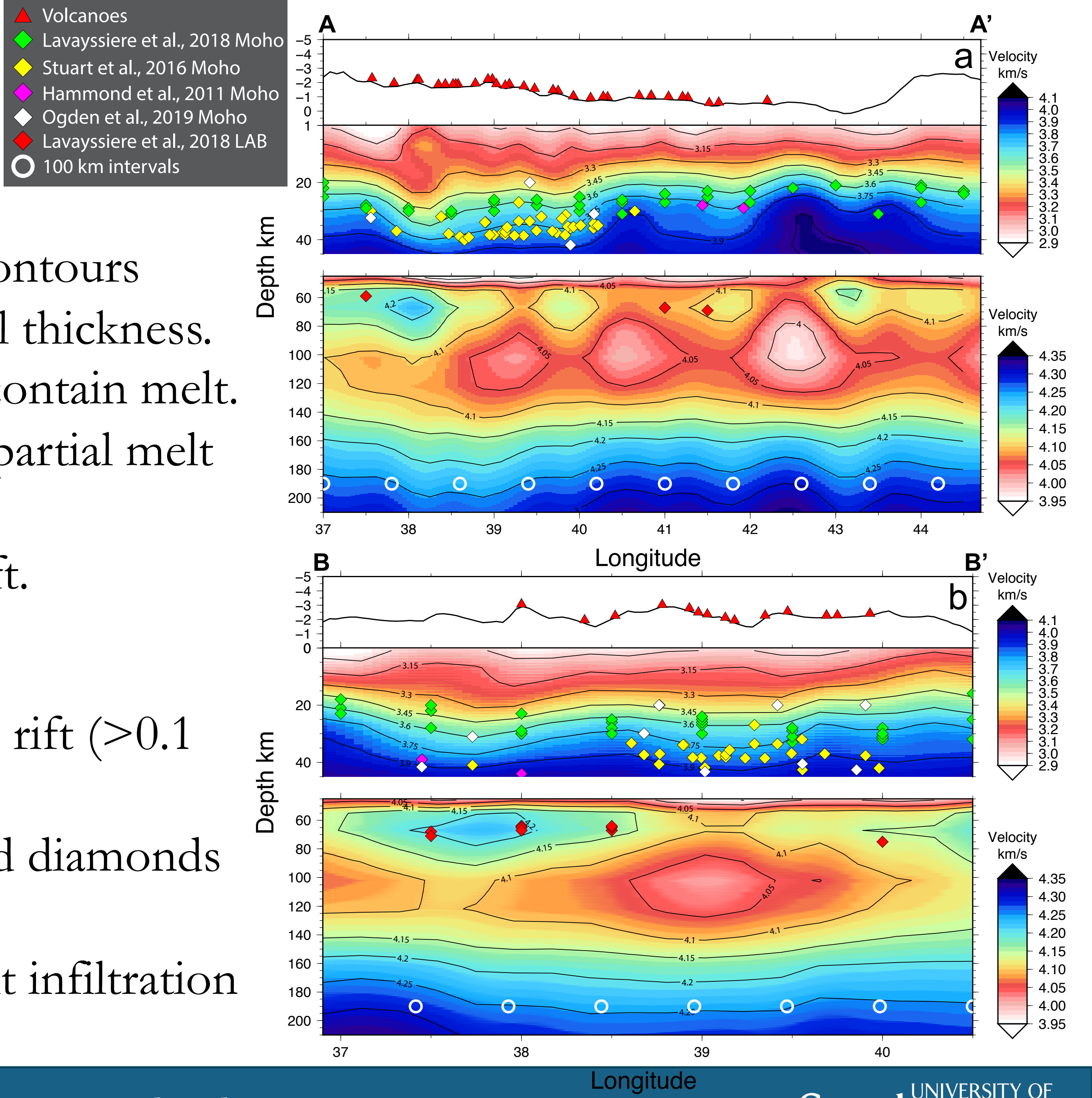
Interpretation

Crustal Depths (10 – ~40 km)

- In general the 3.60 and 3.75 km/s velocity contours match well to previous estimations of crustal thickness.
- The Main Ethiopian Rift is slow enough to contain melt.
- The eastern Ethiopian Plateau also requires partial melt to explain slow velocities.
  → Ongoing magmatic emplacement off rift.

Lithosphere-Asthenosphere-Boundary

- Fast lid from 60 – 80 km depth observed off rift (>0.1 km/s faster thank surroundings).
- Matches well to S-to-P receiver functions (red diamonds Lavayssière et al. 2019).
- Obscured beneath the rift, interpreted as melt infiltration into the lithosphere of the rift.



