Viscoelastic relaxation: A mechanism to explain the decennial large surface displacements at the Laguna del Maule silicic volcanic complex

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Silicic systems generate the most explosive eruptions on Earth. In contrast to basaltic systems, they can accumulate large volumes of magma without systematically erupting, confronting the classical interpretation that a volcano inflates when a magmatic intrusion occurs. Understanding the mechanisms of volcanic inflation and unrest is thus one of the most important challenges in volcanic risk assessment. Laguna del Maule (LdM) in the Southern Volcanic Zone (SVZ) of Chile, is one of the most active Holocene silicic complexes in the world and it has been inflating since 2007, accumulating 2 m of uplift without erupting. Several geophysical and geochemical studies conclude that a large crystal rich reservoir would be residing beneath LdM, in consistency with other multi-disciplinary studies showing that such crystal-rich reservoirs (?mush zones?) can be maintained beneath silicic volcanoes, fed by mafic magma recharge from below. Nevertheless, the mechanical state of such reservoirs remains unclear. Here, we characterize for the first time the mechanical properties of such a mush reservoir, able to promote large surface displacements such as those measured at LdM. Using a 3D finite element method we simulate a recharge of magma at the base of a crystal rich reservoir, by assuming an overpressurized source surrounded by a large viscoelastic shell. Inversion results show that this model fits the observed temporal and spatial evolution of ground displacements measured with InSAR data and GNSS data between 2007 and 2017. We interpret the temporal behavior of ground displacement at LdM as resulting from two contributions. A magma recharge occurred within the first 4 yr of the active inflation, followed by the viscous response of the large viscoelastic shell, set to a viscosity of 1017 Pa s. Compared to a purely elastic solution, our model suggests that up to 50% of the accumulated surface displacement during the ten-year period can be explained by this viscous response, and predicts ongoing displacements 50 yr after the onset of inflation. This model agrees with geophysical and geochemical observations and offers a simple explanation of the temporal evolution of surface displacements. It further allows to reconsider the mechanical behavior of large partially crystallized domains in the upper crust; such significant transient stress transfer over large viscoelastic areas should thus be accounted for in other studies of silicic volcanic complexes.