The problem of determining magma chamber depths under calderas

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Abstract

Volcanoes usually inflate or deflate due to activities of underlying magma bodies. Revealing by space-borne radar interferometry, several deforming calderas (e.g., Wolf and Fernandina, Galápagos; Bardarbunga, Iceland; Piton de la Fournaise, Réunion) show similar superimposed patterns of ground deformation. These patterns often consist of a broad deflation signal affecting the entire edifice and a localized subsidence signal focused within the caldera. While analytical and numerical models with multiple magma chambers at different depths have typically been used to explain these signals, ring-faults and other structures beneath the calderas have usually been ignored in the modeling. This raises questions about how realistic models of multiple magma chambers are, even though they may be able to reproduce the observed deformation patterns.

We explore alternative mechanisms that can produce the observed superimposed deformation patterns. Using two complementary methods, we study the three-dimensional geometry and kinematics of caldera deflation processes evolving from an initial downsag subsidence to later collapses. First, we analyze analog experiments with structure-from-motion photogrammetry (SfM) and particle image velocimetry (PIV) to relate surface deformation to subsurface structures. Second, we use numerical modeling based on the boundary element method (BEM) to characterize the sources that can produce the observed deformation patterns.

Our results show that the broad deflation is mainly caused by the depletion of a deep magma chamber, whereas the buried ring-fault activities to a large extent affect the deformation localization in the caldera. Since there is clear evidence for ring-faulting at several subsiding calderas, we highlight its key role in shaping the observed deformation. Ignoring ring-faulting in models of subsiding calderas and instead using multiple point/sill-like sources will result in erroneous estimates of magma chamber depths and volume changes.

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