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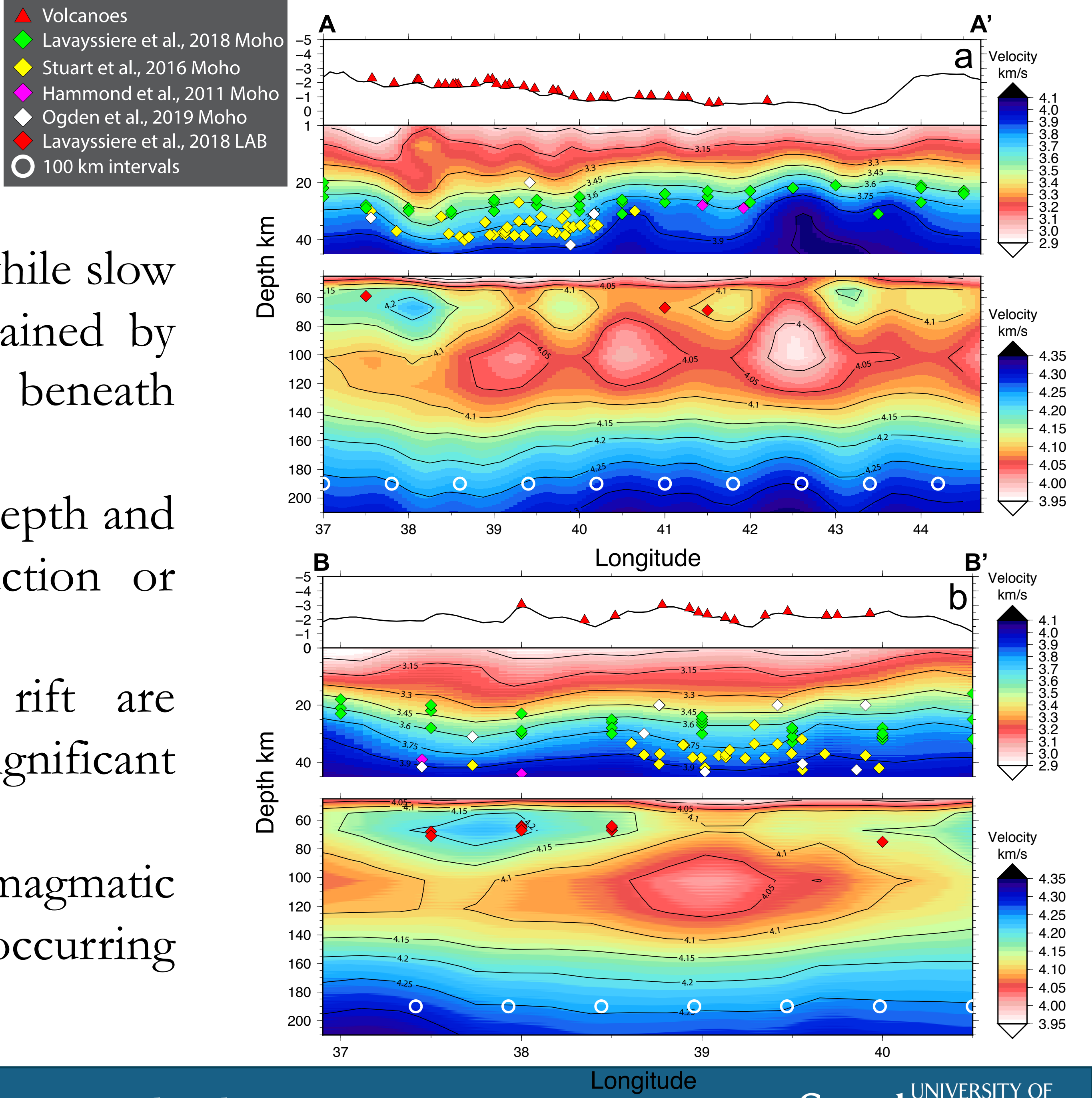

<u>Asthenospheric Depths</u>

- Velocities beneath the Ethiopian Plateau while slow compared to global average can be explained by elevated mantle temperatures while those beneath the rift cannot.
- Disconnect between slowest velocities at depth and in crust suggest ephemeral melt production or lateral melt migration during ascent.
- Segmented slow velocities along the rift are beneath areas that haven't undergone significant crustal thickening.

  → Melt supply starts early during magmatic rifting with majority of plate thinning occurring later during the rifting process.

