Faulting processes during early-stage rifting: analysis of an unusual earthquake sequence in northern Malawi

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On December 6, 2009, an unusual sequence of earthquakes occurred in the northern Malawi Rift near Karonga (Fig. 1), which lies within the weakly extended southern part of the East Africa Rift System. The sequence initiated with an Mw 5.8 event, which was followed 32 hours later by an Mw 5.9 event, and then nearly 12 days later by an Mw 6.0 event. Within this time span there were an additional eight Mw > 4.5 events, with presumably many more events that were at or below the threshold of detection. Such events are rare in the northern Malawi rift valley; prior to this sequence, the NEIC catalog (which dates to 1973) contains only three events of M > 5 within the rift valley between 9-12°S latitude. This contrasts with both the Western and Eastern Rifts through Kenya and Tanzania, which have experienced 115 M > 5 events in the same time period. Most of those events occurred on major border faults, but the locations of the Karonga events are far removed from the border fault. In addition, the events occurred just south of a young volcanic province. They offer a rare opportunity to evaluate the potential roles of magmatism and hanging-wall fault evolution in early-stage rifting. We constrain the faulting in this sequence using a unique set of aftershocks recorded over a four-month interval, combined with estimates of the distribution and mechanisms of the largest events, and models of InSAR images of deformation during the sequence.

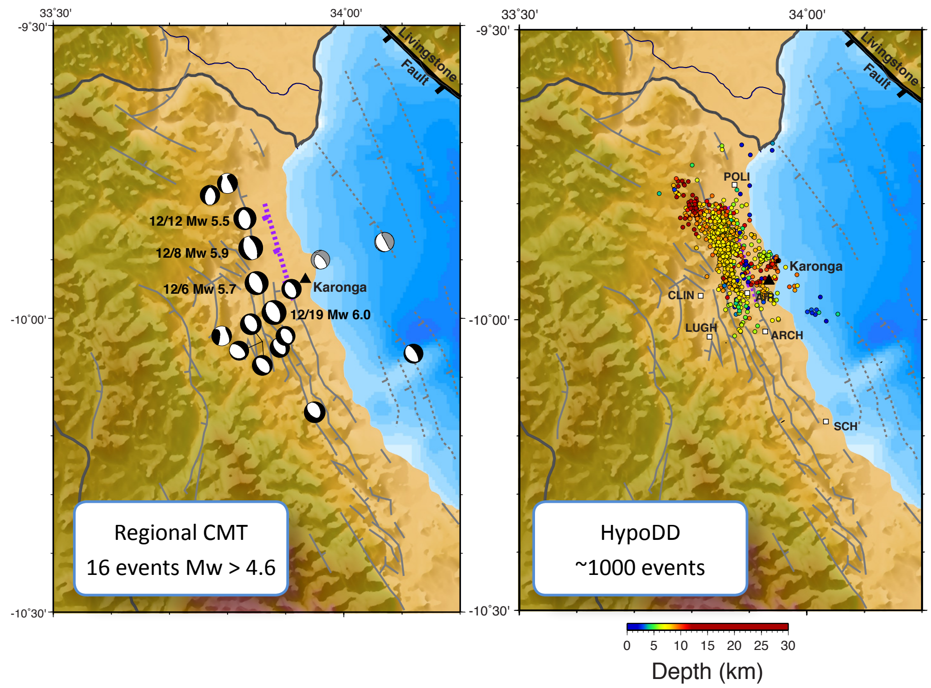

Figure 1. (left) Focal mechanisms of the largest 17 events of the 2009-2010 Karonga sequence. Surface projection of the buried St. Mary's fault, inferred from InSAR, is shown with purple line. Fault locations from PROBE and geologic data shown in grey lines. (right) Epicenters of ~1000 aftershocks relocated using HypoDD, with depth shown by color. Distribution north of Karaonga is consistent with events on the west-dipping St. Mary's fault, but beneath and south of Karonga, earthquake clusters suggest multiple west-dipping faults.

