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Fracture mode analysis and related surface deformation during dyke intrusion: Results from 2D experimental modelling

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The analysis of surface deformation in response to approaching intrusion is important for assessing volcanic hazards. In this paper, we present results from 2D scaled models of magma intrusion, in which we discuss the propagation mode and related surface deformation during dyke growth. Our experiments consist in the injection of analogue magma (Golden syrup) into cohesive fine-grained silica powder, simulating the brittle upper crust. Using an optical image correlation technique (Particle Imaging Velocimetry), we were able to follow the surface deformation, the displacements within the country rock and to calculate strains induced by the magma emplacement. We identified two kinds of intrusion morphologies resulting from different interactions between the dyke and plastic deformations occurring in the country rock near the surface. In both morphologies, the dyke is vertical at depth. Our analysis demonstrates that both hydraulic tensile opening and shear-related propagation operate during this first stage of vertical growth. At the same time, the surface lifted up and formed a smooth symmetrical dome. Both types of morphologies differ in the upper part. During a second stage of evolution, the first type of intrusion inclined at a dip between 45 to 65°. This inclination is not caused by shear deformations and is attributed to stress rotation near the tip. Closer to the surface, the growth of the inclined sheet creates shear bands which conduct the fluid toward the surface. The surface uplift becomes asymmetric. The second type of intrusion does not rotate at depth and continues its vertical propagation by catching vertical tensile cracks. The intrusion of magma in these cracks creates horizontal stresses which are responsible for the closure of fractures and the formation of reverse faults. At the surface the dome remains symmetrical. For both intrusions, the surface uplift accelerates during the second stage and it is strongly influenced by the presence or the formation of tensile cracks and faults.