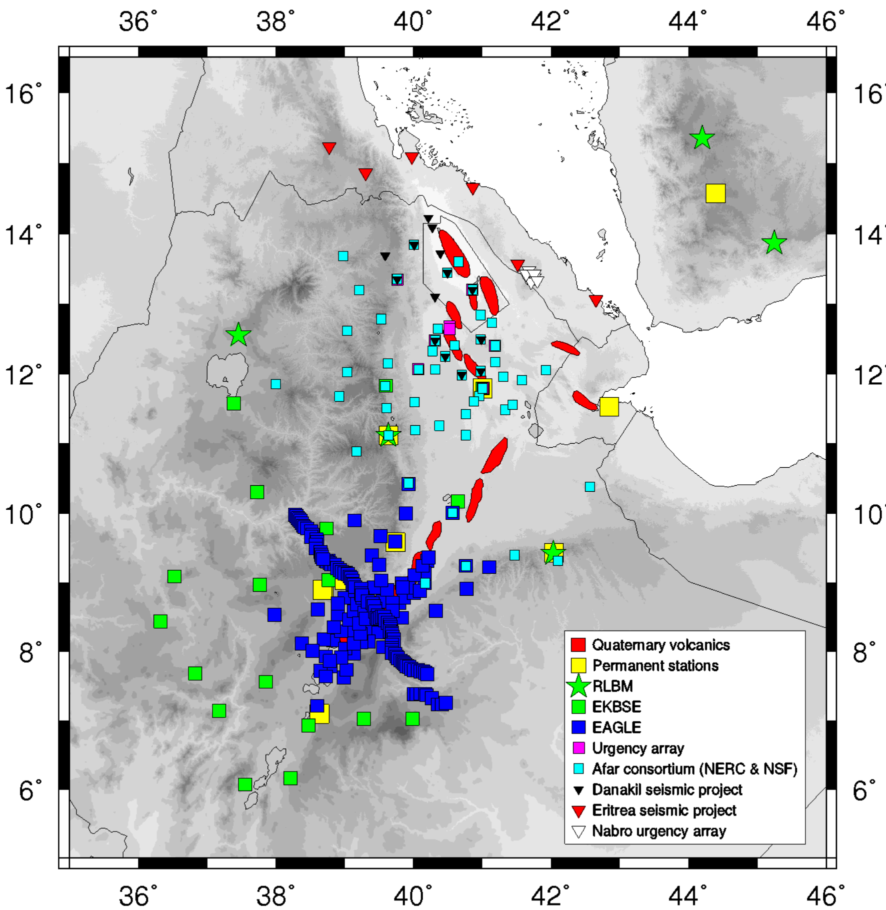
Seismically Imaging the upper mantle beneath the northern East-Africa rift system

Imperial College London	–	James Hammond
University of Bristol	–	Mike Kendall, Ian Bastow, James Wookey, Anna Stork, Dave Thompson
University of Leeds	–	Graham Stuart
National Oceanography Centre, Southampton	–	Catherine Rychert, Derek Keir
University of Rochester	–	Cindy Ebinger, Manahloh Belachew
ICTP, Trieste	–	Mariangela Guidarelli
Addis Ababa University	–	Atalay Ayele, Manahloh Belachew

Seismic Data

Afar Rift Consortium



8 Permanent stations (IRIS, AAU, GEOFON,EIT)

RLBM – 5 stations (1999-2002)

EKBSE – 38 Stations (2000 – 2002)

EAGLE – 86 stations (2001 – 2003)

Urgency Array – 9 stations (2005-2007)

Afar Consortium (US) – 14 stations (2007-2009)

Afar Consortium (UK) – 26 stations (2007 – Present)

Eritrea arrays – 14 stations (2011 – Present)

Seismic Techniques

Pn Tomography

P & S-wave Receiver Functions

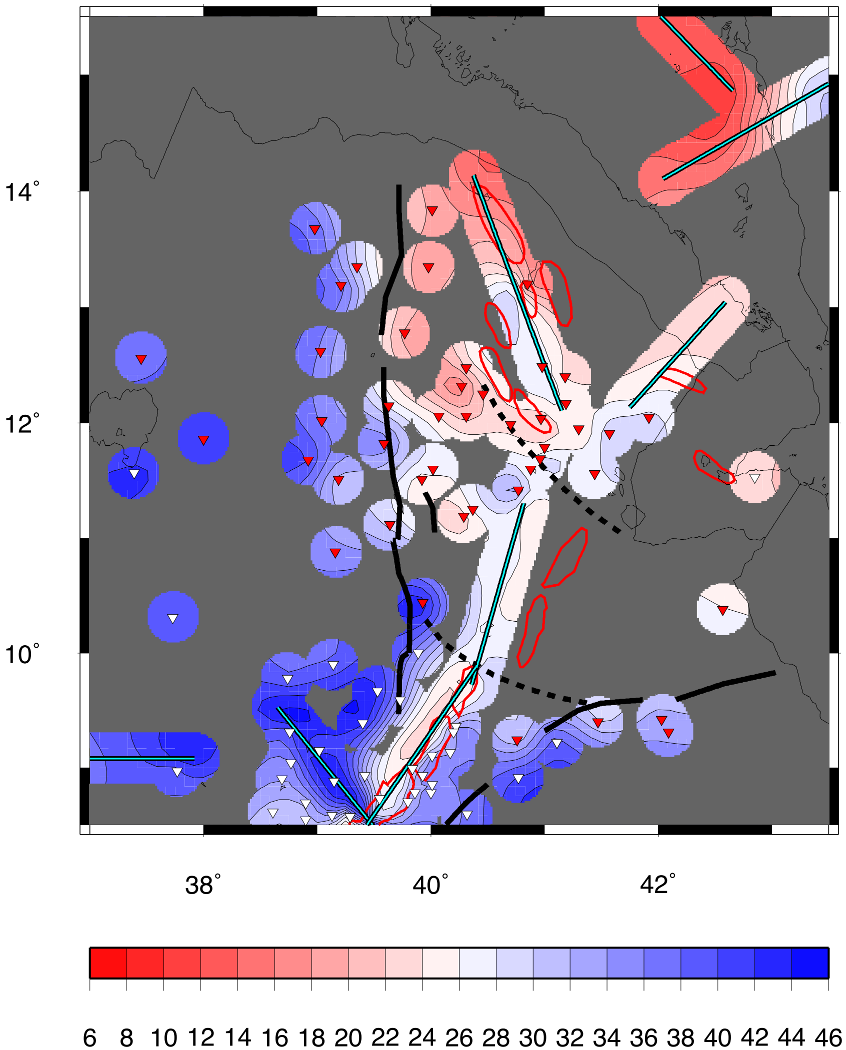
P- & S-wave Relative travel-time tomography

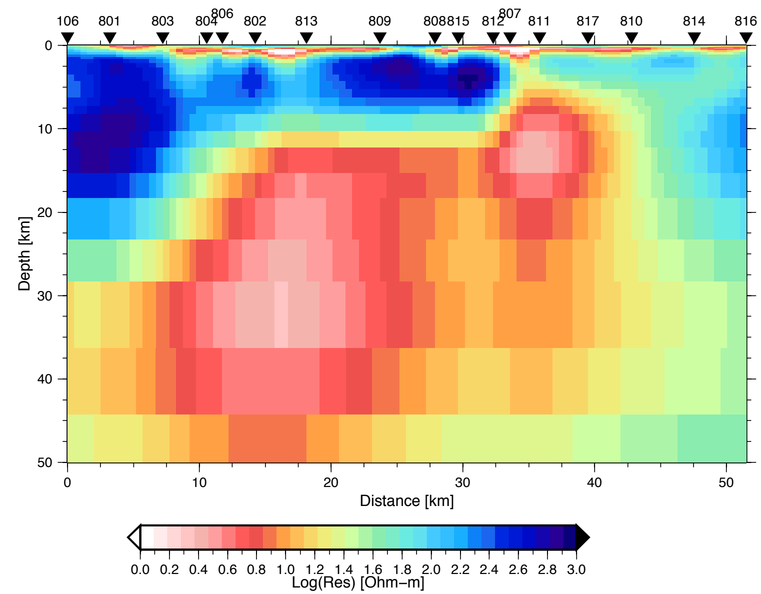
Mantle Seismic anisotropy

University of BRISTOL

Imperial College London

0-40km (crust)



