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Reverse slip on a graben fault induced by a feeder dyke

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Most volcanic eruptions are supplied with magma through dykes, particularly in rift zones. A propagating dyke induces stresses and displacements at the surface. For reliable eruption forecasting, and for general hazard and risk assessments, it is of fundamental importance to interpret the surface deformation correctly so as to be able to infer if, and then when and where, a dyke-fed eruption is likely to occur.

Volcanic rift zones are characterised by volcanic fissures, tension fractures, and normal faults at the surface, the normal faults often forming narrow grabens. Grabens in rift zones are commonly thought to be generated by stresses induced by dykes propagating towards the surface. Geodetic measurements during volcanic unrest periods are routinely interpreted so as to infer dyke-tip depths and dimensions from graben-like deformation at the surface. While this interpretation has been questioned and shown to be unreliable for composite (layered) rift zones, there has not been much surface data as to the actual effects on feeder dykes entering rift zones and grabens.

Here we report for the first time clear field evidence of a 4-5 m reverse faulting on a boundary fault of a narrow graben induced by the overpressure of a nearby feeder dyke. The graben, mostly 200-500 m wide and with vertical displacement (throw) on the boundary faults (outside the influence of the feeder dyke) that in places reaches 20 m. The graben clearly existed when the feeder dyke to the 75-km-long NNE-striking Randarholar Volcanic Fissure was emplaced some 6000 years ago. The graben thus captured the feeder dyke, but only along a part of the dyke's length. Thus, the dyke is partly inside the graben, partly outside it. The dyke is mostly about 2 m thick, except very close to the western boundary (normal) fault where its thickness varies from 6 m to 10 m, the latter value being at the connection of the dyke with its crater row. This 6-10-m thick dyke segment is exposed in the eastern wall of the 100-m-deep deep canyon of the river Jokulsa a Fjollum and is only 30-40 m from the western boundary fault of the graben.

Simple analytical considerations and numerical models indicate that the reverse slip on the boundary fault can be accounted for by the magmatic overpressure at the time when the dyke reached the surface. Also, part of the reason why the dyke is so unusually thick at the surface close to the boundary fault is that the slip on the fault reduced the effective Young's modulus of the (Pleistocene) surface lava flow hosting the dyke.

The results show that dyke-induced surface deformation during unrest periods in volcanoes and rift zones may be complex, and that existing grabens may capture potential or actual feeder dykes. Also, the field observations and models indicate that a dyke entering a rift-zone graben may cause large reverse displacement on a nearby boundary fault, and that the displacement, in turn, may contribute to increasing dyke thickness close to and at the surface. We believe that these results are of vital information for understanding geodetic deformation during volcanic unrest and may help forecast dyke-fed eruptions.