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Effects of ice-cap unloading on shallow magmatic reservoirs

Richard Bakker, Marcel Frehner, and Matteo Lupi
ETH Zürich, Geological Institute, Zürich, Switzerland (richard.bakker@erdw.ethz.ch)

One of the effects of global warming is the increase of volcanic activity. Glacial melting has been shown to cause visco-elastic relaxation of the upper mantle, which in turn promotes upwelling of magmas through the crust. To date, the effects of ice-cap melting on shallow (i.e., less than 10 km depth) plumbing systems of volcanoes are still not clear.

We investigate the pressure changes due to glacial unloading around a magmatic reservoir by combining laboratory and numerical methods. As a case study we focus on Snæfellsjökull, a volcano in Western Iceland whose ice cap is currently melting 1.25 meters (thickness) per year. Our approach is as follows: we obtain representative rock samples from the field, preform tri-axial deformation tests at relevant pressure and temperature (PT) conditions and feed the results into a numerical model in which the stress fields before and after ice cap removal are compared.

A suite of deformation experiments were conducted using a Paterson-type tri-axial deformation apparatus. All experiments were performed at a constant strain rate of 10^{-5} s^{-1}, while varying the PT conditions. We applied confining pressures between 50 and 150 MPa and temperatures between 200 and 1000 ˚C. Between 200 and 800 ˚C we observe a localized deformation and a slight decrease of the Young's modulus from 41 to 38 GPa. Experiments at 900 and 1000 ˚C exhibit macroscopically ductile behavior and a marked reduction of the Young's modulus down to 4 GPa at 1000 ˚C.

These results are used to construct a numerical finite-element model in which we approximate the volcanic edifice and basement by a 2D axisymmetric half-space. We first calculate the steady-state temperature field in the volcanic system and assign the laboratory-derived temperature-dependent Young's modulus to every element of the model. Then the pressure in the edifice is calculated for two scenarios: with and without ice cap. The comparison between the two scenarios allows us estimate the pressure variation due to ice-cap unloading.

Our results show that large pressure changes arise at the surface slopes of the volcanic edifice, potentially resulting in landslides, which in turn cause further unloading. Pressure drops due to ice-cap unloading in the magma chamber are in the order of 1 MPa for a shallow magma chamber at about 2 km depth, typical of Icelandic systems. This may be sufficient to alter the long-term equilibrium of the volcanic plumbing system, ultimately promoting dike intrusion and eventually volcanic activity.