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Volume of magma chamber and eruption ratio for caldera collapse

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Mechanism of caldera collapse is modeled with a comparison of a piston-cylinder caldera model and the compiled data of caldera size and eruptive volume in nature.

Collapse caldera is formed by the fracturing and subsidence of the roof of magma chamber with rapid withdrawal of massive magma from a magma chamber. As the fracturing and subsidence of the roof of magma chamber may enhance the additional eruption of magma inside the magma chamber, understanding of the mechanisms of the precursory eruption is crucial to evaluation of the potential eruption from caldera volcanoes.

Collapse calderas are formed only by the largest eruptions of its life, though, in many cases, caldera volcanoes repeat many eruptions with various scales before and after caldera formation. Smaller eruptions have no significant contribution for collapse. Aira caldera in Japan was formed at 29ka eruption during which ~400 km^3 of magma was erupted. Though many smaller eruptions including Fukuyama pumice eruption (10km^{3}DRE) and Sz-S eruption (4km^{3}DRE) occurred from the Aira caldera, no significant collapse was occurred. During the 29 ka eruption, Osumi pumice fall was erupted prior to the onset of collapse, and the emission of Ito pyroclastic flow followed the collapse. The erupted volume of Osumi pumice fall (~40 km^{3}DRE) is larger than those of the eruptions without collapse. This relationship is commonly observed in other caldera volcanoes. The erupted volume during the precursory eruption is in correlation with the size of caldera.

The volume of magma withdrawal to induce collapse is modeled with piston-cylinder model. The driving force of collapse is the decompression in magma chamber by the magma extraction. The friction in the ring fault sustains the roof. Competition between the decompression of magma chamber and the friction controls the onset of collapse. The decompression of magma chamber is in the function of the eruption ratio (volume of magma withdrawal / total volume of magma chamber). This model shows that a larger volume of magma withdrawal is required for the onset of collapse with larger diameter. The critical eruption ratio for collapse is smaller for the larger caldera.

Though this model has potentially large ambiguity from the simplified shape of caldera fault and the assumption of the bulk modulus of magma, this model can give the total volume of magma chamber associating collapse caldera. In the case of Aira caldera, with 15 km in diameter and 6 km to the roof of magma chamber, the total volume of magma chamber before the eruption is estimated as 600 km^3. The caldera collapse occurred when the erupted volume reached to 8% of the total magma chamber, and 60 % of magma was erupted as Ito pyroclastic flow after the onset of collapse.

Keywords: large eruption, caldera volcano, magma chamber