The earthquake distribution implies that a series of interacting hanging-wall faults produced the Karonga earthquakes (Fig. 1). The depths of the events are quite shallow, less than ~12 km, well above the projection of the main west-dipping border fault at depth. The majority of events appear to be associated with a previously unidentified west-dipping fault ('St. Mary's Fault') to the north of Karonga. This fault was identified by InSAR data (Biggs et al., 2010; Fig. 2) and by field mapping by the Malawi Geological Survey, and the multiple events were interpreted to occur on this single, immature fault. Our InSAR analysis is consistent with this scenario, perhaps on a fault with listric geometry. However, the aftershock locations suggest that the events occurred on multiple west-dipping normal faults along a roughly 40-km-long north-south zone roughly centered on the village of Karonga. Most of the events north of Karonga are consistent with slip on the St. Mary's fault. However, to the south, clusters of events locate on west dipping faults 5-10 km east of the St. Mary's feature. The spacing of these clusters is consistent with west-dipping hanging-wall faults imaged within the lake (Mortimer et al., 2007). In addition, regional CMT analyses of the largest 17 events are distributed primarily along the St. Mary's feature in the northern half of the aftershock region, but show much more east-west variation to the south, with two events well into the lake. These events support the notion of multiple faults. There is no evidence of magmatic control on the sequence. Few events occurred near Rungwe volcanic province, and no geodetic deformation is observed there during this time interval.

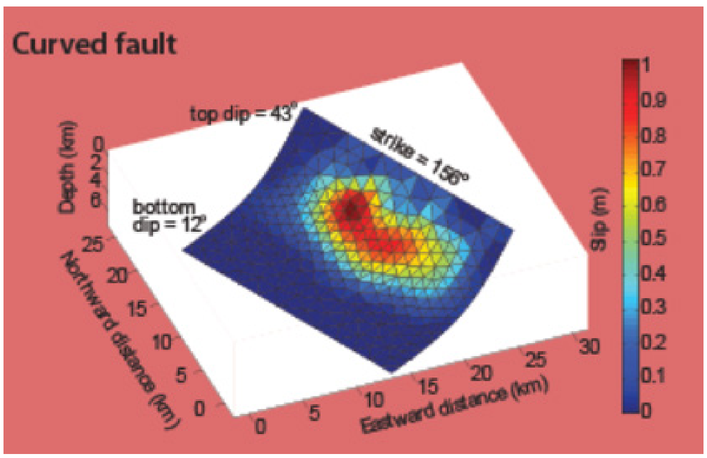

Figure. 2. Estimated slip on a listric geometry St. Mary's fault, which provides the best fit to InSAR estimates of surface deformation spanning the primary 17 events.

We envision two scenarios that can explain the fact that the seismic data suggest two or more active faults, while the InSAR is consistent with slip on a single fault. First, it is possible that primary slip on the St. Mary's fault triggered small aftershocks on the synthetic fault structures, but that no significant slip occurred on these secondary faults during the main sequence. Alternatively, since the faults are parallel and closely spaced, it is plausible that deeper slip on the parallel faults, and/or slip on faults beneath the lake, is masked by the more dominant slip on the shallower St. Mary's feature.

In addition to the significant scientific results, engagement of the Malawi GSD in both the data collection and research activities directly resulted in Malawi's first national seismic network. Based on their experience in this project, the MGSD was able to obtain funding for eight broadband seismic stations. This network represents a long-term investment by the Malawi government to better understand and mitigate seismic hazard affecting their country. Complementing this effort, LDEO hosted three staff from the MGSD for a three-week training session, analyzing the Karonga sequence and developing tools that could be used for their new national network. We also visited the MGDS headquarters to install of data analysis software and continue training.

Results from this analysis have been presented in several forums to date: 2010 and 2012 Fall AGU; 2012 AGU Science Policy conference; 2012 GeoPRISMS planning workshop for the East African Rift system; and at the MGSD and Chancellor College, Malawi. A manuscript is in preparation.