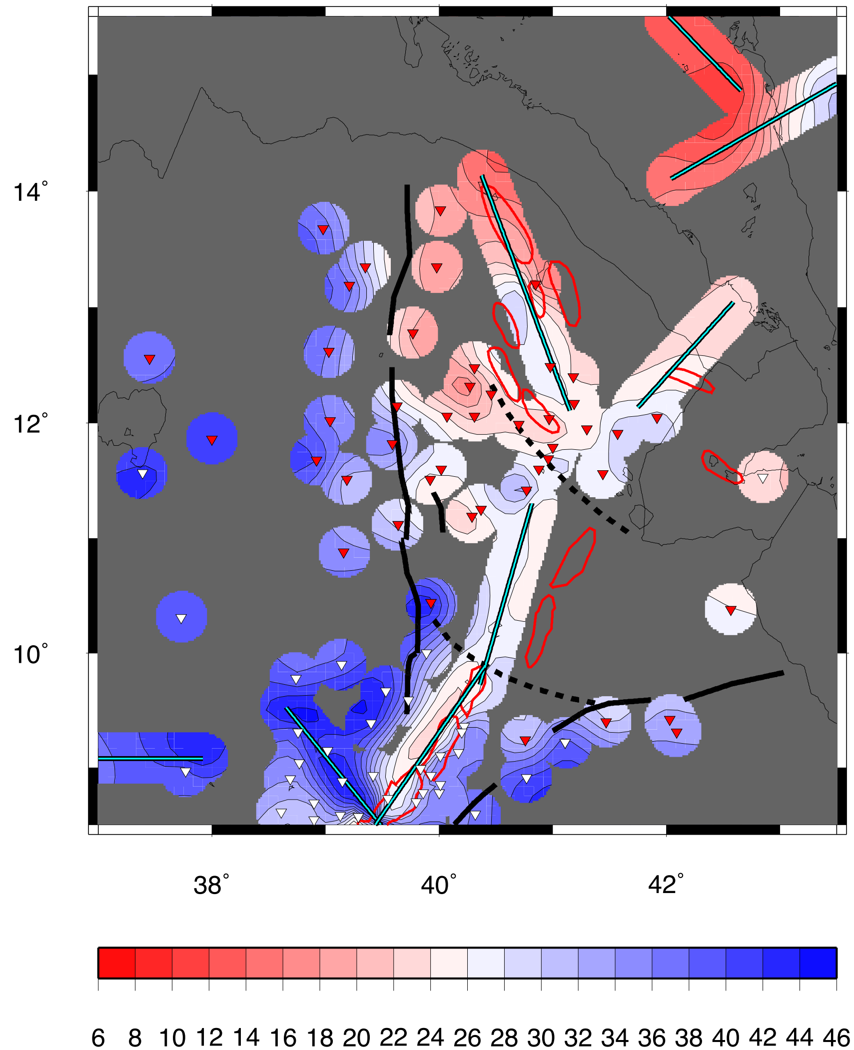


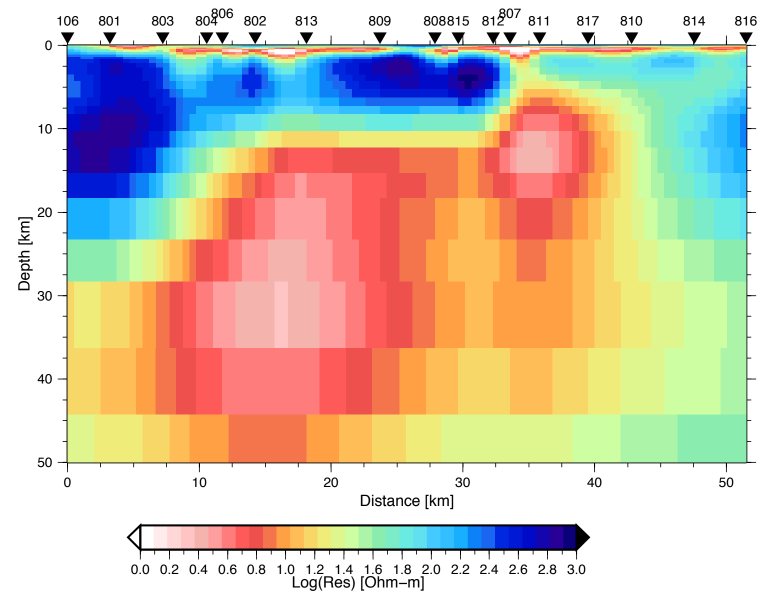
Courtesy of N. Johnson, K. Whaler

- Lots of melt in the crust and uppermost mantle
- How does it get there?

Hammond et al., 2011

0-40km (crust)





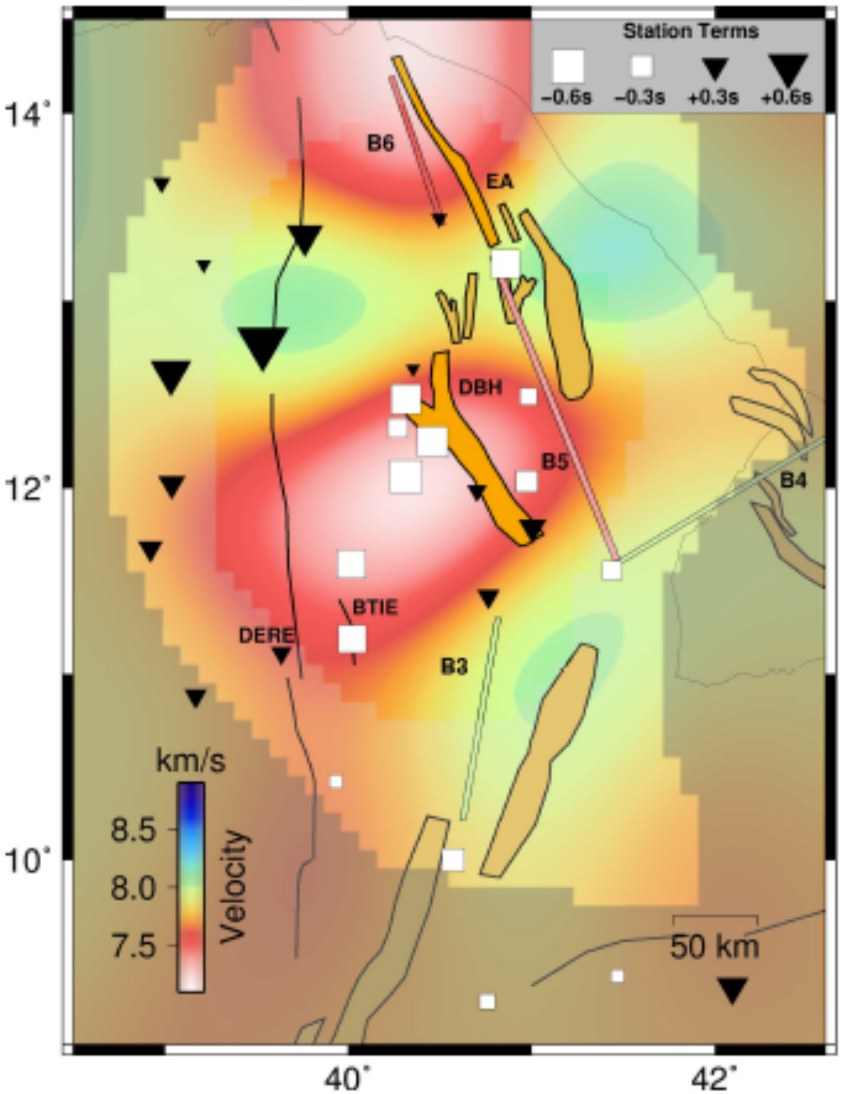
Courtesy of N. Johnson, K. Whaler

- Lots of melt in the crust and uppermost mantle
- How does it get there?
- Where is the Afar plume?

Hammond et al., 2011

20-50km (uppermost mantle)

Afar Rift Consortium



- Pn tomography (Stork et al., submitted)
- Sensitive to P-wave velocities in the uppermost mantle.
- Refracted waves below the Moho or turning waves in the uppermost mantle

- Two isolated low velocity zones (>7.2km/s) beneath Dabbahu-Manda Harraro and Erte'Ale segments.
- Marked asymmetry beneath DMH.
- Suggests considerable amount of melt focused beneath localised segments.
- Similar to mid-ocean ridges

