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What controls time intervals between volcanic eruptions: Analysis using a magma plumbing model

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How long a volcano pauses between eruptive events is a fundamental question for understanding of eruption mechanism and prediction of volcanic eruptions. Eruptions sometimes happen almost regularly with a constant time interval. During the last one hundred years, for instance, Usu volcano erupted about every thirty years and Miyakejima did about every twenty years, informing us about an approximate time of coming eruptions. Even in these two volcanoes, however, natures and magnitudes of eruptions have changed every event and the periodicity of eruptions was sometimes greatly disturbed in earlier events. Furthermore, many of other volcanoes show no evidence for periodic occurrences of eruptions.

Some volcanoes like Kilauea and Etna have frequently erupted with abundant records of when eruptive events happened. It has been pointed out that time sequences of events for these volcanoes do not show presence of any characteristic time like a period but rather a nature of fractal (Dubois and Cheminee, JVGR 45, 197-208, 1991). Even in these cases, however, obtained fractal dimensions significantly fluctuate depending on selected time ranges of analysis so that the fractal nature may not have been well established. Unfortunately, only a few volcanoes have sufficient numbers of eruption records to allow a similar analysis.

With this background we have begun to study the controlling factors of time intervals and magnitudes of eruptions using a simple model of magma plumbing system. We may qualitatively interpret periodic occurrences of eruptions simply supposing that a magma chamber that has been fed with magma from below emits magma to the surface when the accumulation exceeds its capacity. One of the authors earlier proposed a more quantitative model in which the exit of the magma chamber opens or closes with viscous deformation responding to magma pressure changes (Ida, GRL, 23, 1457-1460, 1996). This model was formulated using a simple set of time-dependent differential equations. The present analysis is based on an improved model and aimed to examine how the periodicity and magnitude of eruptions are influenced by disturbances of the supply from below or magma flow in the upper conduit.

In the model used in the present analysis the chamber can be connected to the flow in the upper conduit that may ascend in various styles, but only a simple case of the uniform flow is considered in the presentation. As in the earlier model it is assumed that magma pressure in the chamber is enhanced elastically with magma accumulation and that the exit to the upper conduit opens or closes viscously following the magma pressure. Furthermore, it is newly assumed that the viscosity that controls the exit deformation increases sharply with an exponential dependence as the exit narrows. This magma plumbing system has effectively periodic solutions of magma effusion when magma is supplied from below at a constant rate and the flow in the upper conduit is uniform. In this periodic solution, the time interval between eruptions is shorten almost in reciprocal proportion to the supply rate from below while the erupted mass increases and the peak eruption rate slightly decreases as the supply rate is greater.

In the presentation we examine how the eruptive flow is influenced by a periodic change of the supply from below. According to results of the numerical simulation, when the period of the supply change is same as or shorter than the characteristic period of eruptions, the periodicity of surface eruption is little influenced even if the period is slightly longer and the maximum eruption rate is slightly smaller. On the other hand, when the given disturbance has a sufficiently longer period than the characteristic period of eruptions the period and magnitude of eruptions change concordantly with the supply change. Only between these two cases the eruption process is disturbed irregularly with random changes of time intervals and eruption rates.

Keywords: volcanic eruption, periodicity, magma, magma chamber, magma plumbing system, computer simulation