The effects of solidification on sill propagation dynamics and morphology

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Key words sill propagation, sill dynamics, solidification, pluton growth, sill morphology, analogue modelling

Sills are an integral part of the formation and development of larger plutons and magma reservoirs. Thus sills are essential for both the transport and the storage of magma in the Earth's crust. However, although cooling and solidification are central to magmatism, their effects on sills have been so far poorly studied. Here, the effects of magma cooling and solidification on sill propagation dynamics and morphology are studied by means of analogue laboratory experiments. Hot fluid vegetable oil (a magma analogue), that solidifies during its propagation, is injected as a sill in a colder layered gelatine solid (an elastic host rock analogue). The injection flux and temperature are maintained constant during an experiment. In order to vary the importance of solidification and quantify its effect on sill propagation, the injection flux and temperature are systematically varied between each experiment. The results are analysed using dimensionless analysis, allowing to extend the results to sill intrusion in nature.
Two extreme behaviours for sill propagation dynamics and morphology are observed. When solidification effects are small (high injection temperatures and fluxes), the propagation is continuous and the sill has a regular and smooth surface. Inversely, when solidification effects are important (low injection temperatures and fluxes), sill propagation is discontinuous and occurs by steps. After each propagation step, the sill stalls, thickens progressively by storing hot fluid vegetable oil beneath the partially solidified intrusion, without growing neither in length nor in breadth, and after a pause, the propagation initiates again, soon followed by a new episode of momentary arrest. The morphology of these sills displays ropy structures on their surface, and lobes with imprints of the leading fronts that correspond to each step of surface creation. These experiments show that for a given, constant injected volume, as solidification effects increase, the surface of the sills decreases, their thickness increases, and the number of propagation steps increases. In the same way lower solidification effects promote larger sill surfaces, lower thicknesses, and a lower number of propagation steps.

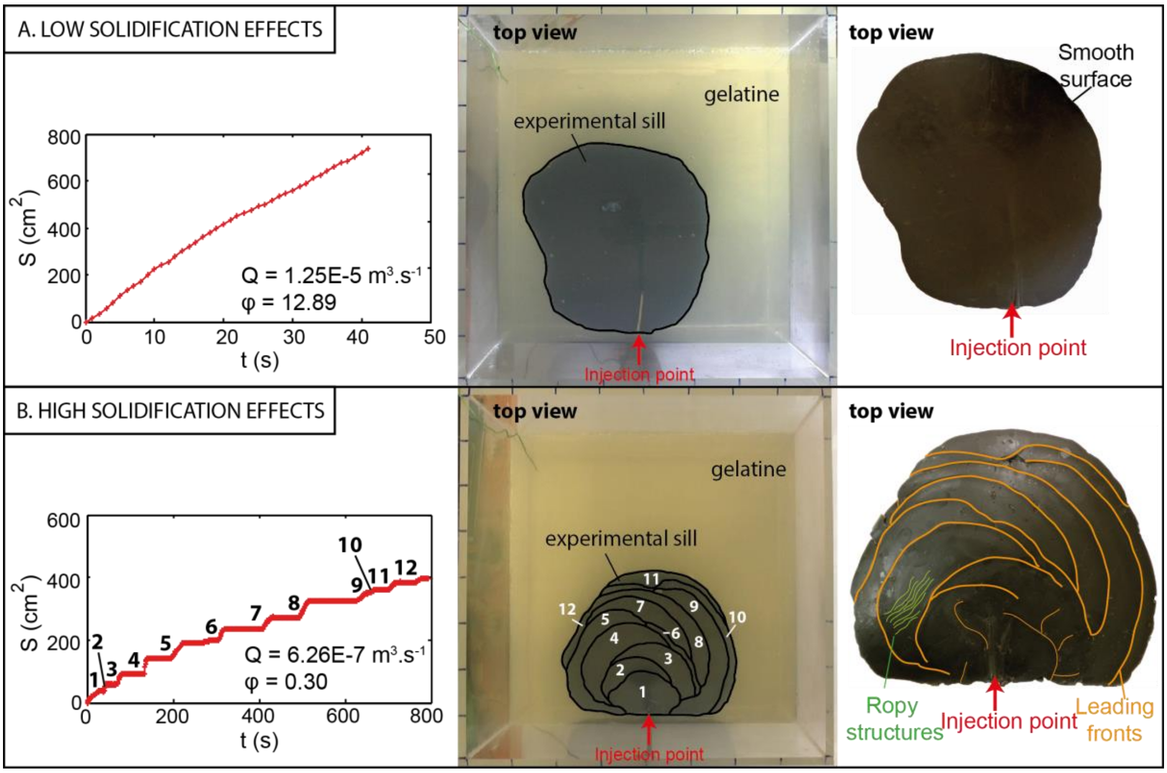

Figure 1: Presentation of the two end-members observed for the effects of solidification on sill intrusion.
(A) Example of an experiment with low solidification effects (high flux Q and dimensionless flux φ; φ is a Peclet number). Evolution of the area S with time t: continuous area creation and simple morphology (smooth surface).
(B) Example of an experiment with high solidification effects (low flux Q and dimensionless flux φ). Evolution of the area S with time t: 12 steps of area creation and complex morphology (ropy structures, imprints of the leading fronts).

These results have various geological and geophysical implications. Regarding the morphology of sills, 3D seismic studies in sedimentary basins reveal sills with lobate structures similar to those of lava flows. Our experiments show how these lobate structures could reflect the effect of magma solidification during their emplacement. Our experiments show also that a non-continuous morphology observed in the field may not necessarily imply multiple sill injections but could instead reflect a continuous, yet complex morphology induced by solidification effects during sill emplacement. Also, as for dykes, important solidification effects in sills will promote a discontinuous propagation associated with bursts of seismic activity, in agreement with the observed seismic activity that preceded the 2010 Eyjafjallajökull eruption. Finally, in restricting the lateral extent of sills, magma cooling and solidification are likely to impact directly the size of plutons constructed incrementally by amalgamated sills.