Seismic Arrays to Study African Rift Initiation

PAGES 213–214

Rifting of stable continents is a key element of plate tectonic cycles. In spite of numerous studies, the mechanism responsible for the initiation and evolution of rift valleys such as the East African Rift System (EARS) is still poorly understood, partly because most previous investigations focused on rift segments that were in the mature stage. Geodynamic modeling [*Huismans et al.*, 2001] suggests that upwelling of the asthenosphere ubiquitously observed beneath mature rifts can either originate from thermal or dynamic anomalies in the deep mantle (active rifting) or be induced by thinning of the lithosphere from far-field stresses (passive rifting) [*Sengor and Burke*, 1978].

The key to distinguishing between the rifting models might reside in incipient rift segments such as the southernmost (Malawi rift) and southwest (Okavango and Luangwa rifts) segments of the EARS (Figure 1). Asthenospheric upwelling and associated mantle flow should already be present beneath the incipient rifts if the active rifting model prevails; in contrast, under the passive rifting model, such upwelling and flow are insignificant because adequate thinning of the lithosphere has yet to develop.

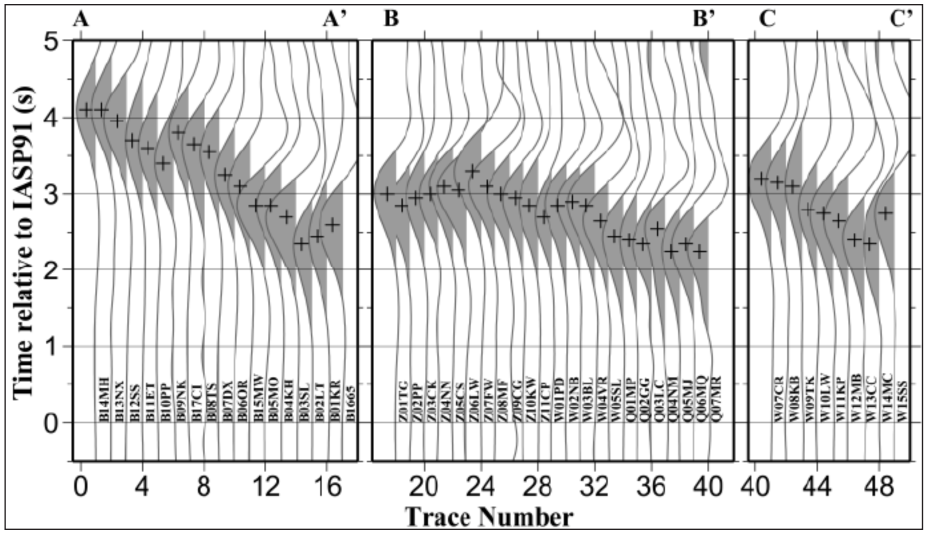

Fig. 2. Examples of seismograms from an earthquake that occurred on the Indian mid-ocean ridge. Seismic wave traveltimes are shown relative to the International Association of Seismology and Physics of the Earth's Interior–1991 (IASP91) velocity model. The three profiles (A to A', B to B', and C to C') are shown in Figure 1. Each trace represents a seismogram recorded by a station. The seismograms demonstrate the quality of the data set and show systematic spatial variations of seismic velocities beneath the profiles.

To provide essential constraints for the rifting models, in the summer of 2012, members of the Seismic Arrays for African Rift Initiation (SAFARI) team installed 50 Program for Array Seismic Studies of Continental Lithosphere broadband seismic stations across the Okavango, Luangwa, and Malawi rifts (Figure 1). The seismic arrays have a total length of about 2500 kilometers with an average station spacing of 54 ± 26 kilometers. The stations, which are equipped with Quanterra Q330 digitizers and Guralp CMG-3T 120 s sensors, are located in four countries: Botswana (17 stations), Malawi (15 stations), Mozambique (7 stations), and Zambia (11 stations). The duration of the deployment is 24 months, and the sampling rate is 50 samples per second.

