Pre-eruptive magma dynamics of the climactic 110ka eruption of Toya caldera, Japan

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[Introduction & Methods] Caldera-forming eruptions are among the most hazardous of natural events and need to be properly predicted. An important part of this effort is to elucidate the pre-eruptive history of the magma systems through detailed petrological studies. Toya caldera, Japan, is an ideal laboratory for this purpose because of its youth and excellent preservation. It has two post-caldera volcanoes, Nakajima and Usu, the latter of which is one of the most active volcanoes in Japan.
According to previous studies (e.g., Suzuki et al, 1970; Ikeda & Katsui, 1986; Machida et al., 1987; Feebrey, 1995; Lee, 1996; Machida & Yamagata, 1996), a catastrophic eruption occurred at ca. 110 ka, producing large-scale pyroclastic flows and a wide-spread co-ignimbrite ash (>150km^3), and the magma was mainly a homogeneous high-silica rhyolite. The eruption sequence and pre-eruptive magma processes are, however, not yet well understood because the stratigraphic units differ between different researchers and previous petrological interpretations includes some errors. Therefore, we have conducted new geological and petrological studies, including analyses of bulk-rock compositions (XRF) and volcanic glass and mineral compositions (EPMA, LA-ICP-MS). Part of the geological studies has been published by Goto et al. (2018).

[Results] We divided the eruptive product into units 1 to 6 [see Goto et al. (2018) for detail]. Unit 1 is an ash-fall deposit consisting of glass shards. Units 2, 4, 5, and 6 are pyroclastic surge and flow deposits. Unit 3 consists of base surge and ash-fall deposits. Large lithic clasts occur in unit 4 and the lower parts of units 5 and 6.
Most pumice clasts are homogeneous white pumice (SiO_2=ca.77%, K_2O=ca.2.8-3.2%; similar to the opx-HSR of Feebrey(1995)). Half of pumice clasts in unit 6 are banded and gray pumice, showing two types of chemical variations. One (hb-LSR, ibid) trends toward the Nakajima andesite, and the other (cum-HSR, ibid) toward the Usu rhyolite.
Glass and mineral compositions also have variations in unit 6. For plagioclase, we identified 3 types (A, B, and C). Type A (An=ca.12) is dominant. Type B is anorthitic (An>=90) with a sub-type B' (An=ca.80). Type C is subdivided into C1 (An=ca.20), C2 (ca.35), and C3 (ca.55). Types C2 and C3 show dissolved textures. Orthopyroxene and magnetite also have similar variations, whereas quartz is type A, clinopyroxene is type B', and both hornblende and ilmenite are types C2 and C3. Magma A, from which type-A phenocrysts derived (the same hereafter), is the high-silica rhyolite. Magma B is a mafic magma. Others are intermediate magmas. Temperatures, estimated with geothermometers by Putirka (2008) and Andersen & Lindsley (1985), are <=800 C for magma A, 800-890 C for C1, C2, C3, and B', and >=900 C for B. Trace element concentrations and zoning profiles of phenocrysts reveal that C2, C3, and B' were closely related to each other but were not in contact with A and C1 until just prior to the eruption, that B' was derived from B, and that C1 interacted with A before eruption.
Type-A phenocrysts do not show significant reverse zonings. Diffusion times estimated for magnetite are < days. On the other hand, type-B phenocrysts show significant diffusion (e.g., Mg in plagioclase), indicating hundreds of years between the injection of magma B and the eruption.

[Inferred magma processes] The Toya eruption commenced with a phreato-Plinian eruption (unit 1), followed by a large-scale pyroclastic surge eruption (unit 2). The eruption once decreased in intensity and changed into small-scale phreatomagmatic eruptions (unit 3). Shortly after that, the caldera-collapse began (unit 4), resulted in a large-scale pyroclastic flow eruption (units 5 and 6). The caldera collapse, following the temporary decrease in intensity, was probably caused by underpressure in the magma chamber due to the evacuation of unit 2.
Just prior to the eruption, there was a large main chamber of magma A with subordinate magma pockets C1, C2, C3, B', and B. Magma A was probably produced by extraction from a crystal mush (e.g., Wolff et al., 2015). Mafic magma (B) injected hundreds of years before the eruption, remelted the mush, producing magmas C2, C3, and B'. Magma A was not disturbed by the mafic magma until just prior to the eruption. Magma mixing occurred during the eruption probably by suction due to the decrease in chamber pressure. The eruption trigger was probably not a mafic injection but an external cause, such as fault movement (e.g., Gregg et al., 2015). The compositional variation in unit 6 indicates a close relationship with Nakajima and Usu magmas, and requires a further examination.

Keywords: Toya caldera-forming eruption, ignimbrite, high-silica rhyolite, silicic magma, magma mixing, time scale

