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Asymmetric slip of normal faults resulting from a series of dike intrusions constrained by InSAR (Afar, Ethiopia)

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An exceptional rifting episode is currently under way in Afar (Ethiopia). Available geodetic data covers not only the main rifting event of September 2005, but also a series of at least 10 smaller events in 2006-2008. These are characterised by rapid dike intrusion/inflation at depth (within hours), and motion on two sets of conjugate normal fault systems above the dike, inducing local subsidence of the ground surface. Geodetic data show that the main dike intrusion was ∼60 km long, and induced an ∼3-6 m offset of the surface due to slip on two roughly parallel fault zones that bound a ∼2-4 km wide unfaulted zone. For later events, surface ruptures are observed to occur over a length of ∼10-20 km along-strike, with slip reaching ∼1 m in a few cases.

We identify three important problems from the study of these faults. These issues seem to discard a series of hypotheses that constitute the basis of previous models of dike-induced faulting. (1) InSAR data encompassing each rifting event allows to retrieve the horizontal (H) and vertical (V) component of surface offset across each of the two conjugate fault systems, assuming deformation is cylindrical. The H/V ratios can be used to infer an "equivalent" fault dip at depth assuming pure dip-slip behaviour. The resulting calculation suggests dip values in the range of ∼30-50°, much shallower than values of ∼60-80° deduced from field observations and fault mechanisms in similar tectonic contexts. (2) A systematic asymmetry of fault motion occurs on each side of the subsiding graben floor. We show that while vertical throws seem to be approximately balanced, horizontal dilation is significantly higher on one side of the rift than on the other. (3) Seismicity accompanying dike emplacement is always low with regard to the amount of static deformation detected by geodetic techniques: the maximum magnitude reaches only M_w=5.6 for the main event, and M_w=4.5-4.8 for the largest subsequent rifting events.

We performed 2D elastic modeling using a Boundary Elements Method in order to test a series of geometric and kinematic configuration of the dike and overlying faults. Combining these observations with fault mapping and topographic analysis, we suggest that we are assisting to the birth of a new set of normal faults in response to the emplacement of dikes at depth. This hypothesis is based on previous models that have suggested that the early stage of fault development is characterised by the formation of Mode I cracks, inducing a dilatancy of the incipient shear zone, prior to the initiation of a through-going rupture surface. We further suggest that, in the case studied here, the presence of a preferred direction of weakness resulting from the pre-existence of a fault fabric may enhance the dilatancy effect. Also, the importance of magmatism in assisting this process should not be forgotten, as well as the low confining pressure within the depth range considered in this study.