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The effects of depth-dependent crustal viscosity variation on visco-elastic response to inflation/deflation of magma chamber

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Development of the satellite observations (GPS and/or InSAR) has allowed us to precisely measure surface deformation. However any geodetic observation by itself does not tell us a mechanism of the deformation. All we can do the most is to compare such an observation to some quantitative predictions, only from which we can deduce a possible deformation mechanism. We therefore need to understand characteristic deformation pattern for a given source mechanism. This study particularly pays attention to magmatic activity in depth as the source, aiming to distinguish magma-induced crustal deformation by better knowing how the activity can be reflected in geodetically observable surface deformation. A parallelized 3-D finite element code, OREGANO_VE [e.g., Yamasaki and Houseman, 2015, J. Geodyn., 88, 80-89], is used to solve the linear Maxwell visco-elastic response to an applied internal inflation/deflation of magma chamber. The rectangular finite element model is composed with a visco-elastic layer overlaid by an elastic layer with thickness of H, and the visco-elastic layer extends over the rest of crust and the uppermost mantle. The visco-elastic crust has a depth-dependent viscosity (DDV) as an exponential function of depth due to temperature-dependent viscosity: 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 has a spatially uniform viscosity hm. The inflation and/or deflation of sill-like magma chamber is implemented by using the split node method developed by Melosh and Raefsky [1981, Bull. Seism. Soc. Am., 71, 1391-1400]. UNV model with c = 0 employed in this study shows that the inflation-induced surface uplift would abate with time by visco-elastic relaxation. The post-inflation subsidence would erase the uplift in $\sim$ 50 - 100 times Maxwell relaxation time of the crust unless the inflation occurs within the uppermost elastic layer. Time-dependent inflation always accompanies with visco-elastic relaxation, and accordingly the inflation, having occurred over the time-scale greater than $\sim$ 50 - 100 times crustal relaxation time, provides insignificant surface uplift. DDV model with c > 0 is then also employed in this study, by which it is attempted to examine how a spatio-temporal deformation pattern is deviated from that for UNV model. Furthermore, a UNV model behaviour, that the post-inflation visco-elastic relaxation depends on the thickness of the uppermost elastic layer, motivates us to examine what controls the effective elastic thickness for a given DDV structure. The DDV model predictions certainly help us to understand the mechanism of complex crustal deformation in volcanic provinces in more systematic way.