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Ground deformation following a caldera collapse: Contributions of viscoelastic response and magma inflow to 2015-2018 deformation field around Bárðarbunga, Iceland

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Recent activity of Bárðarbunga caldera and measurements of ground deformation around the volcano provide an opportunity to study volcano behavior following a major caldera collapse. During the 2014-2015 eruption, the 11 × 8 km elliptical Bárðarbunga caldera collapsed over a 6-month period and subsided by 65 meters, while a total of about 1.5 cubic kilometers of lava erupted in the Holuhraun area. We interpret observed deformation after the eruption in terms of a viscoelastic response to caldera collapse and magma withdrawal, as well as renewed magma inflow.

Elevated seismicity within the Bárðarbunga caldera has been observed since December 2015, including seven Mw > 4.5 earthquakes. Global Positioning System (GPS) and Interferometric analysis of Synthetic Aperture Radar (InSAR) data show uplift and horizontal displacement radially away from the caldera in 2015-2018. The largest horizontal velocity is measured at GPS station KISA (3 km from caldera rim), 141 mm/yr in direction N47°E relative to the Eurasian plate. InSAR observations show that deformation velocity decays significantly with distance; a profile extending from 2 to 13 km from the caldera rim indicates a rapid decay in the eastward direction from 59 mm/yr to 5 mm/yr. After corrected for Glacial Isostatic Adjustment and plate spreading signal from our observation, the remaining signals for both GPS and InSAR indicate subsidence at some surrounding areas.

We use numerical models to evaluate the contribution of three processes to the observed deformation field: 1) viscoelastic response to surface unloading caused by the caldera collapse, 2) viscoelastic response to magma withdrawal at 10 km depth during the eruption, modelled as a pressure drop in a spherical source, and 3) magma inflow after the eruption. We model the deformation within a half-space composed of a 7 km thick elastic layer on top of a viscoelastic layer with 5×10^{18} Pa s viscosity. Each of the aforementioned processes create horizontal outward movement around the caldera, and uplift at the surface projection of the source center in our study period. The viscoelastic response to surface unloading and magma inflow following the eruption generates only uplift in all the surrounding areas. Magma inflow can create the rapid surface velocity decay as observed. A viscoelastic response due to magma withdrawal results in subsidence in the area outside the icecap. Our study suggests that the viscous response to large-scale mass removal at depth can create inflation-like deformation fields without the direct addition of new melt to the system. We set up a joint model incorporating all three sources parameterized to fit our deformation observations. Nonetheless, just the viscoelastic response from both surface unloading and magma withdrawal at depth cannot recreate the observed spatially rapid velocity change in the models tested. Our study provides an improved understanding of the deformation that follows caldera collapse and major magma movements and, furthermore, improves interpretation of deformation signals generated through a combination of viscoelastic responses to surface unloading and magma withdrawal, as well as renewed melt supply.