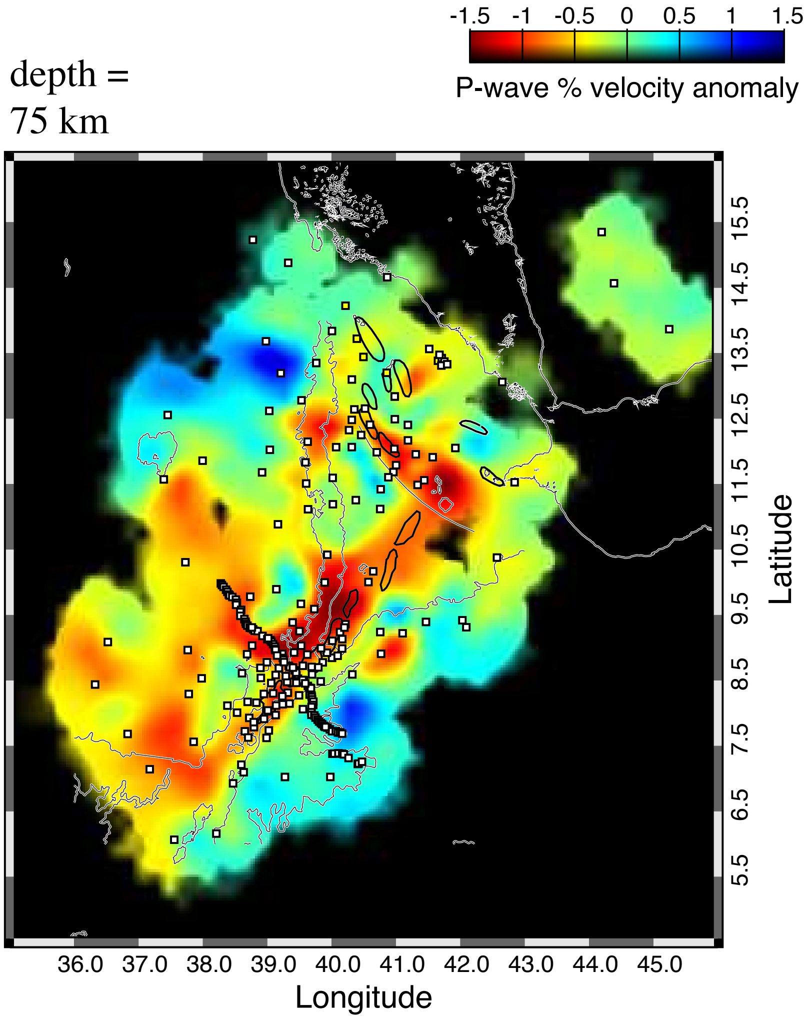
University of BRISTOL

Stork et al., submitted

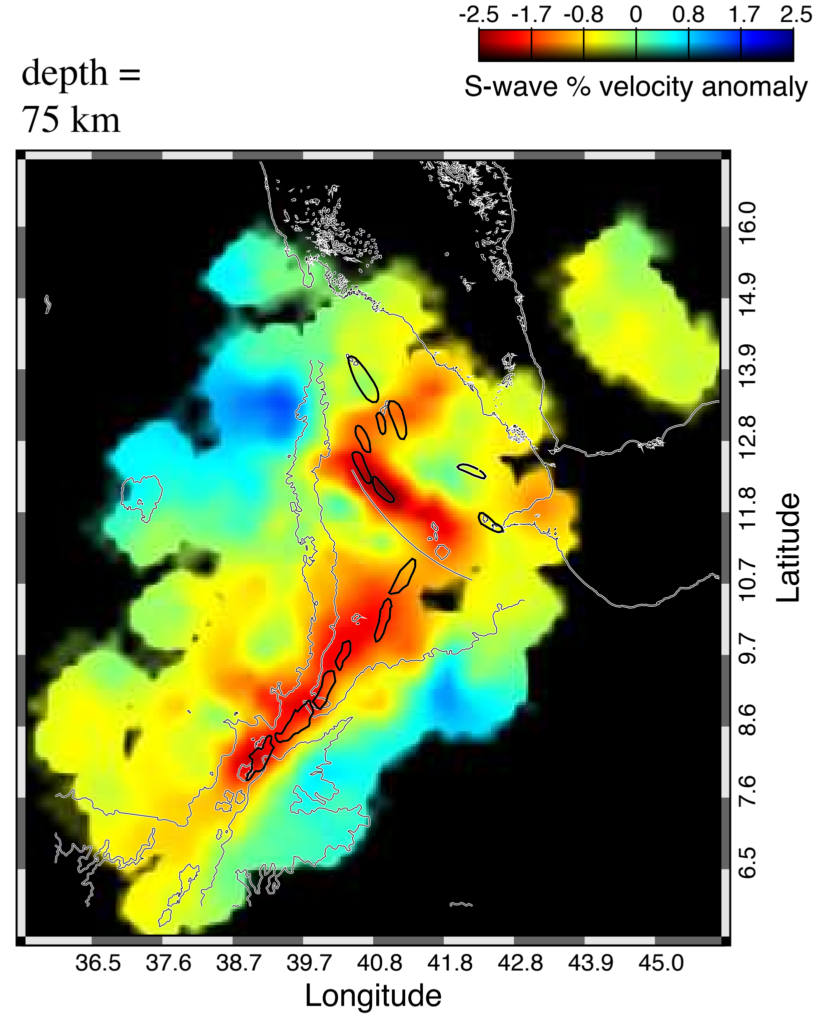
Imperial College London

50 – 150 km

Afar Rift Consortium



P-wave model – 10132 arrivals

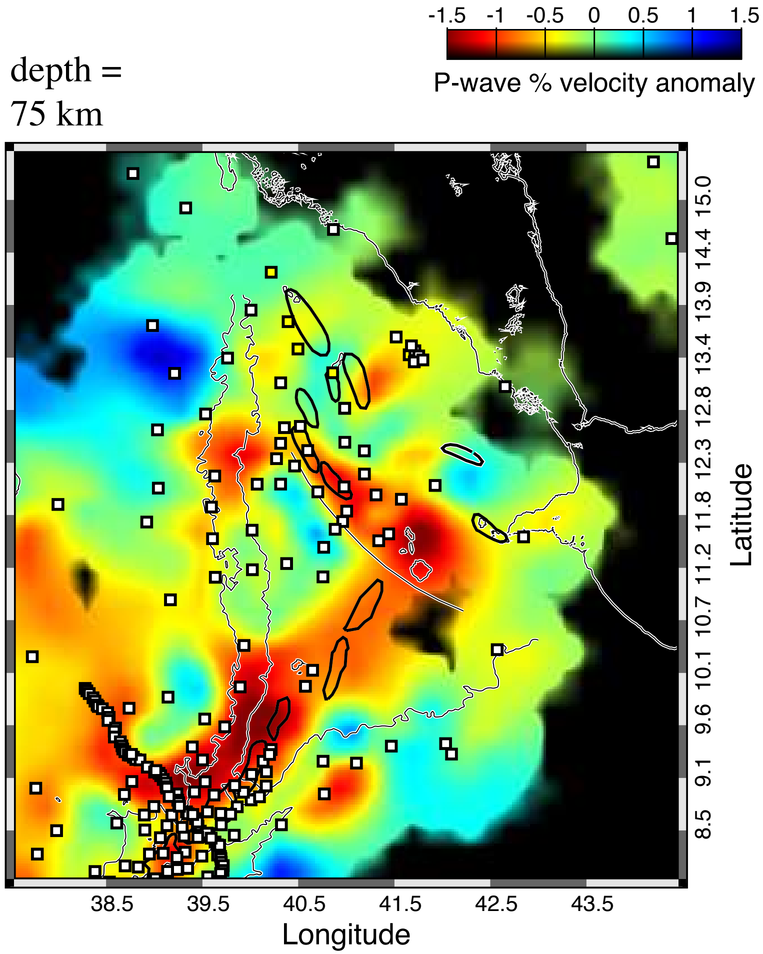


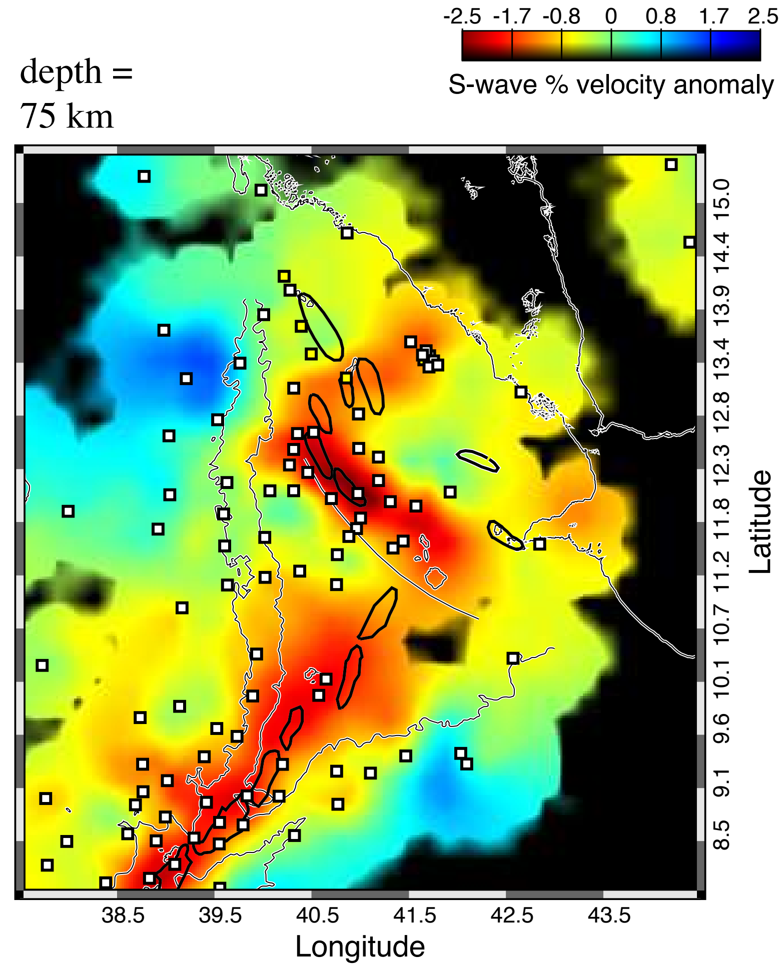
S-wave model – 10811 arrivals

University of BRISTOL

Imperial College London

50 – 150 km



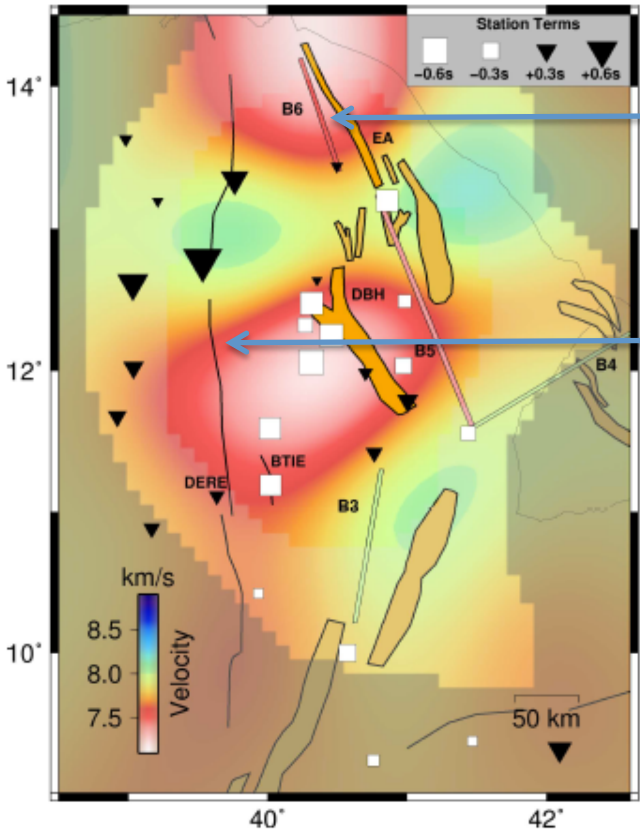


- Lowest velocities beneath MER and triple junction
