The Afar R-R-R Triple Junction, a Focus Area for MARGINS RIE, Plate Boundary Deformation and Geodynamics

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The Afar Triple Junction (ATJ) is defined by the intersection of the Red Sea (RS), Gulf of Aden (GA), and East Africa Rift (EAR) system. These three structures cover the full range of rifting stages and styles from the earliest stages of continental breakup (EAR) through the initial stages of ocean spreading (central/northern Red Sea), to full-ocean rifting along the GA. Deciphering the kinematic complexities of the ATJ and its time evolution as the Aden rift propagated into the Nubian plate to form the present Afar Depression and Danakil Block is critical to improving understanding of three topics in geodynamics: i. What are the critical parameters that control the initiation of rifting of the continental lithosphere (the roles of pre-existing weaknesses, the sub-lithosphere erosion [hot spot], subduction/continental collision), ii. How do extensional plate boundaries evolve over time, and how do real R-R-R triple junctions develop under finite extension (in contrast to the limit of a 0D triple junction in a vector sum approximation), and iii. How is the distribution of surface deformation related to crustal/lithospheric mechanics and rheology?

The relative motion between AR, NU, and SO, as well as the motions of AR and NU with respect to Eurasia, are well constrained by plate tectonic, geologic, and geodetic studies – these motions are remarkable for their simplicity and uniformity in time. NU-AR and SO-AR motion, and resulting RS and GA extension, developed in 2 stages, initial, slow extension starting at 24 ± 4 Ma that accelerated by a factor of 2 at ~11 Ma, and has remained steady to the present time (ArRajehi et al., 2010; McClusky et al., 2010). NU-SO motion likely initiated simultaneously with that in the RS and GA (i.e., 24 ± 4 Ma; e.g., Garfunkel and Beyth, 2006), although the rate of extension has been slower by roughly a factor of 4 – 5 than that in the RS and GA, and there is no clear evidence for changes in rate since rift initiation. These well-defined motions provide simple boundary conditions for the rifting process allowing focus on the influence of the rate and orientation of plate motions, the influence of pre-existing structures (lithospheric and crustal), magmatism, and mantle flow, among other possible factors.

Despite the recent research focus on both the ATJ and the Ethiopian Rift, the available data for the region is limited and insufficient to determine whether the classic Wilson cycle concept of rifting and margin formation fits the African example. In the Ethiopian Rift, a variety of active and passive source seismic products image the structural rift, but have very limited resolution beyond the rift bounding faults (Keranen et al., 2009; Keranen and Klemperer, 2008; Bendick et al., 2006; Pasyanos, 2005; Kendall et al., 2005; Bastow et al., 2005). Geodetic data is also most dense within the structural rift. Geochemical and structural studies extend further into the Nubian and Somalian plates, but are still sparse. In the Red Sea and Gulf of Aden recent geodetic results provide bounds on the total extension rates, but not on how or where extension is accommodated (e.g. ArRajehi et al., 2010; Pallister et al., in press). In the Afar region itself, geodetic data has been collected mostly in a transect along a single, sparse transect from the Ethiopian Highlands to the Red Sea coast, with additional observations around the Dabbahu dike injection site, supported
by limited seismic data (Figure 1). All of these observations suffice to place some bounds on the kinematics and mechanics of the region, but have also stimulated new questions, especially about how continental breakup initiates and evolves, how feedbacks between strain and temperature evolution affect the process, and how the mechanics of continental rifting change in space and time.

The ATJ and associated rift structures continue to be the focus of a broad range of geologic and geophysical studies by US, African, Arabian, and European investigators. Substantial geophysical studies were supported under the MARGINS RCL initiative (seismic, geologic, geodetic) that provide a strong basis for future studies. Saudi Arabia is dedicating major resources to study rifting processes and associated hazards along the Red Sea, ARAMCO has an expanding interest in seismic exploration of the Red Sea, and European investigators have long focused on Mediterranean active tectonics that are a direct consequence of changes in NU-EU convergence (Jolivet and Facenna, 2000; McClusky et al., 2010). The development of AFREF, a US lead project to initiate geodetic infrastructure in Sub-Saharan Africa, will facilitate all future active tectonic studies, as will the proliferation of national GPS networks in N Africa (Morocco, Libya, Algeria, Egypt). Establishing this broad region as a GeoPRISMS focus site will provide further opportunities for the academic Earth science community to gain access to these important data.

Broader Impacts: Development of Geophysical expertise in Africa and Arabia through direct collaborations. Constraints for, and development of, basin models for resource exploration. International collaborations. Student involvement in international research. Hazard mitigation (e.g., surface failures, volcanic events, improved weather forecasting using national GPS networks).

Methodology: Possible research targets for the region should include enhanced geodesy for deformation monitoring (distribution of strain across rift structures at different stages of evolution and in different tectono-magmatic settings), ongoing study of existing geodetic assets to improve temporal resolution, improvement of geodetic resolution within the ATJ with network expansion, seismic studies for constraining crustal, lithospheric, and deep mantle structure, fault geometry, and basin evolution within the ATJ and extending into the Nubian and Somalian “plates”, geodynamic simulations, and geochemistry and geochronology of regional magmatic activity.

References


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Figure 1. The proposed rift mechanics study area. The approximate EAGLE seismic experiment footprint is the black box. Existing GPS sites are open circles. The red boxes show the target regions for new seismic and numerical simulation studies; red circles are potential new geodetic observation sites. Broad scale studies of the mechanics of plate motions will consider the full AR, NU, SO, EU plate system.