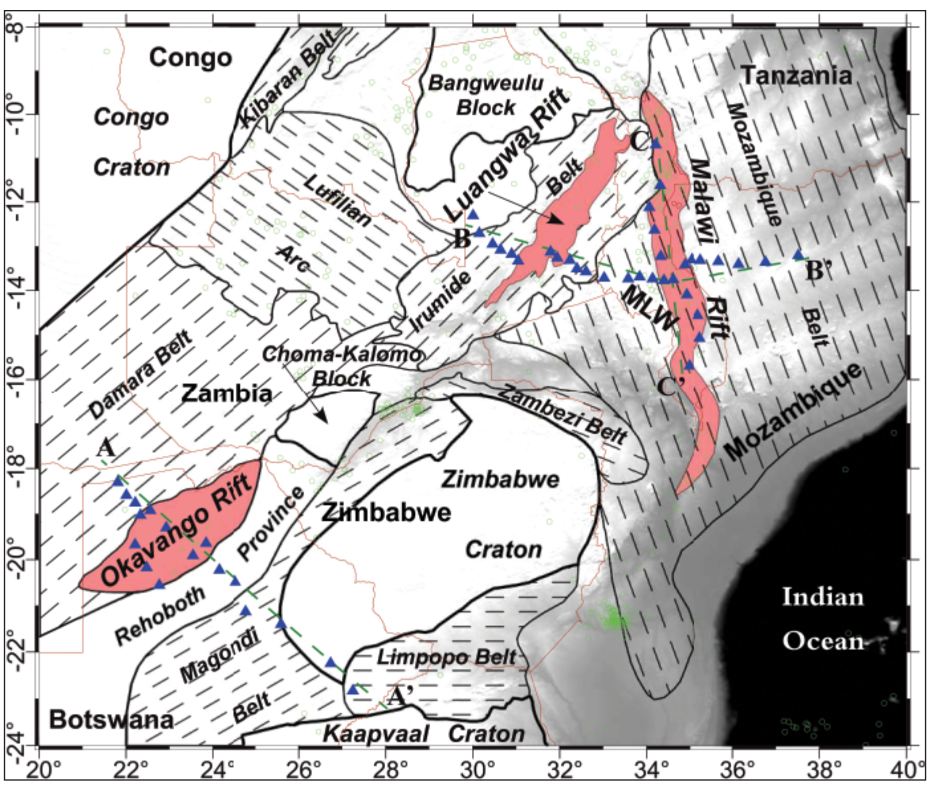

Fig. 1. Major tectonic units, recent earthquakes (green circles), and Seismic Arrays for African Rift Initiation (SAFARI) stations (blue triangles). MLW is Malawi.

The rift-perpendicular arrays across the Okavango, Malawi, and Luangwa rifts were designed to image seismic velocity and anisotropy contrasts between the rifted and neighboring stable areas, and the north-south array along the Malawi rift was deployed to investigate along-strike variation of crustal and mantle structure and dynamics. Because previous studies indicate that the Malawi rift becomes progressively younger toward the south [*Ebinger et al.*, 1987], such spatial variations provide critical information on the temporal evolution of rifting processes.

Figure 2 shows vertical seismograms from a teleseismic event recorded by the SAFARI stations obtained from the first service trip conducted in January 2013. The $M_b = 5.6$ earthquake occurred on 6 November 2012 near the northern end of the mid-ocean ridge of the Indian Ocean. The seismic waves of the event arrived at the SAFARI stations from the northeast direction, and the distances from the earthquake to the stations were in the range of 30°–45°.

The *P* waves from the event arrived at all of the stations more than 1 second after the traveltimes predicted by the commonly used International Association of Seismology and Physics of the Earth's Interior–1991 (IASP91) velocity model traveltimes, suggesting overall lower-than-normal *P* wave velocities along the raypaths. The traveltime delays increase almost linearly by as much as 2 seconds from the Limpopo Belt to the northern end of the Okavango rift (Figure 2, left). The axial area of the Luangwa rift also corresponds to a traveltime delay of about 1 second relative to the eastern extreme of the east-west profile (Figure 2, middle). It is noteworthy that no significant traveltime delays corresponding to the Malawi rift are observed along the east-west profile. Instead, there is a southward reduction of traveltime residuals of about 1 second along the north-south profile (Figure 2, right).

That seismic wave velocities are lower than normal seems to support the idea that the mantle beneath southern Africa is hotter than normal, probably associated with the proposed superplume beneath this area. However, analysis of just one event is not enough to tomographically image structures below these rift features. Ideally, given the rate of teleseismic retrievals from the area, the equipment would need to be running for another 1–2 years before a general idea of the rifting mechanism in segments of EARS could be determined.

Results from seismic velocity and anisotropy studies using data from SAFARI, when combined with anticipated results from other studies, will provide crucial constraints on geodynamic models for the initiation and evolution of continental rifting. They also lay the groundwork for future larger-scale investigations with denser two-dimensional passive and active seismic arrays and other geological/geophysical techniques.

Acknowledgment

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