- Faster velocities beneath Danakil depression
- Anomalies beneath western border faults and Nabro

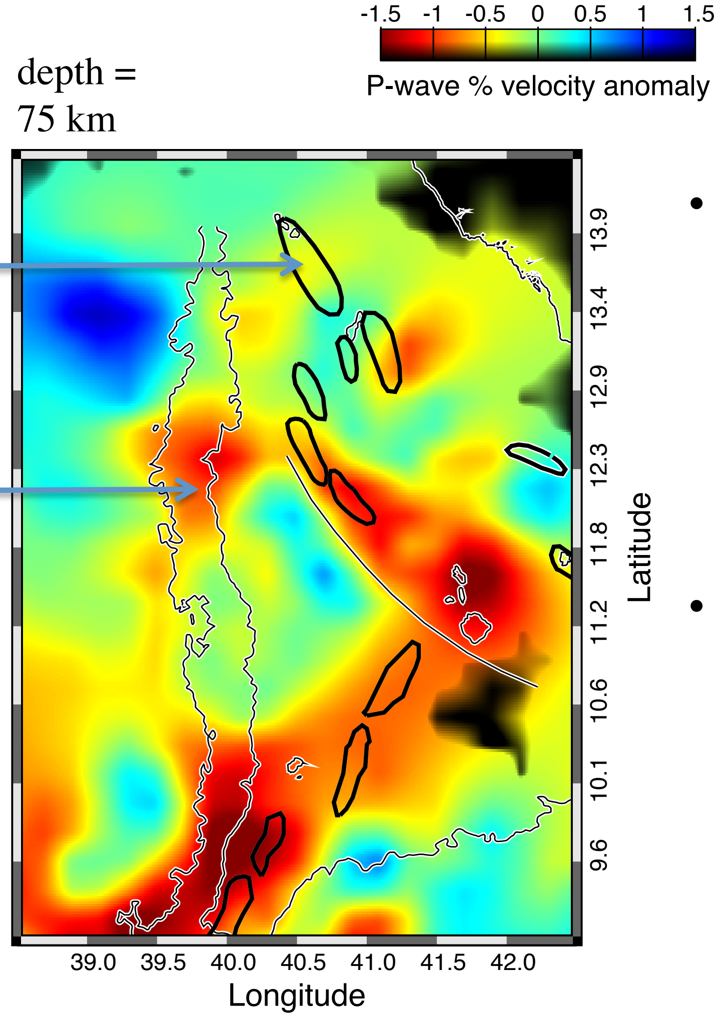
Afar Rift Consortium

Imperial College London

50-150km



Stork et al., submitted



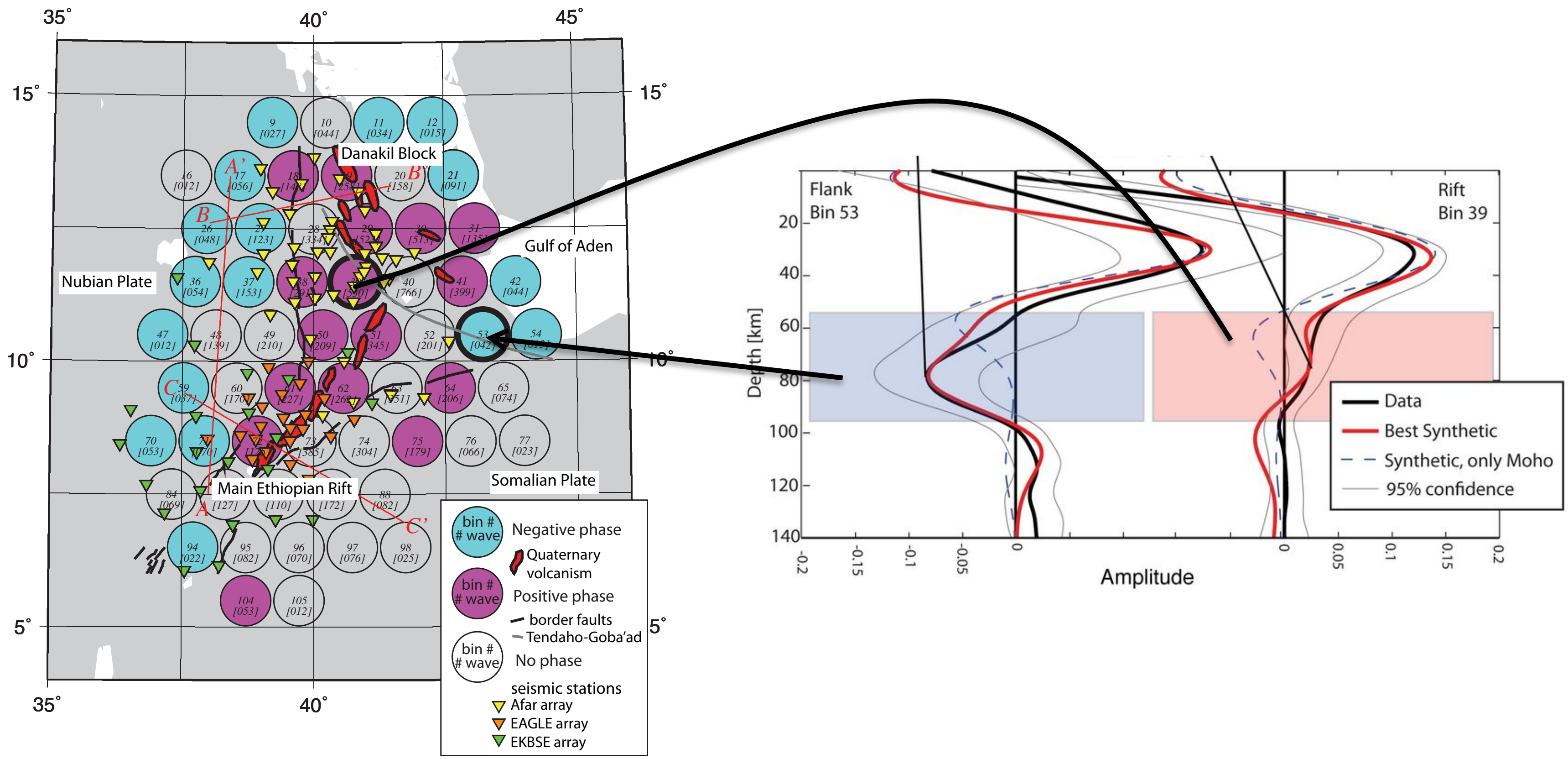
Hammond et al., in prep

- West of DMH travel-time and Pn tomograpy correlate
  - Melt from 75 km feeds DMH
- Beneath EA range, travel-time and Pn tomography anti-correlate
  - Melt shallower than 75km feeds EA.

