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Fragmentation mechanism of bubbly-magma and two pressure conduit model

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Explosive volcanic eruptions are characterized by magma fragmentation, that is, the process through which the bubbly magma is transformed into the gas-pyroclast dispersion. There are some models for magma fragmentation. In the first model, the magma behaves as a Maxwell body and is fragmented when the strain rate exceeds a critical value. In the second model, bubbles disrupt when the tensile hoop stress on the bubble walls exceeds the tensile strength of magma. This model is based on the fact that the magma pressure fails down though the gas pressure in bubbles remains high as the bubbly-magma ascends. In the third model, the magmapressure becomes negative due to the rapid decompression and the magma suffers tensile force. It is not known which type of fragmentation actually occurs in the conduit.

We numerically study the bubbly-magma flow dynamics with the bubble growth in the conduit and investigate how the fragmentation occurs depending on the various parameters such as the magma viscosity, the initial flow velocity from the magma reservoir, and the gas mass fraction. We assume that the gas and the magma ascend with the same velocity, that all bubbles are the same size, and that the flow is one-dimensional, steady, and isothermal. The one-dimensional spherical cell model with viscous magma is used for bubble growth. The basic equations are expressed by simultaneous ordinary differential equations. We numerically integrate these equations using fourth-order Runge-Kutta method and change the magma viscosity(10 kPa s-100 MPa s), the initial flow velocity from the magma reservoir(1-20 m/s), and the gas mass fraction(0.03-0.05). We take the effects of the elasticity into account treating the magma as a Maxwell visco-elastic body when the strain rates are large.

Results show that as the flow ascends, the pressure difference between the gas and the magma increases and the viscous hoop stress increases in proportion to the flow strain rate. Near the choking condition where the flow velocity increases as large as the sound velocity, the strain rate and the hoop stress abruptly become large and the magma pressure becomes negative; the three fragmentation conditions are satisfied in a narrow region. It is notable that in the two pressure model the increase of the strain rate is limited in the case of large viscosity while the strain rate increases in an infinitely narrow region to an infinitely large value in the one pressure model where the gas-magma pressure difference is neglected. This is because a part of the kinetic energy is converted into the viscous energy around bubbles and the potential energy of gas compressibility in the two pressure model. In the case of small gas mass fraction, the increase of the strain rate is reduced. The magma pressure can become negative in the case of large viscosity because the gas-magma pressure difference increases in proportion to the magma viscosity while the the mean pressure is determined by the momentum conservation law independent of the viscosity. Therefore the negative magma pressure criterion and the bubble rupture one are correlated. Consequently, in the case of high viscous, high initial velocity, and low gas mass fraction, the fragmentation criterion of the bubble rupture or the negative magma pressure are reached earlier than the strain rate one. This conclusion does not depend on the initial bubble size. Furthermore, we found that the elasticity reduces the increase of the hoop stress. This effect is remarkable in the case that the viscosity is small and the bubble size is large, i.e., the strain rate criterion is expected to play a significant role in fragmentation of low viscosity magmas.