Visco-elastic relaxation in volcano deformation

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Satellite-based observation (GPS and/or InSAR) has precisely measured surface deformation, but by itself does not derives a mechanism of the deformation. We therefore need to employ some theoretical model in order to understand characteristic deformation pattern for a given source mechanism, only based on which the deformation source mechanism can be objectively deduced from the observation. Magmatic activity in depth is particularly considered as the source mechanism in this study. We employ a parallelized 3-D finite element code, OREGANO_VE [e.g., Yamasaki and Houseman, 2015, J. Geodyn., 88, 80-89], to solve the linear Maxwell visco-elastic response to a given internal inflation/deflation of magma chamber. In a rectangular finite element model domain, the crust is mechanically two-layered, in which an elastic layer with thickness of H is underlain by a visco-elastic layer, but the entire mantle behaves as visco-elastic material. A depth-dependent viscosity (DDV) is adopted for the visco-elastic crust, where the viscosity exponentially decreases with depth due to temperature-dependency: hc = h0 exp[c(1 - z/L0)], where h0 is the viscosity at the bottom of the crust, c is a constant; c > 0 for DDV model and c = 0 for uniform viscosity (UNV) model, z is the depth, and L0 is a reference length-scale. The visco-elastic mantle is contrarily assumed to have a spatially uniform viscosity hm. A sill-like magma chamber is approximated as a spheroid, and it inflation/deflation is implemented by using the split node method developed by Melosh and Raefsky [1981, Bull. Seism. Soc. Am., 71, 1391-1400]. We first employ UNV model with c = 0, which shows that visco-elastic relaxation abates the inflation-induced surface uplift with time; The post-inflation subsidence would erase the uplift in ~ 50 - 100 times Maxwell relaxation time of the crust unless the inflation occurs within the uppermost elastic layer. The rate of the subsidence is governed by a depth of the inflation and the equatorial radius of the sill; but the latter is not important for the earliest post-inflation period. Time-dependent inflation always accompanies with visco-elastic relaxation, and any significant surface uplift is not expected if the inflation has occurred over the time-scale greater than ~ 50 - 100 times crustal relaxation time. DDV model with c > 0 is also employed in this study to examine how a spatio-temporal deformation pattern at the surface is deviated from that for UNV model. The predicted model behaviour shows that UNV model behaviour approximates DDV model behaviour, but the apparent UNV which best fits a DDV displacement history depends on distance from the centre of the inflation; smaller viscosities are required at greater distances from the centre of the inflation. Such a model behaviour would expect that the spatio-temporal ground movement also depends on the depth of the sill inflation. Furthermore, a UNV model behaviour that the post-inflation subsidence depends on the thickness of the uppermost elastic layer requires us to examine the DDV model behaviour in terms of an effective elastic thickness for a given DDV structure. The model predictions obtained in this study provide important insights into geodetically detectable ground movement in volcanic provinces.

Keywords: Volcano deformation, Visco-elastic relaxation, Maxwell relaxation time