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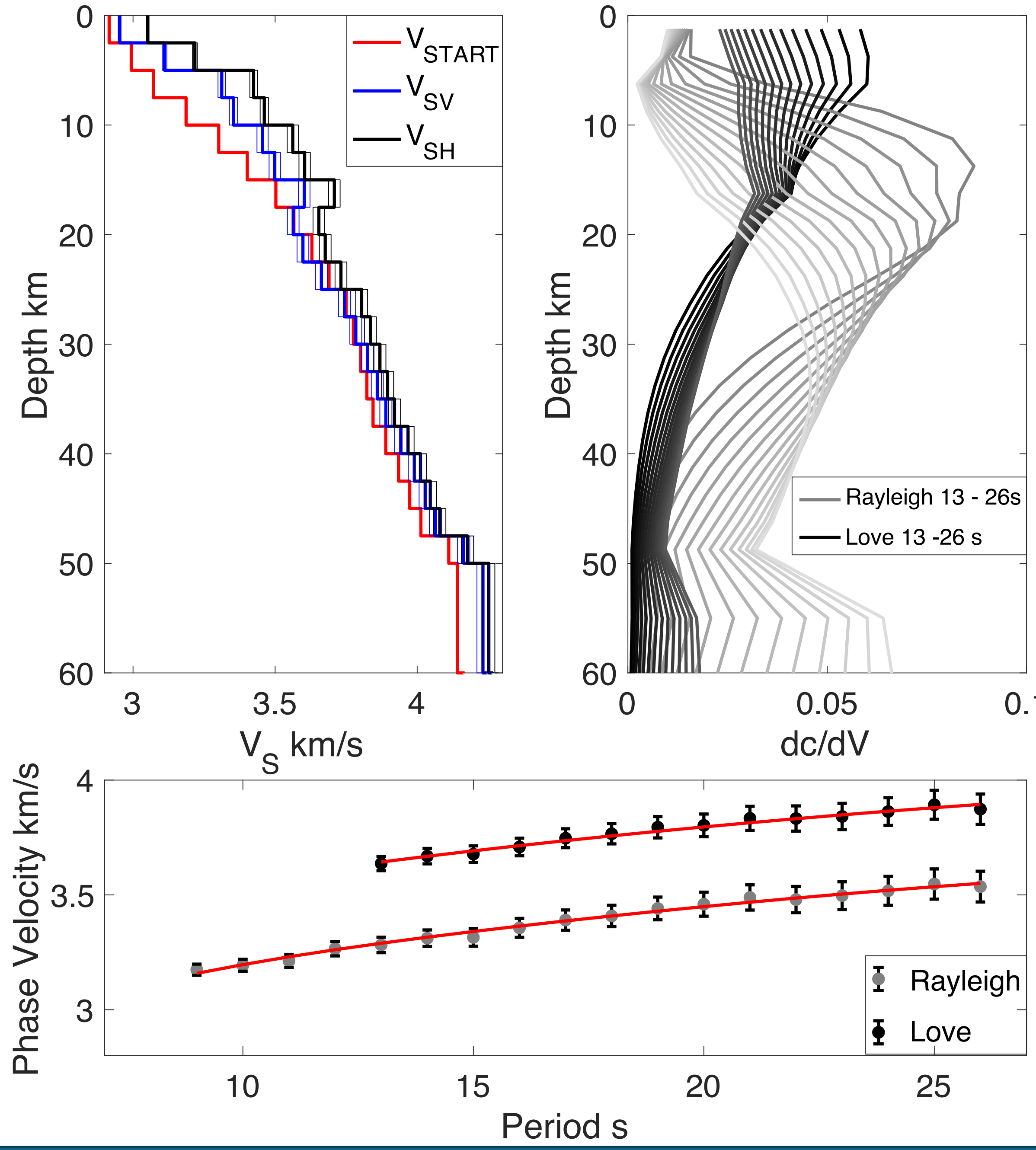
Radial Anisotropy

- Slow velocities (slow enough to contain melt) at crustal depths beneath the Ethiopian Plateau are off rift.
- We investigate further to determine the cause of the slow velocity whether melt, or anisotropy or a combination of the two.
- Calculated Radial Anisotropy by comparing Love and Rayleigh wave components of the ambient noise cross correlations.
- Input model is best fit model for the joint inversion, interpolated to 2.5 km from 5 km intervals.
- Anisotropy significant from 5-30 km depth



