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Viscoelastic crustal deformation in the Aira caldera before and after the 1914 eruption of the Sakurajima volcano

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Long-term volcano deformation cannot be well understood without considering crustal viscoelasticity because the presence of magma is expected to significantly lower the crustal viscosity beneath volcanoes. In this study, we examine viscoelastic crustal response to continuous magma supply into the upper crust and its sudden discharge. We use a three-dimensional (3-D) finite element model composed of an elastic layer underlain by a linear Maxwell viscoelastic layer with spatially uniform viscosity, in which a sill emplaced at the bottom of the elastic layer inflates with constant rate, during which the deflation due to an eruption suddenly occurs. Our numerical experiment finds that viscoelastic response to the sill deflation causes post-eruption surface uplift, depending on how much viscoelastic relaxation progresses in response to sill inflation due to pre-eruption magma supply and how much the sill deflates during the eruption. However, the recovery of the post-eruption surface is always later than that of the sill volume, because the viscoelastic response to the sill inflation reduces the surface uplift. Magma recharge is required to bring the surface to the elevation that was at immediately before the eruption. We adopt our viscoelastic model to geodetic data in and around the Aira caldera, southern Kyushu, Japan. It is found that the observed exponential-like surface recovery after the 1914 eruption can be explained if: (1) The effective crustal viscosity is $\approx 5 \times 10^{18}$ Pa s, (2) the sill emplacement, whose equatorial radius is ≈ 2 km, occurs at a depth of ≈ 11 km, (3) a constant inflation rate of the sill is ≈ 0.009 km³/yr, which has continued since ≈ 50 yr before the 1914 eruption, and (4) the sill deflates by ≈ 0.4 km³ during the 1914 eruption, ≈ 4 times less than the eruptive volume. The sill inflation during the first ≈ 50 yr after the eruption is lower than that predicted by an elastic model, but larger thereafter. Fit to geodetic data after ≈ 1975 can be improved by introducing temporal variation of the inflation rate, which is a topic of investigation for a future study.