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Fault attribute analysis for unraveling rifting processes at a Continent-Ocean Transition rift: example of Dabbahu-Manda-Hararo (Ethiopian Afar)

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Analyses of fault attributes help us understand fault growth processes in diverse tectonic settings. Here we present a detailed analysis of a fault population integrated at the scale of the Dabbahu-Manda-Hararo (DMH) rift segment (Central Afar, Ethiopia), a rift in a late phase of the continent-ocean transition. We investigate the along-rift axis variations in faulting processes, and compare these to those observed at oceanic ridges so as to better unravel the processes leading to the continental breakup.

We quantify fault azimuth, length, and throw attributes for 668 normal faults we mapped. Along DMH rift, the mean fault density is 0.87 ± 0.7 km/km^2 and the median tectonic strain ranges from 1.8% to 3.1% assuming fault dip of 60° and 45°, respectively. North of the transversal Ado Ale volcanic chain, between N12.35° and N12.45°, the azimuth of DMH rift changes from N150º to N165º accommodated by the fault population. This rift section also reaches the maximum tectonic strain observed along the rift (∼12% and ∼20% assuming a 60° and 45° dipping fault) and is also characterized by long faults (4-12 km) distributed evenly at the rift axis and margins. Combined to scaling laws and morphological analysis, these results suggest specificities of the northern part of the rift that cannot be explained by regional processes such as changes in the direction of extension between Nubia and Arabia tectonic plates. Instead, our observations suggest that the Dabbahu volcano influences rift development. Using thermomechanical arguments, we suggest that crustal magma chambers act as stress concentrators. Hence, the Dabbahu volcano, located at the northern tip of the rift, has captured the propagating Manda-Hararo rift in the last ∼100 kyr resulting in a different rifting stage in the northern part of the rift.

The morphotectonic analysis reveals numerous common features (segment length, spreading rate, associated magmatic system, tectonic strain, fault growth) with slow-spreading ridge segments, such as the Lucky Strike oceanic spreading center (LS-OSC) at the Mid-Atlantic ridge. The comparison led between DMH rift and LS-OSC segment shows that the upper crustal extension is accommodated at first-order similarly at both extensional systems, represented at ∼80% by diking and ∼10-20% by faulting. A further analysis of the lithospheric structure and dynamics of these two extensional systems using observations from the literature suggests 1) a decoupling of the lithospheric crust/mantle at DMH rift and 2) a decoupling of the lithospheric crust/mantle at LS-OSC segment center and decoupling at the segment ends. These variations are related to the different thermal conditions that characterize the transitional continental lithosphere and oceanic ridges. These common features and differences result from the depth-dependent extension and induced feedback that likely determine the transitional present-day surface expression of late rifting stages like at DMH rift.