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Influence of surface load variations on shallow magma storage zones: Application to Icelandic subglacial volcanoes

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Many types of surface change occurs at volcanoes in addition to eruptive activity, such as flank instability and landslides, load variations and Earth tides. These events cause stress perturbations in the crust, which can perturb the shallow magma storage zone below the volcanic edifice. The resulting stress changes act on the stability of the magma reservoir by promoting or preventing the initiation of magmatic intrusions from the reservoir. Here, we first investigate how unloading events at surface modify failure conditions of magma reservoirs. Stress perturbations induce a variation of the threshold pressure required for dyke initiation but also a magmatic pressure change inside the reservoir. Influence of surface events on reservoir stability will be thus determined by the interplay between these two pressure changes. In order to calculate both parameters, numerical calculations are performed for axial mechanical models where an elliptical compressible reservoir is embedded in an elastic medium. From a parametric study, we conclude that results are highly dependent on the reservoir shape as well as the surface load distribution.

Magmatic intrusions are promoted in the case of spherical or horizontally elongated reservoirs whereas there are prevented for vertically elongated reservoirs. The triggering effect will be also enhanced if the reservoir is filled by highly compressible magma. We apply our model to two Icelandic subglacial volcanoes: Katla and Grimsvötn. Katla is covered by the thick Myrdalsjökull icecap, which produces two temporal load variations: a seasonal change due to the annual accumulation/melt of snow and long-term ice thinning due to global warming. Our model predicts that initiation of dykes is more likely in summer when the seasonal snow cover is smallest. This result appears consistent with the fact that all the nine last historical eruptions at Katla occurred during the warmer period. For long-term effect associated to ice retreat, our elastic model predicts that intrusions are prevented. However, in this case, visco-elastic, related to the relaxation of the lower crust and upper mantle in response to long-term thinning, needs to be considered. At Grimsvötn volcano, we have studied the effects of glacial outburst floods (jökulhlaups) associated with sudden discharge from the subglacial caldera. Such events have immediately preceded some eruptions, like in 2004. The unloading appears to able to trigger eruptions when pressure in a shallow magma chamber under Grimsvötn is high. The most recent jökulhlaup was, however, not associated with eruption, despite inferred relatively high magma pressure in a shallow magma reservoir under Grimsvötn.