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Exploring the interior of an active volcano with deformation models

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The migration of restless magma within an active volcano produces a deformation signature at the Earth's surface. The internal structure of a volcano and specific movements of the magma control the actual deformation that we observe. Data from radar satellites can map this deformation for an entire volcanic system and ground-based seismic instruments can image the internal structure. Deformation models simulate this internal structure, subjected to the forces of magma movements, and provide the quantitative linkage between the observed surface deformation and the movements of magma at depth. Satellite radar data indicate that Okmok volcano, Alaska, subsided more than a meter during its eruption in 1997. The deformation pattern suggests magma extraction from a shallow reservoir. New seismic tomography reveals two weak zones within Okmok. The shallow weak zone corresponds to a region of fluid-saturated rock that extends from the caldera surface to a depth of 2 km. The deep weak zone indicates the presence of the magma chamber at a depth of about 4 km. We construct finite element models (FEMs) to simulate deformation caused by magma extraction from a chamber that is surrounded by a viscoelastic rind of country rock. Thermal models define the brittle-ductile transition and thickness of the viscoelastic rind. This assemblage, which represents the deep weak zone, is embedded in an elastic model domain that includes a shallow weak zone filling the caldera. Because the predicted surface deformation is the combined elastic and viscous response to magma extraction, these viscoelastic FEMs reduce the required magma chamber depressurization (compared to strictly elastic models) to within lithostatic constraints, while simultaneously predicting the magnitude and pattern of deformation observed with satellite radar data. More precisely, the satellite radar data are best predicted by an FEM simulating a rind viscosity of 7.5×10^{16} Pa·s and a magma flux of -4.2×10^{9} kg/d from the magma chamber. Additionally, the shallow weak zone provides a co-eruption stress regime and neutral buoyancy horizon that support lateral magma propagation from the central magma reservoir to the observed lava extrusion near the rim of the caldera.