Simulation of non-stationary magma ascent: release of gas components and eruption types

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A simple computer program to calculate non-stationary magma flow has been developed as the first step toward a practically usable simulator of volcanic eruptions. A one-dimensional model that treats the vertical flow velocity and all other variables averaged over the cross-section of the conduit at each depth is employed for the calculation. The model assumes a simple phenomenological relation that describes release of gas component from the magma in terms of the volume fraction of gas phase in the magma. The inertia term and the relative motion between the gas and liquid phases are neglected in the equation of motion. The conduit is connected at its bottom to a magma chamber. The conduit is first filled with magma free from gas and then supplied with magma containing a prescribed amount of the gas component from the chamber after the magma begins to flow upward.

The simulation gives spatial distribution of flow velocity, volume ratio of gas phase and all other variables in the conduit as a function of time. Where amount of the gas component exceeds its solubility, bubbles form in the magma and the bubbly zone expands upward with ascending flow. If the parameter of gas release is chosen so as to keep most of the gas component from escaping from magma, bubbles occupies major volume of magma near the top of the conduit so that the flow may lead to an explosive eruption with fragmented magma. In contrast, the magma flow with substantial release of gas components allowed during the ascent restricts bubbles to minor volume in the bubbly zone so that it may cause a non-explosive lava effusion. In this way, the simulation represents both explosive and effusive eruptions. It is noted that these two types of eruptions are produced by relatively small difference of the gas release condition. This is interpreted to reflect a feedback effect between ascent motion and gas release. Namely, once release of gas is effective enough to slow the ascending velocity down through decrease of buoyancy, the release is further enhanced with a longer stay of magma in the conduit.

When the pressure at the bottom of the conduit is kept constant, the magma flow finally attains to a stationary state. When the conduit is connected at the bottom to a magma chamber with finite capacity, the flow finally ceases after accumulated magma in the chamber is gone. In this case, the initial pressure of the magma chamber, which may reflect how much the magma system endures pressure increase associated with magma accumulation, plays an important role. If the initial pressure is relatively low, magma in the chamber is exhausted before the bubbly zone reaches the top of the conduit. This may represent an underground activity of magma that is enhanced temporarily but terminated without surface eruptions. If the initial pressure is a little higher, the bubbly zone reaches the surface but substantial bubbles in it are lost during a slow ascent. This process should lead to an effusive eruption. For the initial pressure more enhanced, the eruption caused by the flow is explosive with major part of bubbles kept in a fast flow up to the top of the conduit. In this way, non-eruptive, effusive and explosive activity of magma is predicted to take place following a rather small difference of the initial condition.