Along- and cross-axis variations in crustal rift structure observed in the Main Ethiopian Rift

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We estimate a 3D shear wave velocity model for the crust of the Main Ethiopian Rift (MER) using the technique of ambient noise tomography. The obtained model includes the entire central MER (CMER) and much of the southern MER (SMER), and therefore provides new information on crustal structure along the MER. In the CMER, our model shows higher velocities to the south of the southernmost Quaternary magmatic center along the Wonji Fault Belt (eastern part of the CMER), and the persistence of low velocities through the crust beneath the Silti-Debre zeit Fault Zone (western part of the CMER). This is consistent with the magmatic plumbing model for the MER proposed by geochemical studies. With respect to the along-axis direction, higher velocity in the SMER indicates that the mid and lower crust is not currently being modified by magmatism. In contrast, a prominent lower velocities are shown beneath the Boset-Kone magmatic segment in the NMER, where the significantly less seismicity, the increase in crustal anisotropy, and the overall higher crustal Vp/Vs ratios were observed. This region also coincides with the present-day intense zone of melt extraction from asthenosphere, which is expected by the lowest velocity in the upper mantle and the maximum SKS delay time. These evidences show that the along-axis variation can be attributed to the discontinuous development of the MER parts, which show that rift initiation in the Afar and the SMER could be at least 10 Ma older than in the CMER and the NMER.

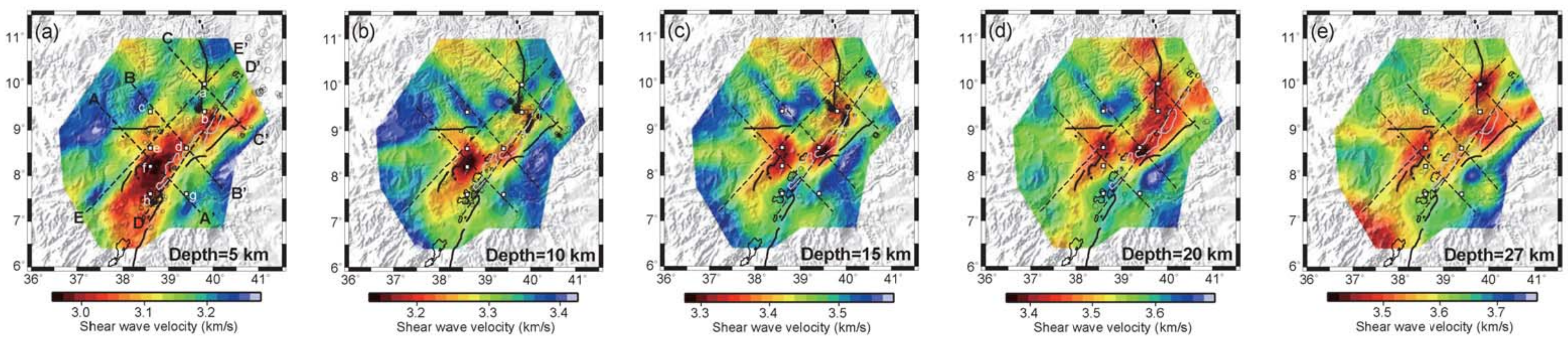

Figure 1. Shear wave velocity maps for selected depths. Depth is indicated in the lower right corner of each map. Dashed lines show locations of vertical profiles in Figure 2. Earthquake epicenters from (Keir et al., 2006) within ± 2.5 km of the depth of each model slice are shown with open circles.

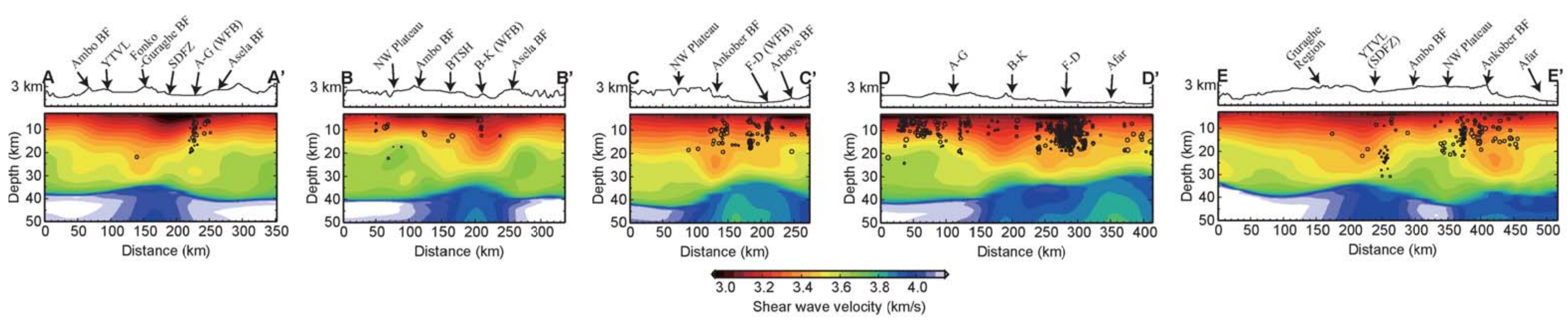

Figure 2. Vertical profiles of shear wave velocities. The locations of the profiles are shown with dashed lines in Figure 1. Vertically exaggerated topography and names of major tectonic structures are shown on the top of each profile. Earthquake epicenters (open circles) from Keir et al., (2006) within a 0.3° distance from each profile are projected onto each profile.es.

