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Beyond elasticity: Are Coulomb properties of the Earth's crust important for volcano geodesy?

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Geodetic modelling has become an established procedure to interpret the dynamics of active volcanic plumbing systems. Most established geodetic models implemented for inverting geodetic data share similar physical assumptions: (1) the Earth's crust is modelled as an infinite, homogeneous elastic half-space with a flat surface, (2) there is no anisotropic horizontal stress to simulate tectonic stresses, (3) the source boundary conditions are kinematic, i.e., they account for an instantaneous inflation or deflation of the source. Field and geophysical observations, however, provide evidence that significant inelastic shear deformation of the host rock can accommodate the propagation of dykes and sills. We show that inelastic processes accommodating the emplacement of dykes in the brittle crust have large implications for dyke-induced surface deformation patterns.

We present two quantitative laboratory experiments that simulate two distinct dyke emplacement mechanisms, in agreement with geological and geophysical observations: (1) dyke propagation as a tensile fracture through a dominantly elastic host in gelatin, and (2) dyke propagation in the silica flour as viscous indenter, which pushes its ahead plastic host that dominantly fails in shear. The syn-emplacement surface deformation is monitored during each experiment. Each dyke emplacement mechanism triggers drastically distinct surface deformation patterns: two uplifting bulges separated by a trough in the gelatin experiment, in good agreement with the expected dyke-induced deformation predicted by the rectangular dislocation model, versus a single uplifting elongated bulge above the apex of the dyke in the silica flour experiment. This first-order difference shows that (1) the rheology of the host and the emplacement mechanisms of dykes are key factors for interpreting dyke-induced geodetic data at active volcanoes, and (2) static, kinematic geodetic models, such as the rectangular dislocation model, have limitations for revealing the physics and dynamics of volcanic plumbing systems.

There is no geodetic model associated with dyke emplacement able to reproduce the single uplifting bulge measured in our silica flour experiment. Instead, such surface deformation pattern is usually fitted with geodetic models of inflating spherical, ellipsoidal or horizontal planar sources. Our silica flour experiment thus shows that (1) a successful data fit is not sufficient and does not imply a physically relevant interpretation, and (2) dykes emplaced as viscous indenters should be

considered as an alternative interpretation of single uplifting bulges measured at active volcanoes. This implies that novel geodetic models accounting for dykes emplaced as viscous indenters should be designed to interpret dyke-induced surface deformation patterns in favorable geological settings, e.g. felsic volcanoes.

In summary, our study motivates the design of new geodetic models that move beyond elasticity, i.e. that account for the realistic elasto-plastic mechanical behavior we know occurs in the Earth's brittle crust. In addition, it highlights the added value of our *laboratory volcano geodesy* approach, which can be the foundation for designing novel geodetic models that accounts for processes that cannot be implemented in numerical models.