Numerical simulations of magma intrusion into crust near the surface by means of discrete element method

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We employed the software PFC2D (Particle Flow Code in 2 Dimensions) based on the discrete element method and attempted to simulate magma intrusion into crust near the surface. Although behaviors (e.g., initiation of a shallow magma chamber and formation of a sill) of the intruded magma depend on various factors, here we paid attention to the intrusion magma velocity, which reflects overpressure conditions.

In discrete element modeling, all materials are approximated as assemblies of many particles, and each particle is connected by two elastic springs (having normal and shear stiffness). In addition, "contact bond" parameters for determining the strength of material (rock) must be set between all adjacent particles. By trial and error, these parameters are determined by biaxial test in a computer. A Young modulus of 16 GPa and a Poisson ratio of 0.21, as elastic constants of the surface crust, and viscosities in range of 10^7 - 10^{10} Pa s, for middle-high viscous magma, were assumed in this study. The normal and shear contact bonds for intruded magma were not set in order to maintain fluidity.

Before applying the above-mentioned magma model to simulations of magma intrusion into the crust, extrusions to the surface of these magma were simulated in order to confirm whether the magma model behaves realistically. As a result, it was shown that the shape of extruded magma (lava) depends on the viscosity of the magma and its flow velocity in the conduit. The high viscous magma makes a lava dome at the surface and its interior structure is distorted concentric circle patterns. These structures due to the high viscous magma have been simulated by some analogue experiments. From these pre-simulation results, it was concluded that the developed magma model was suitable for simulations of magma intrusion.

As a preliminary simulation model for magma intrusion, we modeled the surface crust by a rectangle of width and depth 5 and 1.6 km, respectively. The radius and density of the particles constituting the model crust were assumed to be 4.8 - 6.4 m and 2500 kg/m^3, respectively. The radius and density of the particles constituting the model magma were assumed to be 0.8 - 0.96 m and 2200 kg/m^3, respectively, and a probable intrusion velocity was given to the particles. The volume of the intruded magma was set to 2 10^5 m^3 in all simulations. As a result, it was found that the shape of the intruded magma was circular at an initial stage of intrusion, and that this initial shape did not depend on the intrusion velocity. However, the subsequent change in the shape over time did depend on the velocity. A low velocity made the intruded magma become elliptical, elongating upward and deforming the surface greatly over a wide area. In contrast, a high velocity made the magma intrude into a circular shape, the lower parts of which elongated sideways, or in a rounded triangular shape.

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