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Computer simulation of time-dependent magma ascent processes: bubbly and gassy flows

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Computer simulation of magma ascent processes has an increasing importance for integrating the knowledge about various features and elementary processes of volcanic eruptions and for establishing a comprehensive understanding of eruptions. Based on a new formulation of horizontal permeable gas migration, I have made some simulation of time-dependent bubbly magma flow and predicted that an eruption should be explosive or effusive when a dimensionless degassing factor proportional to the permeability and viscosity of magma is smaller or greater than a critical value (Y. Ida, J. Volcanol. Geotherm. Res., 162, 172-184, 2007). More recently, the analysis has been developed so as to include a gassy flow that arises above the bubbly flow as a result of magma fragmentation, as is described below.

In the simulation we employ a simple criterion that magma fragmentation should occur at the critical gas volume fraction of 75 %. Since the time scale of gassy flow is very short we assume that the gassy flow may be in a quasi-static state corresponding to each condition of the underlying bubbly flow that varies with time. This assumption greatly simplifies the simulation scheme even if it excludes descriptions of such fast phenomena as propagate at the sound-wave or shock-wave velocity. In gassy flows the wall friction is significantly reduced, compared with bubbly flows, while the inertia term cannot always be neglected any longer. These two factors actually turn out to give apparently similar effects on the magma flow.

According to the simulation, gassy flows that may induce explosive eruptions have significantly greater particle velocities at the surface than bubbly flows that may effuse as lava. Deeper magma flow incoming from the conduit bottom is also significantly enhanced as soon as the gassy flow begins to erupt from the surface. The magma flow is thus enhanced over the whole conduit because the pressure gradient in the bubbly follow zone increases so as to compensate a reduced pressure gradient in the gassy flow zone resulting from a reduced wall friction. Such a peculiar pressure distribution allows much more magma than has accumulated in the magma chamber to effuse from the surface. The eruption thus can make large underground vacant space that may possibly lead to a surface subsidence and even a caldera formation above the chamber.

During an explosive eruption lasts the particle velocity of gassy flow decreases with discharge of magma from the chamber and the eruption suddenly stops when the velocity becomes sufficiently small. The stop of eruption seems to occur when the interface between bubbly and gassy flows becomes unstable. The eruption is expected to start again, however, because deeper magma supply from the chamber still continues. The intermission of eruptive activities that is often observed in real explosive eruptions may be thus explained by the instability of gassy flow.