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Quantitative analogue modelling of the surface deformation associated with cone-sheet and dyke emplacement

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Inclined cone-sheets and sub-vertical dykes constitute the two principal types of magmatic sheet intrusions produced by volcanic systems. In active volcanic systems, the emplacement of sheet intrusions causes measurable surface deformation, which is analyzed through geodetic models. Geodetic model output is classically the shape of underlying intrusions causing the surface deformation, however, the results of these models are not testable as the subsurface intrusion is not accessible. Such test would only be doable with a physical system in which both (1) the surface deformation pattern and (2) the 3D shape of the underlying intrusion are known. In addition, established geodetic models only consider static magma intrusions, and do not account for emplacement and propagation processes. This would require combined good time- and space-resolution, which is not achievable with classical geodetic monitoring systems.
We present a series of analogue models that may be a way of accurately linking surface deformation to the underlying intrusions and associated emplacement processes. We systematically varied depth of intrusion, the cohesive properties of the silica powder representing the country rock and the velocity of injected magma. The pressure of the intruding vegetable oil was measured through time, and the model surface topography was monitored. The low viscosity magma was simulated by molten vegetable oil, which solidified after intrusion; the solidified intrusion was then excavated and its shape was measured. By linking the development of the surface uplift in height, area, and volume with the pressure data from the onset of intrusion until the time of eruption, we identify characteristic laws of surface deformation. First results indicate that the pattern of uplift over time varies, depending on whether deformation is caused by a dyke- or a cone-sheet-shaped intrusion. The results from all experiments may enable us to distinguish the two intrusion types using surface deformation data alone. In addition, the different signatures of surface deformation patterns associated with dykes and cone sheets provide strong insights into their contrasting emplacement regimes: dykes mainly inject as open fractures, whereas local shear deformation is likely to control cone-sheet emplacement. This key can then be applied to presently active volcanic areas where surface deformation is monitored.