Afar Rift Consortium

Imperial College London

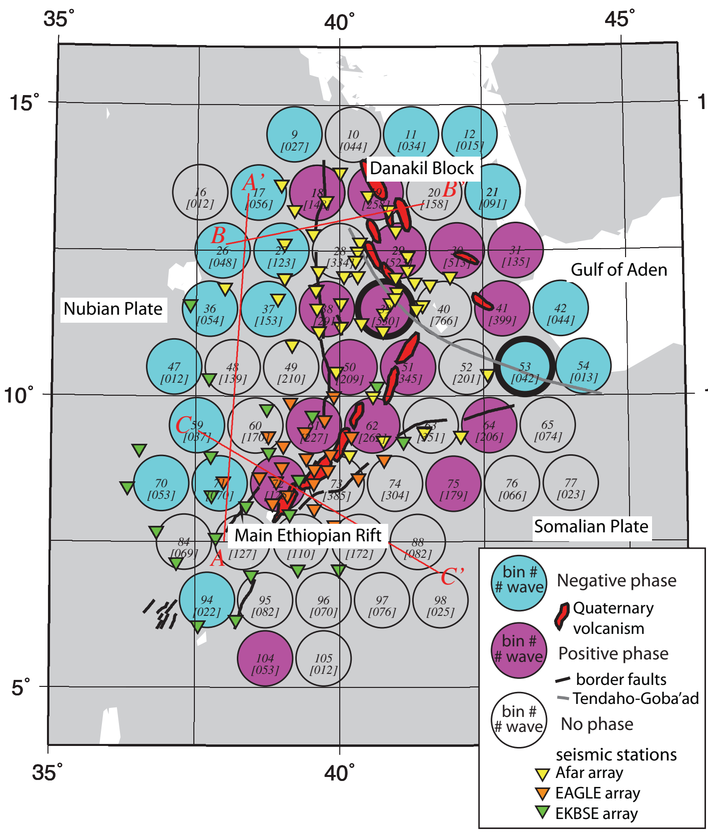
50-150km



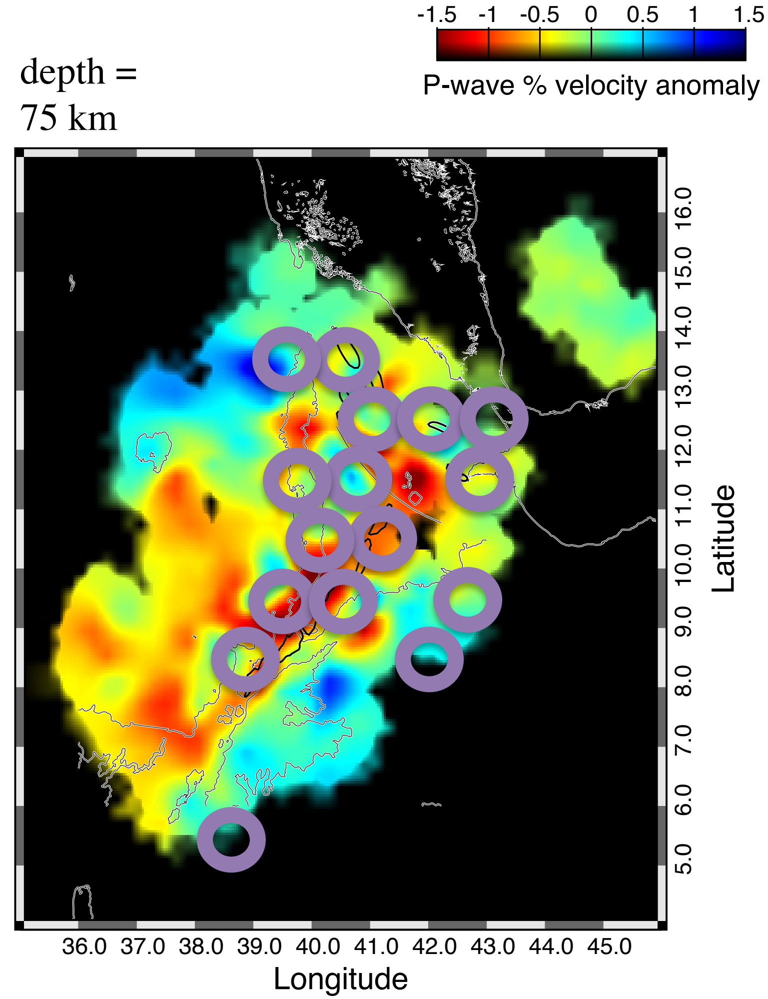
Rychert et al., submitted

- At ~75km S-wave receiver functions show a velocity decrease beneath the Plateau and a velocity increase beneath most of Afar (Rychert et al., submitted)
- Suggests decompression melting dominates the melting regime, with little need for a large thermal anomaly (Rychert et al., submitted)

50-150km



Rychert et al., submitted



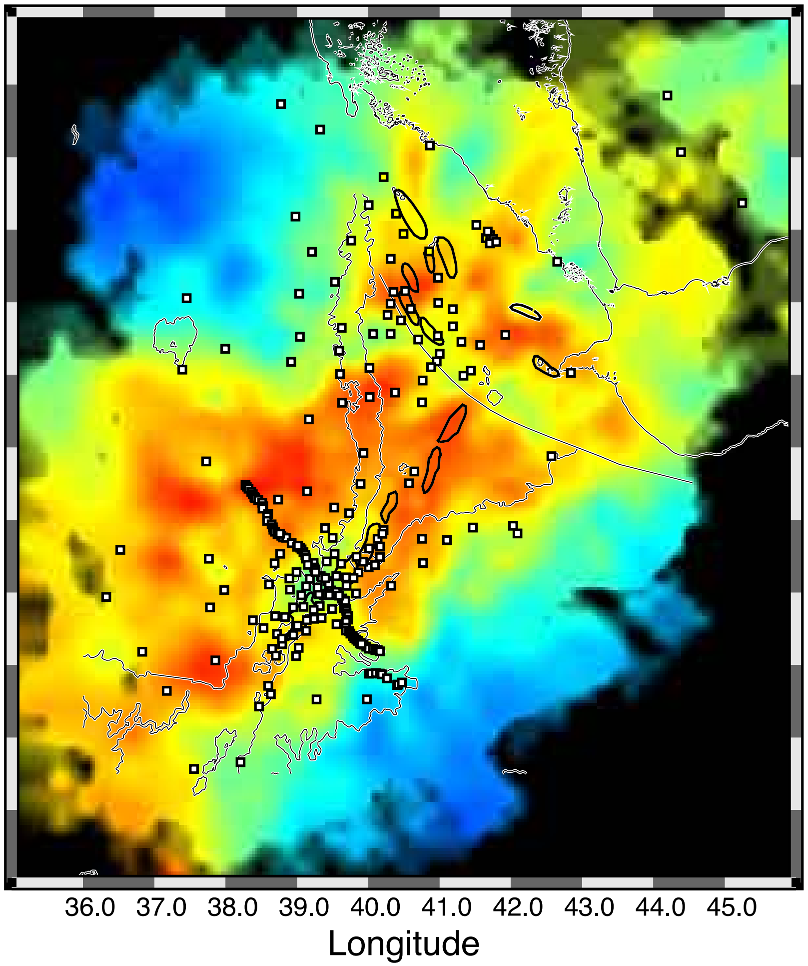
Hammond et al., in prep

- Correlates with faster velocity regions in travel-time tomography.
- Regions of lower velocity lack the velocity increase with depth; suggests very localised regions of upwelling in S. Afar.