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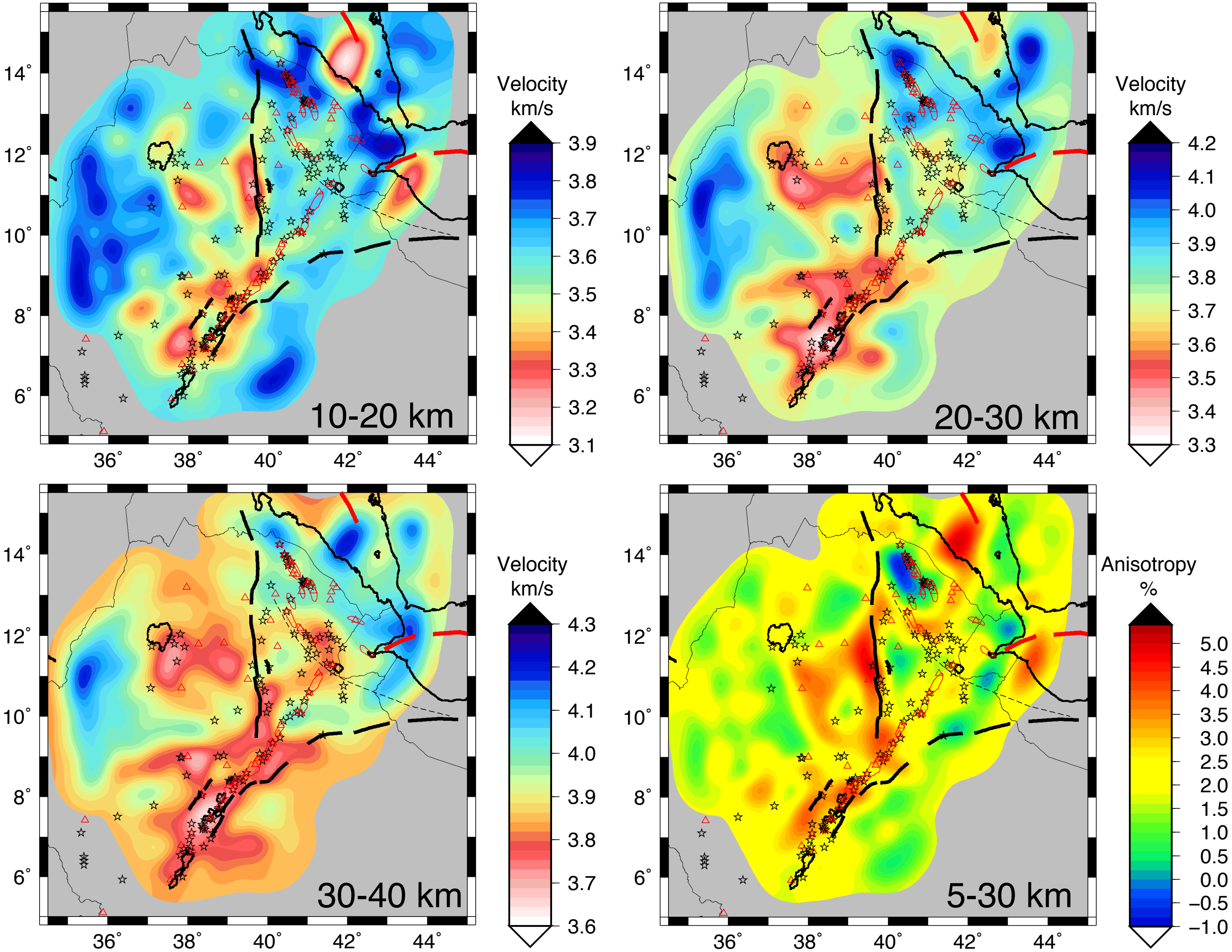
Radial Anisotropy



- Radial anisotropy is predominantly horizontally aligned.
- Strongest positive anisotropy ($V_{SH}>V_{SV}$) is beneath areas of slowest vertically polarized shear velocity.
  → Alignment of horizontal sills.
- Negative anisotropy ($V_{SH}<V_{SV}$) is beneath areas of recent eruptions such as Erta Ale and southwest of the Dabbahu-Manda Hararo dykes 2005-2008.
  → Vertical ascent of melt for eruptions.