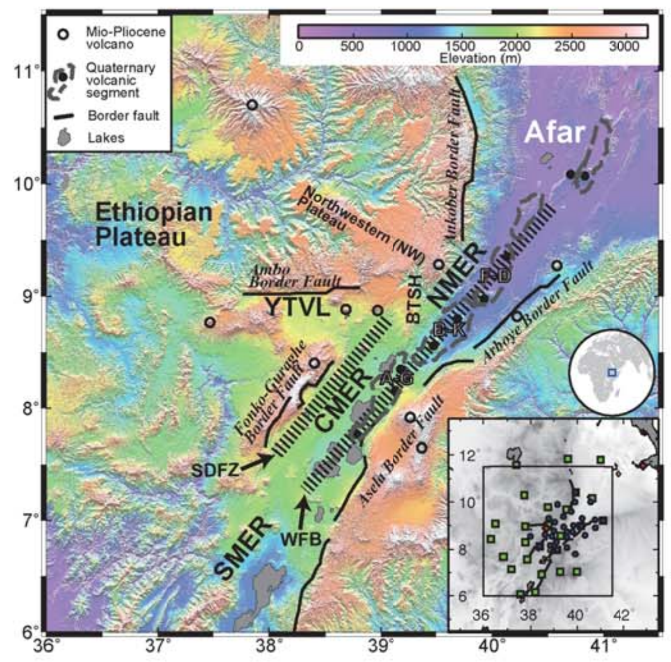

Figure 3. Relief map of the Main Ethiopian Rift (MER) and surrounding Ethiopian Plateau. Major border Faults (BF) are labeled and shown by black lines. Polygons with dashed grey lines indicate the Quaternary volcanic segments (A-G, Aluto-Gedemsa; B-K, Boset-Kone; F-D, Fentale-Dofen). The Wonji Fault Belt (WFB) and Silti-Debre zeit Fault Zone (SDFZ) are presented by wide dashed lines. NMER, Northern MER; CMER Central MER; SMER, Southern MER; YTVL, Yerer-Tullu Wellel Volcanotectonic Lineament; BTSH, Boru-Toru Structural High. Inset in bottom-right corner shows stations used in this study. Red diamonds, green squares, and blue circles show locations of permanent seismic stations and those of the Ethiopia Broadband Seismic Experiment (EBSE) (Nyblade and Langston, 2002), and the Ethiopia Afar Geoscientific Lithosphere Experiment (EAGLE) (Maguire et al., 2003), respectively.

Main findings

(1) A region of lower shear wave velocities at all crustal depths beneath the YTVL
(2) Lower shear wave velocities throughout the MER at upper crustal depths (< 10km)
(3) Prominent regions of lower shear wave velocities at mid (10-20 km) crustal depths beneath the WFB on the eastern side of the MER, in the transition between the NMER and CMER, and beneath the SDFZ on the western side of the CMER
(4) An offset in the velocity pattern at mid-crustal depths between the NMER and CMER coincident with the BTSH
(5) Little evidence for lower shear wave velocities at mid or lower crustal depths beneath the SMER.

1. Interpretation of the low shear wave velocities beneath the NMER and the CMER

(1) Upper crust (Figure 1a): magmatically perturbed upper crust and basin fill.

(2) Middle crust (Figure 1b-d): Mafic intrusion associated with some partial melt
- High P-wave velocity (correlate with the Quaternary magmatic segments)
- High Vp/Vs ratio
- Positive gravity anomalies
- High electrical conductivity

2. High velocity beneath the BTSH

(1) Coincides with an offset in the velocity pattern between the NMER and CMER (Figure 1b-c)

(2) The BTSH has been interpreted as a transfer zone formed by north-to-south propagation (Bonini et al., 2005), or as a breached structure by the joining of the southern Red Sea rift with the EARS (rooney et al., 2007)

3. Low velocities beneath the WFB in the NMER VS. the SDFZ in the SMER - matched with geochemical models (e.g., Rooney et al., 2007)

(1) The WFB magmas are stored for less time and fractionate dominantly in the upper ~5 km of the crust before their eruption.
- The lower velocities observed in the upper crust south of the A-G magmatic segment, which are absent at greater depths (Figure 1 and A-A' in Figure 2).

(2) In the SDFZ, magmas fractionate over a broader depth range
- The magmatic bodies are imaged as lower velocity anomalies extending throughout the crust (Figure 1 and B-B' in Figure 2).

4. Higher velocity in the SMER

(1) The SMER crust is not being modified by magmatism
- Lesser amounts of Quaternary volcanism, especially the absence of basaltic fissure.

(2) Recent volcano deformation suggests the presence of some melt within the upper crust.
- The high velocities in the middle crust indicate that the magmatic feeder systems are either sufficiently narrow or that the conduits are sufficiently separated such that they cannot be resolved.

5. Thermaly modified crust - checked by the comparison with depth distribution of seismicity

(1) Good correlation between the depth extent of seismicity and the shear wave velocity pattern (Figure 2).
- There is significantly less seismicity beneath the B-K segment where lower velocities are found.

6. The along-strike variation of the crustal magmatism related to the melt extraction from the upper manlte

(1) High and low velocity regions in crust show a parallel pattern to upper mantle velocities at 75 km depth (Bastow et al., 2008) and the maximum SKS delay times.

(2) It has been suggested by Bastow et al. (2008, 2010) that the difference in the initiation of rifting along strike could lead to larger melt volumes beneath the CMER and NMER than in southern Afar and the SMER due to more recent decompression melting.