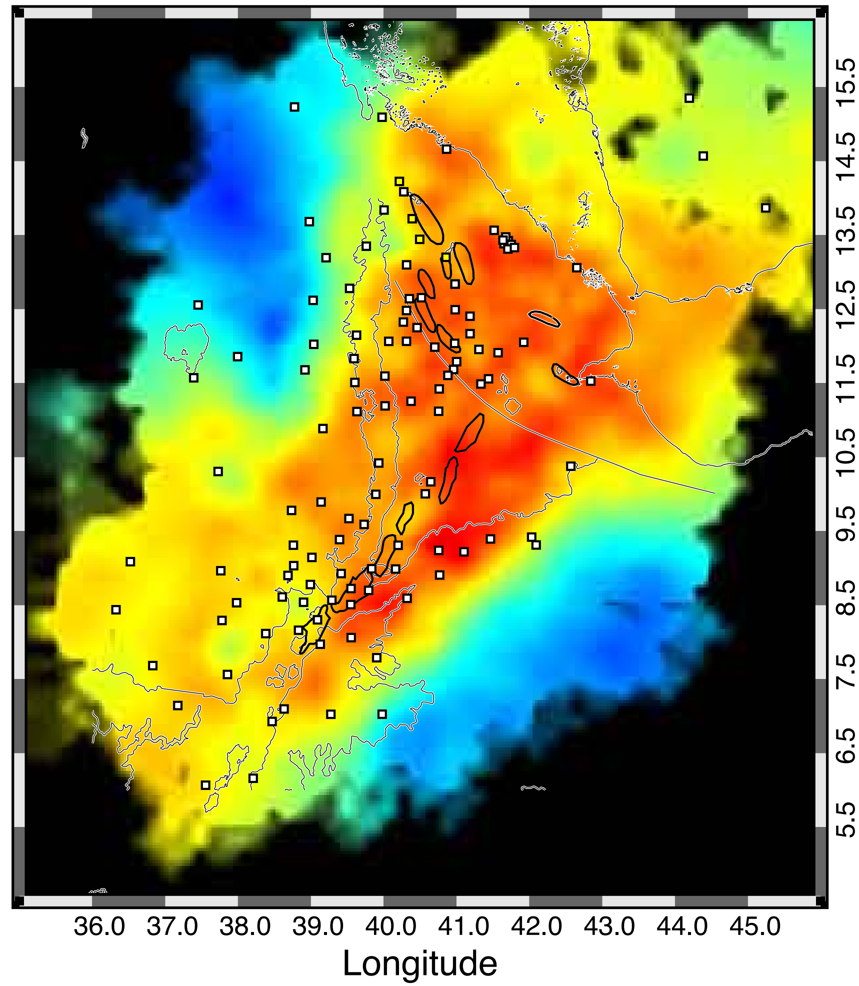
150-400km

Afar Rift Consortium

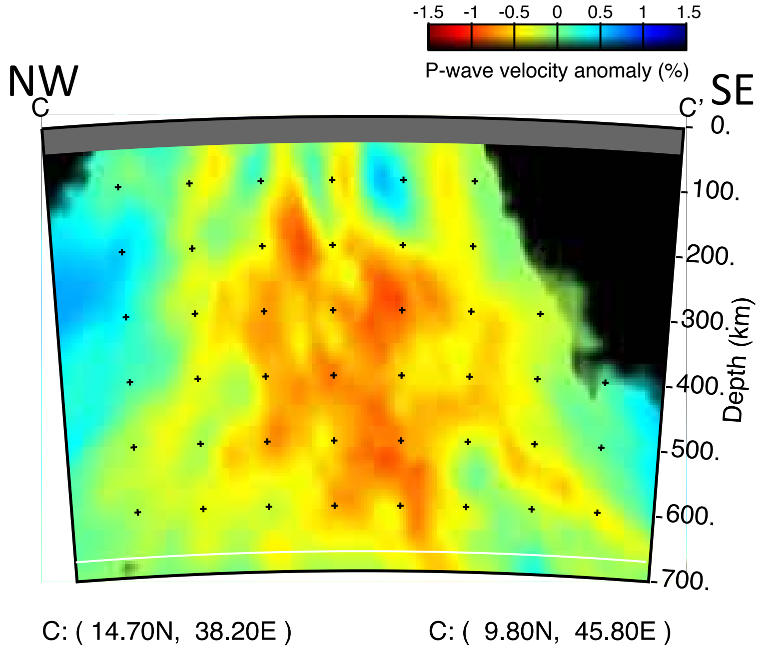
300 km

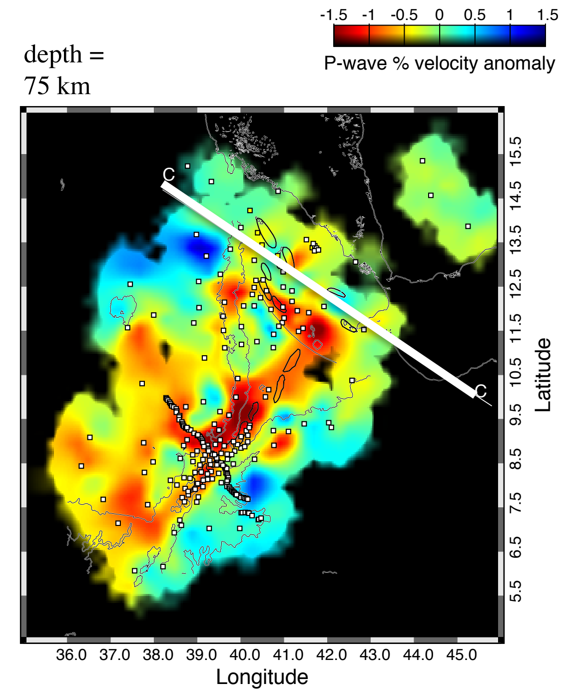


300 km

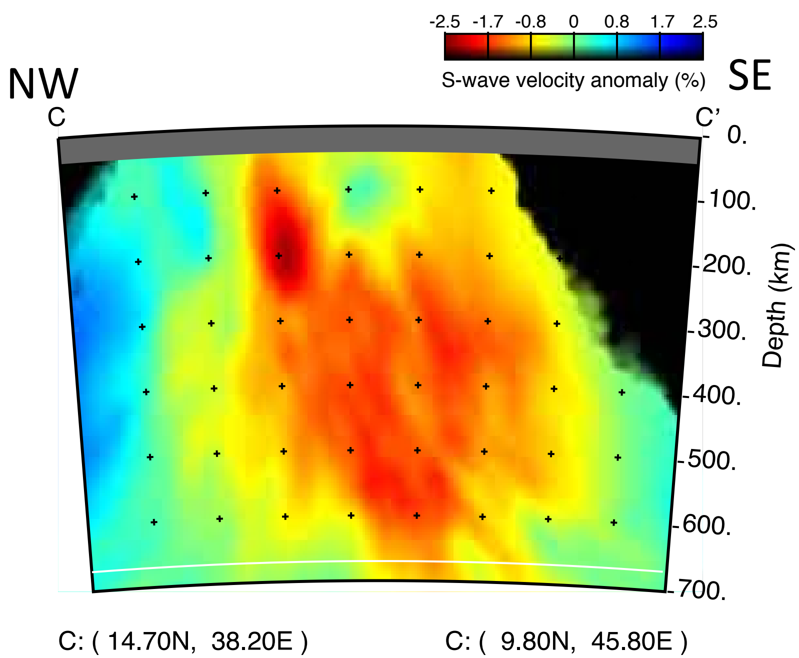


- Below 300km broad upwelling fills the upper mantle
- Extends to the top of the transition zone



