Seismic anisotropy and the signature of rifting in Africa

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The rifting of continents and eventual formation of ocean basins is a fundamental component of plate tectonics, yet the mechanism for break-up is poorly understood. The East Africa Rift system (EARS) is an ideal place to study this process as it captures the initiation of a rift in the south through to incipient oceanic spreading in north-eastern Ethiopia. Seismological investigations can be used to test models of rifting. I will summarise results of the recent EAGLE and AFAR projects, which provide detailed seismic images of the portion of the Ethiopian Rift that spans the transition from continental rifting to incipient oceanic spreading.

Between 2002 and 2003, seismic data were acquired in 3 phases of the EAGLE project, two of which were designed to record passive seismicity. In Phase I, 29 broad-band seismometers were deployed for 16 months with a nominal station spacing of 40 km and covering a 250 km x 350 km region centred on the transitional part of the rift. In Phase II, a further 50 instruments were deployed for 3 months in a tighter array (nominal station spacing of 10 km) in the rift valley. In response to a massive diking event in the Dabbahu region of Afar in October 2005, a further 41 stations were deployed throughout Afar and the adjacent rift flanks. Both projects have been part of larger multi-national, collaborations involving universities and organisations from the UK, US and Ethiopia (see Figure 1).

A variety of techniques have been used to study velocity structure and anisotropy beneath the Main Ethiopian Rift. Travel-time tomography and receiver function analysis illuminate a magamatic rift zone with little crustal stretching. Cumulatively, these observations support models of magma assisted rifting, rather than those of simple mechanical stretching.

In this talk I will describe how measurements of seismic anisotropy can be used to test models of rifting. Here we summarize observations of anisotropy beneath the EARS from local and teleseismic body-waves and azimuthal variations in surface-wave velocities. Special attention is given to the Ethiopian part of the rift where the recent EAGLE and Afar projects have provided a detailed image of anisotropy in a region that spans the transition from continental rifting to incipient oceanic spreading.

Analyses of regional surface-waves show sub-lithospheric fast shear-waves coherently oriented in a north-eastward direction from southern Kenya to the Red Sea. This parallels the trend of the deeper African superplume, which originates at the core – mantle boundary beneath southern Africa and rises towards the base of the lithosphere beneath Afar. The pattern of shear-wave anisotropy is more variable above depths of 150 km. Analyses of splitting in teleseismic phases (SKS) and local shear-waves within the rift valley consistently show rift-parallel orientations. The magnitude of the splitting correlates with the degree of magmatism and the polarizations of the shear-waves align with magmatic segmentation along the rift valley. Analysis of surface-wave propagation across the rift valley confirms that anisotropy in the uppermost 75 km is primarily due to melt alignment. Away from the rift valley, the anisotropy agrees reasonably well with the pre-existing Pan-African lithospheric fabric. An exception is the region beneath the Ethiopian plateau, where the anisotropy is variable and may correspond to pre-existing fabric and ongoing melt-migration processes.

These observations support models of magma-assisted rifting, rather than those of simple mechanical stretching. Upwellings, which most probably originate from the larger super-plume, thermally erode the lithosphere along sites of pre-existing weaknesses or topographic highs. Decompression leads to magmatism and dyke injection that weakens the lithosphere enough for rifting and the strain appears to be localized to plate boundaries, rather than wider zones of deformation.

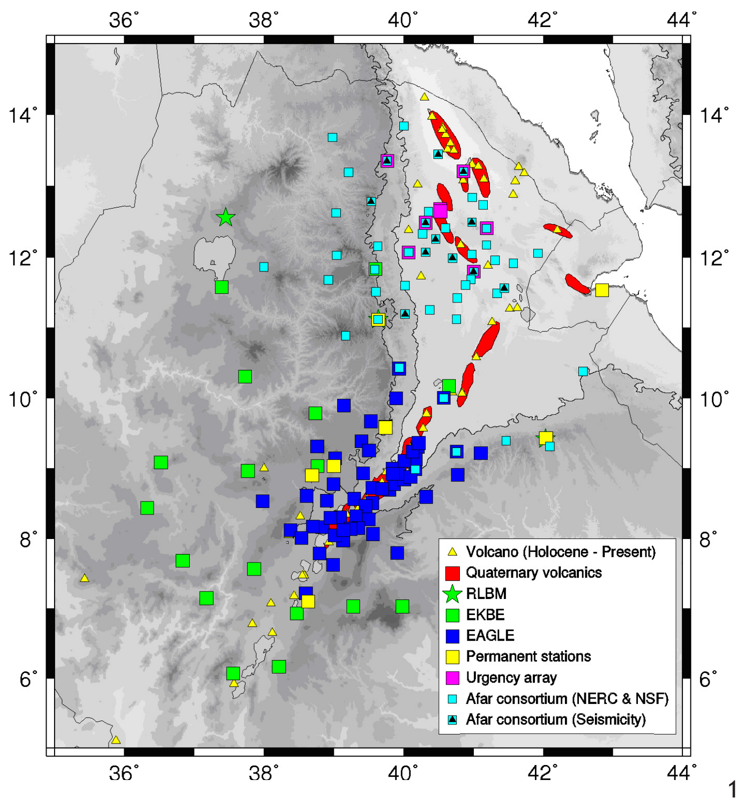

Figure 1: Seismic stations used to study anisotropy beneath the NE portion of the East Africa Rift system. Also shown are volcanoes and Quaternary magmatic segments.