Effects of rapid icecap melting on a shallow magma chamber: A multi-discplinary case study of Snæfellsjökull volcano, Western Iceland

Richard Bakker*, Matteo Lupi*, Marcel Frehner*
*ETH Zürich, ERDW, Geological Institute, Sonneggstrasse 5, CH-8092

The most dramatic effect of global warming is the water level rise due to rapid melting of ice sheets. However, recent studies suggest that accelerated glacial retreat and associated viscoelastic relaxation of the mantle may enhance upwelling of magmatic fluids through the litoshpere (e.g. Hooper et al., 2011). Here, we investigate whether, also at short geological timescales, shallow magmatic systems may be affected by rapid melting of ice caps. As a case study, we chose the Snæfellsjökull volcanic system in western Iceland, whose ice cap is rapidly melting with 1.25 $m_{w.e./}$year (Jóhannesson et al., 2011). To investigate the role of deglaciation in promoting volcanic unrest we use a cross-disciplinary approach integrating geophysical field data, laboratory rheological rock tests, and numerical finite-element analysis.

Initial results from seismic data acquisition and interpretation in 2011 show seismic activity (occasionally in swarm sequences) at around a depth range of 8–13 km (Fuchs et al., 2013), indicating the presence of a magmatic reservoir in the crust. In addition, a temporary seismic network of 21 broad-band stations has been deployed in spring 2013 and continuously collected data for several months, which will help better constrain the subsurface geometry.

During summer 2013 we collected samples of Tertiary basaltic bedrock from the flanks of Snæfellsjökull, which we assume to be representative for the subsurface volcanic system. Cores drilled from these samples were tri-axially deformed in a Paterson-type apparatus at a constant strain rate of 10^{-5} s^{-1}, a confining pressure of 50 MPa (i.e., ~2 km depth), and a temperature ranging from 200 °C to 1000 °C (i.e., various proximities to magma chamber). We observe a brittle ductile transition between 800 and 900 ˚C. From the obtained stress-strain curves the static Young's modulus is calculated to be around 35 (±2) GPa, which is not significantly influenced by increasing temperatures up to 800 °C. Beyond the elastic domain, cataclastic shear bands develop, accommodating up to 7% strain before brittle failure. In the ductile cases we observe a gradual hardening after an intial elastic phase.

The subsurface geometrical constraints from geophysical field data and the rheological parameters from laboratory testing are fed into a numerical finite-element model solving for the pressure in the magma chamber and the stress field in the surrounding basement rock before and after the retreat of an assumed 200 m thick ice cap. Preliminary results (see figure 1) show that ice unloading has two effects. First, it leads to significant stress release at shallow depths in the volcanic edifice, possibly resulting in a destabilization of the flanks, which in turn leads to further unloading of the volcanic cone by means of landslides. Second, the pressure change around the magma chamber is in the order of 0.5 MPa. This may be sufficient to induce volatile exsolution and accelerated pressurization of the magmatic reservoir, ultimately leading volcanic unrest, in particular in critically stressed environments prior to glacial retreat.

We point out ice cap melting as a possible mechanism for triggering volcanic unrest of shallow magmatic systems.

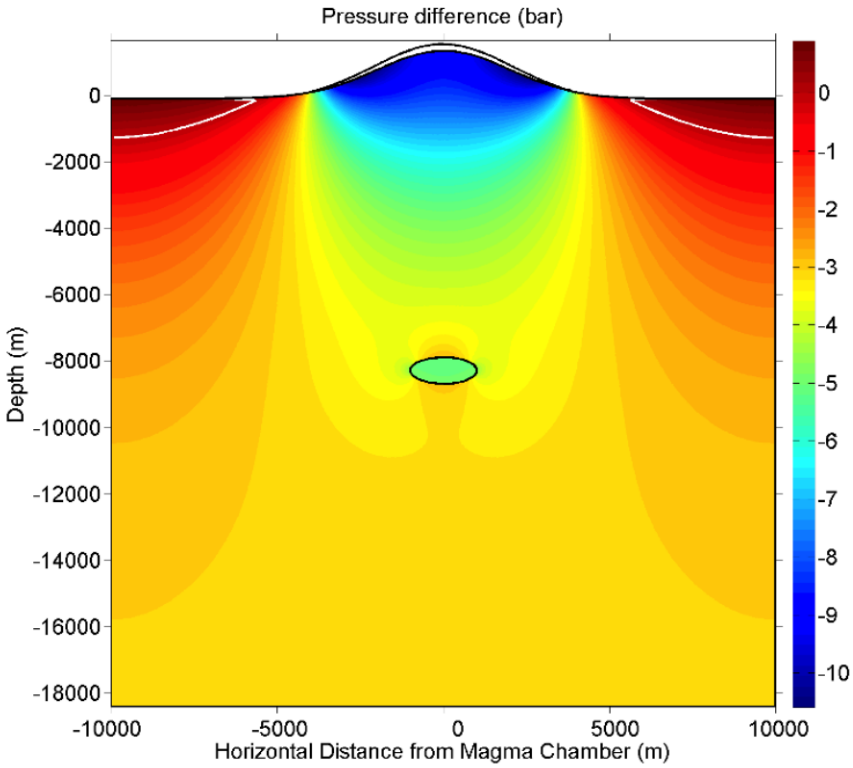

Figure 1. Calculated pressure difference inside the volcanic edifice. The white line illustrates the where the pressure difference is zero.

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