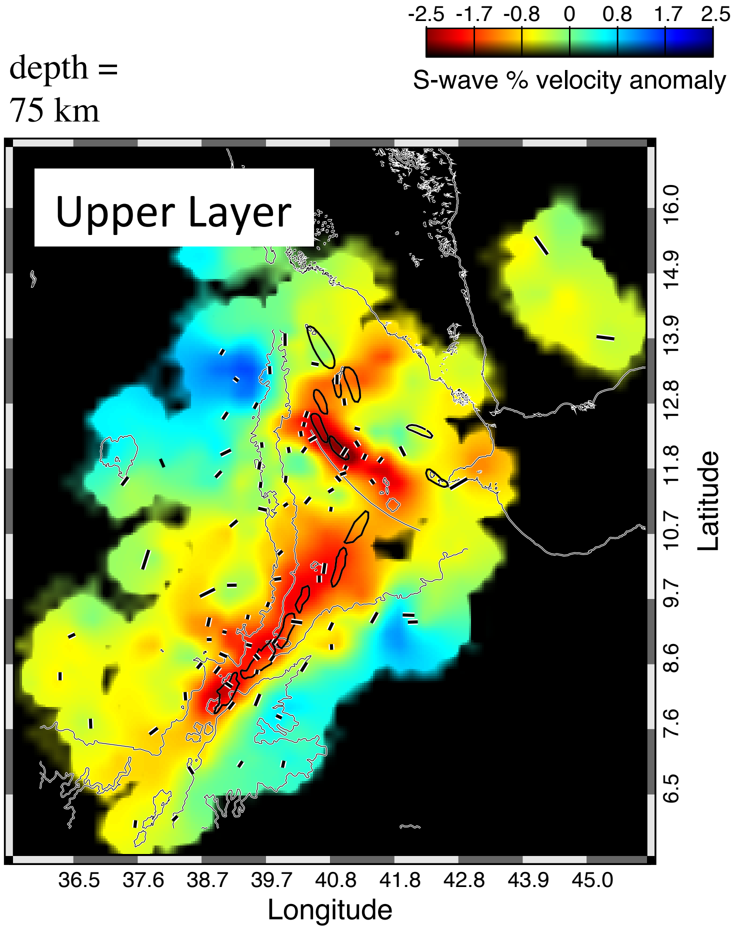


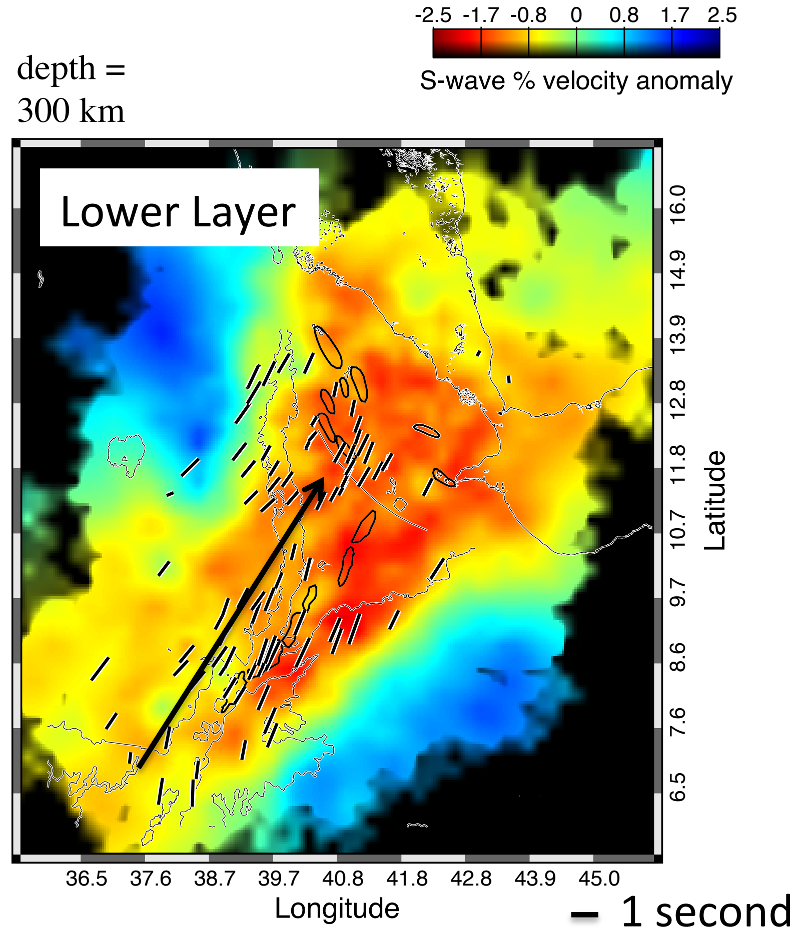
C. Afar



- Low velocities exist from surface to base of the transition zone.
- Isolated fast velocities in the top 100km.

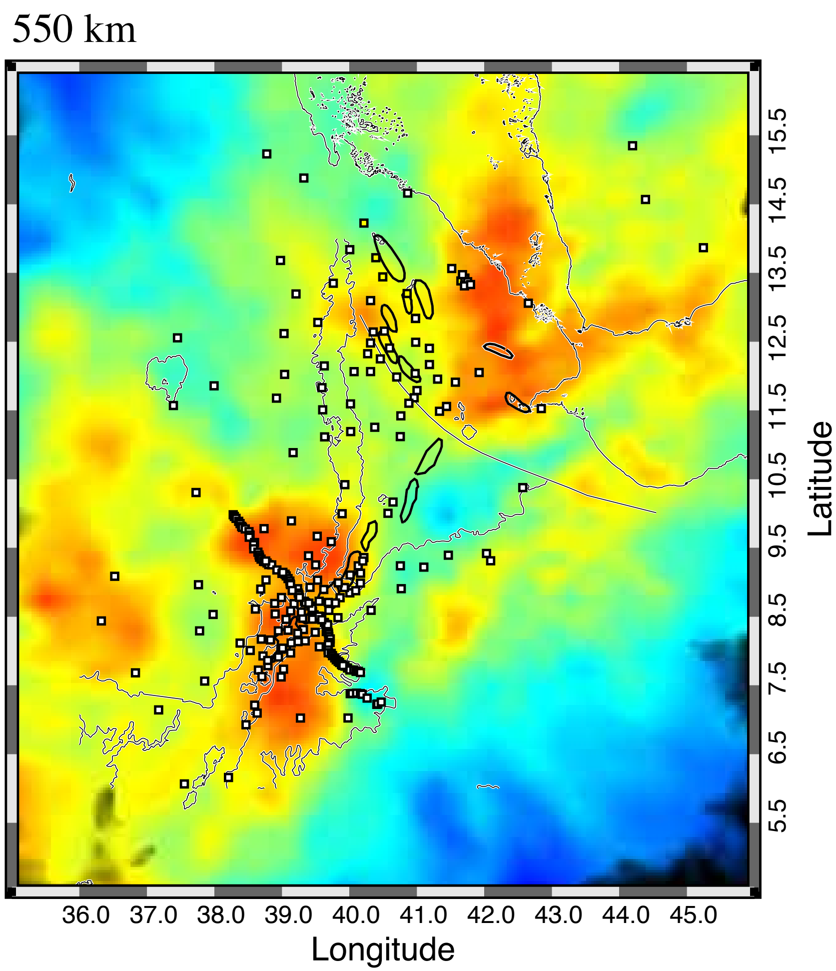
150-400km

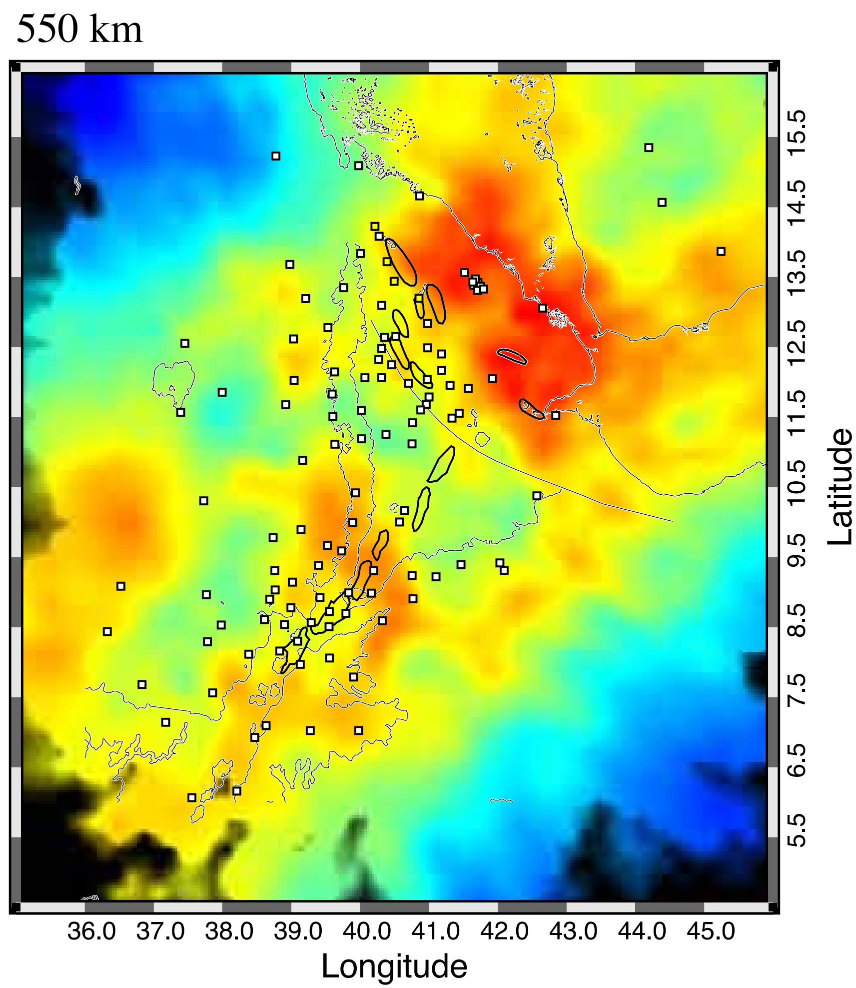




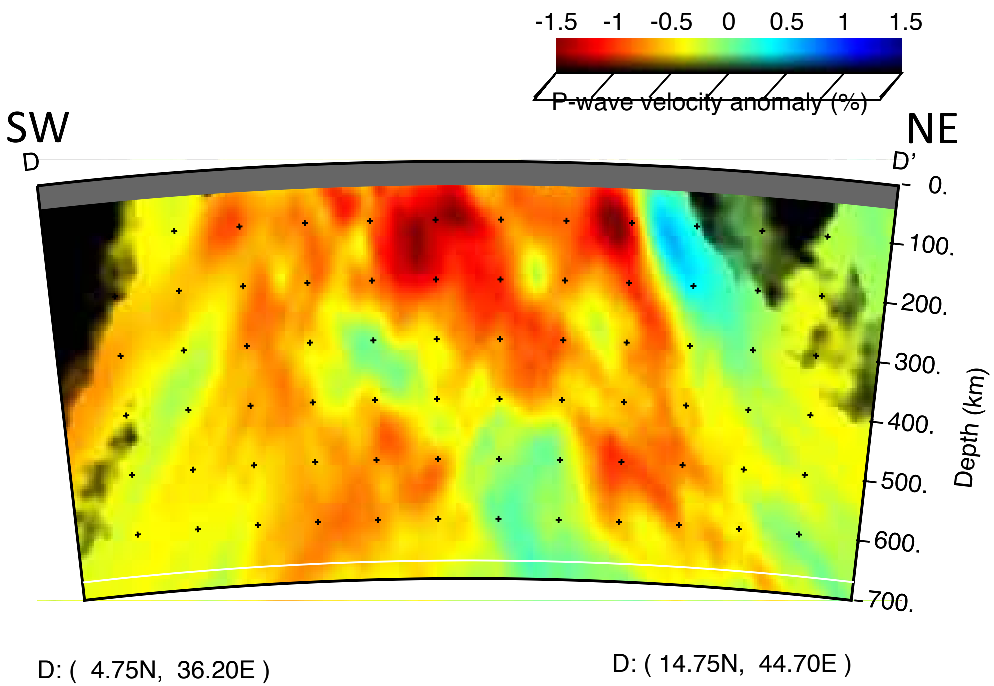
- Shear-wave splitting tomography (Wookey et al., in press) shows two layers of anisotropy (Hammond et al., in prep).
- Upper layer dominated by melt & fossil fabric.
- Lower layer dominated by SW/NE orientation – likely flow from superplume
    - No evidence of radial flow from plume structures

