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Analysis of eruption sequences based on a model of magma plumbing system: Effects of variable magma temperatures

Yoshiaki Ida[1*], Jun Oikawa[2]

[1]Advance Soft Co., [2]Earthquake Res. Inst., Univ. of Tokyo

How the magnitudes and time intervals of volcanic eruptions are determined is one of the basic problems for better understanding of eruption mechanism as well as eruption prediction. We intend to analyze this problem based on a simple model of magma plumbing system. Our main interest is to find physical factors that control eruption sequences. The analysis is based on a model of magma effusion that formulates the opening and closure of an exit conduit through viscous deformation of the ambient country rock responding to magma pressure (Ida, GRL, 23, 1457-1460, 1996). Using this mechanical model, we showed last year how much varieties of eruption sequences are generated under periodic supplies of magma flux, but calculated eruption sequences were not variable enough to compare with natural eruptions. So we here study the problem taking the effect of changing magma temperature into account.

The model used in this analysis consists of a magma chamber with variable pressure and an attached exit conduit with variable radius. Magma pressure in the chamber elastically responds to the supply and emission of magma compared with its capacity, and the exit conduit opens and closes through viscous deformation of the ambient country rock following pressure change. The magma flux that flows out in the exit conduit is determined as a continuous function of time by solving a set of simple ordinary differential equations but the flux is actually concentrated into some points of short time intervals so as to give effectively discrete episodic eruptions. We further consider the thermal effect in which heat is lost from the magma chamber by thermal conduction. The magma temperature is determined by the balance between conductive heat loss and mixing of supplied hot magma and influences the magma outflow process through the temperature dependent magma viscosity.

For a constant magma supply rate the calculated magma temperature converges on a certain value that balances cooling effect with magma supply so that the thermal process little affects manners of magma effusion. When the supply changes periodically the magma temperature follows the supply with a delay associated with thermal conduction and influences the effusion process. Time intervals between eruptions as well as erupted masses of individual eruptions change in various ways, fluctuating sometimes periodically and sometimes with their gross long-term variations. Magma temperature changes more moderately over the eruption sequences. Features of eruption sequences sensitively reflect the period of magma supply and the efficiency of thermal conduction.

The calculation result in smaller time scales shows detailed natures of magma supply during individual eruptions. The supply history in an eruption gives an almost symmetric curve before and after the peak. Namely, supplied magma flux increases to the peak in a certain time and decreases to the end in an almost same time. Within the same eruption sequences the duration of an eruption tends to be shorter as the erupted mass is greater. Magma temperature increases a little during an eruption but its change is small.

Because real eruptions occur in a quite variable way it is not easy to find common natures of eruptions empirically. In most volcanoes available data of eruption histories are too poor to draw some definite conclusions on statistical natures of eruptions. Our analysis may help to reduce such difficulties.

Keywords: volcanic eruption, eruption sequences, magma temperature, magma chamber, magma plumbing system, computer simulation