Rheologic and Topographic Controls on Deformation Due to a Shallow Magma Reservoir

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Abstract

Introduction: Surface deformation is a phenomenon commonly observed in connection with volcanic unrest. Most deformation models approximate the model volume as a linearly elastic, homogeneous half-space, with point sources of pressure. The point source estimation breaks down when the reservoir is shallow, and the presence of heterogeneous materials and high temperatures in volcanic regions affects the rheological behavior of the medium surrounding the magmatic source.

At Kilauea Volcano in Hawaii, repeated ground deformation is measured using ground and space based geophysical methods. The repeating deformation is thought to be caused by cycles of pressurization in a shallow (~ 1 km depth), well-established magma reservoir. However, the extreme topography of the caldera, the thermal effect of the reservoir and the proximity of the reservoir to the surface mean that traditional models may not be appropriate.

Use of COMSOL Multiphysics®: To assess the control of varying rheology and topography on surface deformation due to a shallow magma reservoir, a 3D finite element model was constructed using COMSOL Multiphysics®. The model geometry includes topography from high-resolution digital elevation models with anchored features for areas needing a finer mesh. Solutions of surface deformation and stress distribution due to a spherical pressurized body will be compared for different rheologies including homogeneous and heterogeneous elastic, heterogeneous viscoelastic and temperature dependent viscoelastic media. The effect of the depth and size of the reservoir will also be tested in each case.

Results: Preliminary results using a homogeneous elastic medium show that sharp topography can deflect the deformation field and hence produce misleading tilt vectors, as has been observed in monitoring data at Kilauea Volcano. It is expected that this effect will be less pronounced with a deeper pressurization source. The surface deformation is also affected by including a visco-elastic rind around the spherical pressurized body or a viscoelastic caldera fill embedded in the elastic medium. The resulting surface deformation from the former of these geometries is also expected to be less pronounced with a deeper pressure source but, in contrast, the latter geometry may cause the effect to accumulate over a greater distance and therefore, the expected difference in deformation may become more pronounced with a deeper magma reservoir.

Conclusion: The use of high-resolution topography in the finite element model has demonstrated

that deformation from a shallow pressure source can be dramatically affected by overlying relief, not only in magnitude, but also in azimuth. This result is significant as it allows traditionally anomalous data to be evenly weighted during inversions for magma reservoir parameters.

The result that surface deformation may be either enhanced or subdued by varying the rheology of the medium in the model has profound consequences for the estimation of the depth and pressurization of a magma reservoir from field data. It means that the rheological properties must be well known for the estimations of depth and pressurization to be meaningful.