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Ring dykes as partially captured inclined sheets: insights from field observations and numerical modelling

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The subsurface structure of caldera-bounding ring faults remains a contentious issue. Analogue models provide useful insights into an underlying fault structure; however, results are commonly benchmarked only by near-surface observations and geophysical interpretations. Here we present field observations of a deeply eroded and uniquely well exposed section of caldera ring fault in a Tertiary central volcano in south-western Iceland. The Hafnarfjall ring fault represents the outermost fault complex of an elliptical caldera with an original diameter of approximately 5 km. Vertical displacement is estimated to be > 300 m on the steeply inward-dipping ring fault. Field observations (presented here) of the exposed section of the ring fault, however, show that the fault does not exhibit a constant dip. Hafnarfjall is a predominantly basaltic edifice made of many hundreds of lava flows, although thin layers of tuff and intrusions of more evolved magmas are also observed. These layers have contrasting mechanical properties; therefore local heterogeneities within the original edifice may have altered the stress field enough to influence the propagation of ring faults during collapse. The lava pile on the outer margins of the caldera dips shallowly to the southeast. Within the caldera, dips increase dramatically toward the centre of subsidence and, furthermore, increase with depth. Several thin (< 1 m) dykes occupy an approximately 5 m section within the ring fault; this region is interpreted to have once acted mechanically as the fault core with a lower stiffness or Young's modulus than the surrounding host rock. Many faults which have been active over an extended period develop a damage zone around the fault core; this is a zone of high fracture frequency which is generally stiffer than the core but softer or more compliant than the surrounding host rock. We observe a number of inclined sheets, presumably originating from the shallow magma chamber within the caldera margin, which become either arrested or deflected upon contact with the ring fault. Sheets that deflect into the fault may be wrongly interpreted at the surface as a ring dyke directly connected with extrusion of magma during collapse caldera formation. Using the commercial numerical modelling software COMSOL, we offer a mechanical explanation for the deflection of inclined sheets into sub-vertical dykes at a mechanically stratified fault damage zone and core. A model is proposed whereby ring faults can act as a barrier for the propagation of inclined sheets away from a magma chamber within the caldera. Furthermore, stress field homogenisation within the fault core can promote vertical dyke propagation, which offers a further explanation for the prevalence of renewed volcanism along caldera ring faults.