Post-eruptive volcano inflation following major magma drainage: Interplay between models of viscoelastic response influence and models of magma inflow at Bárðarbunga caldera, Iceland, 2015-2018

Siqi Li[1], Freysteinn Sigmundsson[1], Vincent Drouin[2], Michelle M. Parks[3], Kristín Jónsdóttir[3], Benedikt G. Ofeigsson[3], Ronni Grapenthin[4], Halldór Geirsson[1], and Andy Hooper[5]

[1]Nordic Volcanological Center, Institute of Earth Science, University of Iceland, Reykjavik, Iceland (sil10@hi.is)
[2]Iceland GeoSurvey (ÍSOR), Reykjavik, Iceland
[3]Icelandic Meteorological Office, Reykjavík, Iceland
[4]Geophysical Institute and Dept. of Geosciences, University of Alaska Fairbanks, Fairbanks, USA
[5]COMET, School of Earth and Environment, University of Leeds, Leeds, UK

Unrest at Bárðarbunga after a caldera collapse in 2014-2015 includes elevated seismicity beginning about six months after the eruption ended, including nine Mw>4.5 earthquakes. The earthquakes occurred mostly on the northern and southern parts of a caldera ring fault. Global Navigation Satellite System (GNSS, in particular, Global Positioning System; GPS) and Interferometric Synthetic Aperture Radar (InSAR) geodesy are applied to evaluate the spatial and temporal pattern of ground deformation around Bárðarbunga caldera outside the icecap, in 2015-2018, when deformation rates were relatively steady. The aim is to study the role of viscoelastic relaxation following major magma drainage versus renewed magma inflow as an explanation for the ongoing unrest.

The largest horizontal velocity is measured at GPS station KISA (3 km from caldera rim), 141 mm/yr in direction N47^{o}E relative to the Eurasian plate in 2015-2018. GPS and InSAR observations show that the velocities decay rapidly outward from the caldera. We correct our observations for Glacial Isostatic Adjustment and plate spreading to extract the deformation related to volcanic activity. After this correction, some GPS sites show subsidence.

We use a reference Earth model to initially evaluate the contribution of viscoelastic processes to the observed deformation field. We model the deformation within a half-space composed of a 7-km thick elastic layer on top of a viscoelastic layer with a viscosity of 5 x 10^{18} Pa s, considering two co-eruptive contributors to the viscoelastic relaxation: "non-piston" magma withdrawal at 10 km depth (modelled as pressure drop in a spherical source) and caldera collapse (modelled as surface unloading). The other model we test is the magma inflow in an elastic half-space. Both the viscoelastic relaxation and magma inflow create horizontal outward movements around the caldera, and uplift at the surface projection of the source center in 2015-2018. Viscoelastic response due to magma withdrawal results in subsidence in the area outside the icecap. Magma

inflow creates rapid surface velocity decay as observed.

We explore further two parameters in the viscoelastic reference model: the viscosity and the "non-piston" magma withdrawal volume. Our comparison between the corrected InSAR velocities and viscoelastic models suggests a viscosity of 2.6×10^{18} Pa s and 0.36 km^3 of "non-piston" magma withdrawal volume, given by the optimal reduced Chi-squared statistic. When the deformation is explained using only magma inflow into a single spherical source (and no viscoelastic response), the optimal model suggests an inflow rate at 1×10^7 m^3/yr at 700 m depth. A magma inflow model with more model parameters is also a possible explanation, including sill inflation at 10 km together with slip on caldera ring faults. Our reference Earth model and the two end-member models suggest that there is a trade-off between the viscoelastic relaxation and the magma inflow, since they produce similar deformation signals outside the icecap. However, to reproduce details of the observed deformation, both processes are required. A viscoelastic-only model cannot fully explain the fast velocity decay away from the caldera, whereas a magma inflow-only model cannot explain the subsidence observed at several locations.