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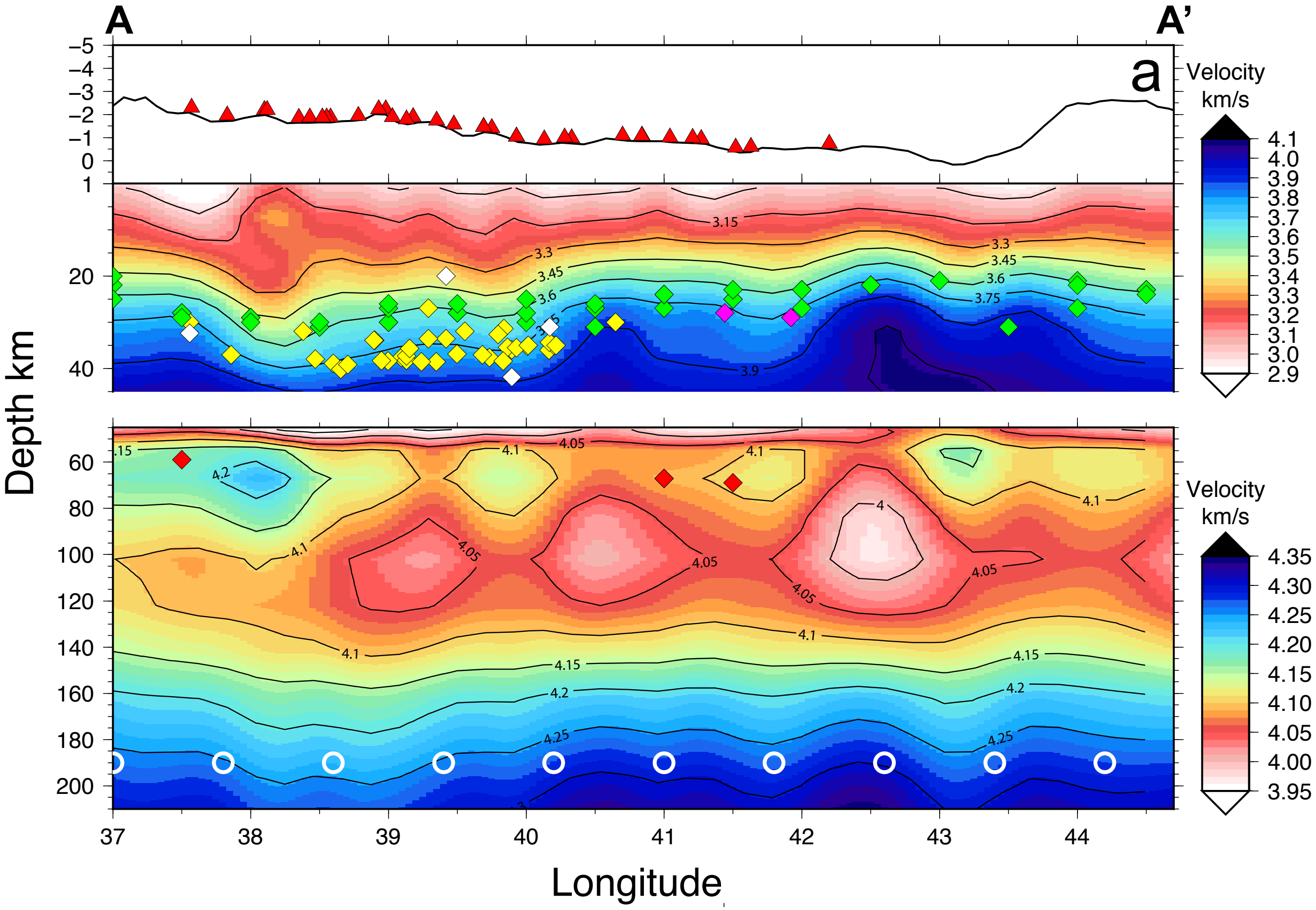
Conclusions

- Slow velocities are segmented in the asthenosphere, occurring beneath lithosphere that has not undergone significant thinning.
- A fast lid is visible at Lithosphere-Asthenosphere-Boundary depths which is obscured within the rift, potentially by melt.
- The Ethiopian Plateau has ongoing off axis melt emplacement.
- Vertical anisotropy present beneath areas of recent volcanism including Erta Ale and the Dabbahu dyking event suggesting aligned melts in the form of dykes.
- Strong horizontal anisotropy beneath the Main Ethiopian Rift and off-axis beneath the Ethiopian Plateau indicative of horizontally aligned melt sills.
- Further work into the azimuthal anisotropy is needed to determine if melt is flowing from the Main Ethiopian Rift to off rift areas of the Ethiopian Plateau.



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Presentation based on:

- Chambers et al. (2019) Geochemistry Geophysics Geosystems
- Joint inversion: Chambers et al. (submitting to Journal of Geophysical Research in coming weeks)
- Radial anisotropy: Chambers et al. (in prep)

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