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# Emplacement mechanisms of a dyke swarm across the Brittle-Ductile transition

**Hans Jørgen Kjøll**[1], Olivier Galland[2], Loic Labrousse[3], and Torgeir B. Andersen[1]
[1]The Centre for Earth Evolution and Dynamics (CEED), University of Oslo, Oslo, Norway
[2]Physics of Geological Processes, the NJORD Center, University of Oslo, Oslo, Norway
[3]Institut des Sciences de la Terre, Sorbonne Université, Paris, France

Dykes are the main magma transport pathways through the Earth's crust and, in volcanic rifts, they are considered the main mechanism to accommodate tectonic extension. Most models consider dykes as hydro-fractures propagating as brittle tensile, mode I cracks opening perpendicular to the least principal stress. This implies that dykes emplaced in rifts are expected to be sub-vertical and accommodate crustal extension. Here we present detailed field observations of a well-exposed dyke swarm that formed near the brittle-ductile transition at a magma-rich rifted margin during opening of the Iapetus Ocean. It was related to a ca 600 million year-old large igneous province. Our observations show that dykes were not systematically emplaced by purely brittle deformation and that dyke orientation may differ from the typical mode 1 pattern. Distinct dyke morphologies related to different emplacement mechanisms have been recognized including: 1) Brittle dykes that exhibit straight contacts with the host rock, sharp tips, and en-echelon segments with bridges exhibiting angular fragments; 2) Brittle-ductile dykes with undulating contacts, rounded tips, folding of the host rock and contemporaneous brittle and ductile features; 3) Ductile "dykes" with rounded shapes and mingling between partially molten host rock and the intruding mafic magma. The brittle dykes exhibit two distinct orientations separated by ~30° that are mutually cross-cutting, demonstrating that the dyke swam did not consist of only vertical sheets oriented perpendicular to regional extension, as expected in rifts. By using the host-rock layers as markers, a kinematic restoration to quantify the average strain accommodating the emplacement of the dyke complex was performed. This strain estimate shows that the dyke swarm accommodated >100% horizontal extension, but also 27% vertical thickening. This suggests that the magma influx rate was higher than the tectonic stretching rate, which imply that magma was emplaced forcefully, as supported by field observations of the host-rock deformation. Finally, observations of typical "brittle" dykes that were subsequently deformed by ductile mechanisms as well as dykes that were emplaced by purely ductile mechanisms suggest that the fast emplacement of the dyke swarm triggered a rapid shallowing of the brittle-ductile transition. The abrupt dyke emplacement and associated heating resulted in weakening of the crust that probably facilitated the continental break-up, which culminated with opening of the Iapetus Ocean.