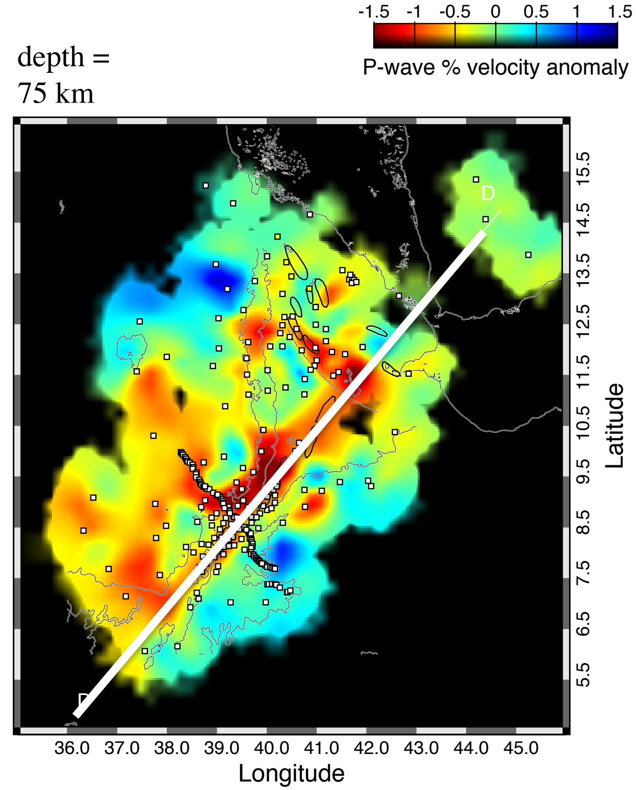
Transition Zone (550km)

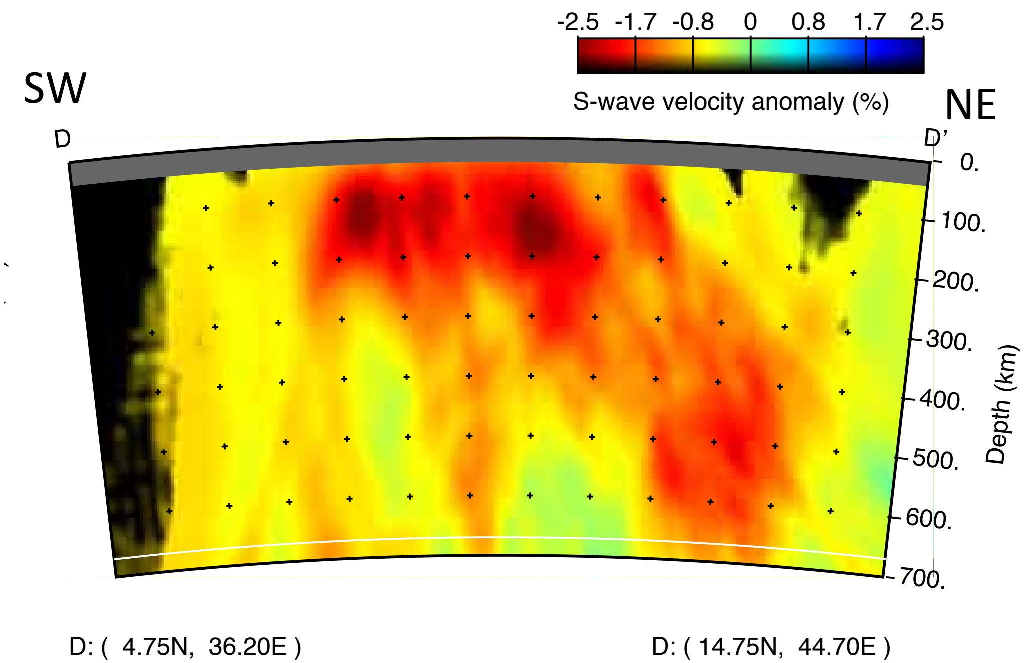




- Isolated regions of low velocity in the transition zone
- Located beneath regions of largest low velocity regions in uppermost mantle (MER, triple junction)

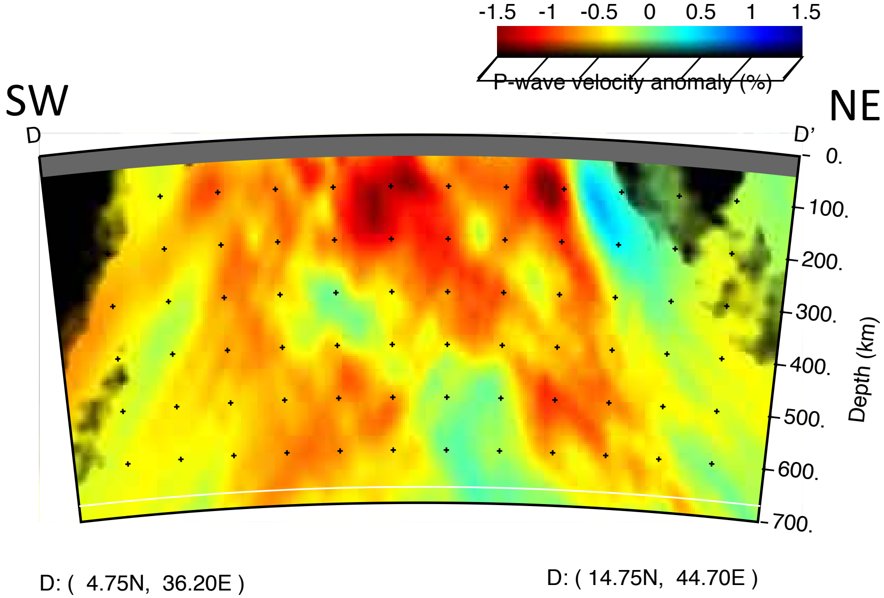


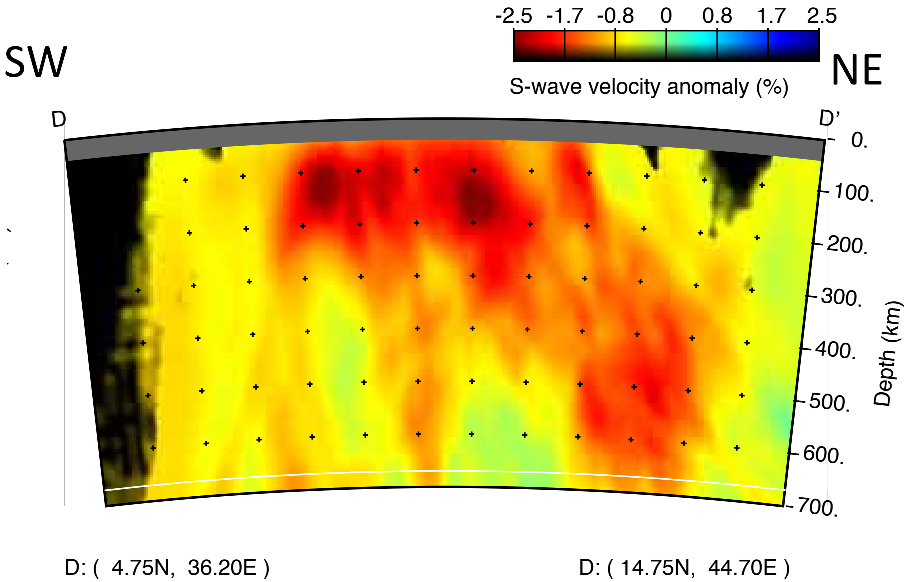




- Mantle between surface and transition zone full of low velocity material.

- Two regions of focused low velocities in the transition zone.





Kumagi et al., 2007

Afar Rift Consortium

- No evidence for a single narrow conduit beneath Afar
- Models suggest that secondary plumes arise from some larger feature below the transition zone

University of BRISTOL

Imperial College London

Afar Rift Consortium

Summary

- <400km structure
  - Lowest velocities beneath MER and triple junction
  - Follows rift axis in Afar
  - Faster velocities beneath the Danakil depression
  - •Depth of melting from S-wave receiver functions suggest decompression melting dominates
    - Some localised regions of deeper melt (triple junction, western border fault, Nabro)
  - •Broad lower velocities below ~150km

University of BRISTOL

Imperial College London

Summary

- Deep structure
  - Broad lower velocities extend to the transition zone
  - Two isolated regions of low velocity in the transition zone
  - One continuous upwelling
    - Not consistent with isolated deep anomalies
  - Heterogeneous plume
    - Models match with ideas of small upwellings rising from larger upwelling