Re-examination of magma plumbing system beneath Usu volcano, Hokkaido, Japan, during the 1663 eruption

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Usu volcano, located on Southwest Hokkaido, has erupted nine times since AD 1663 after ca. 7000'yrs dormancy. The 1663 eruption was the first and the most explosive among the historic activities. The previous studies suggested that the 1663 juvenile materials were mixing products between two end-member magmas, which contained Type A felsic, and Type B mafic phenocrysts respectively. However, these studies focused only on the climactic stage of the eruption. However, the 1663 explosive deposits can be divided into three stages, (1)Stage-1: pumice fall and pyroclastic surge, (2)Stage-2: main pumice fall and (3)Stage-3: a pile of surge and pumice fall deposits in ascending order. We examined the magma plumbing system and the eruption processes of the 1663 eruption based on this eruption sequence.

The juvenile materials are composed of three types of nearly aphyric (phenocrysts less 5 vol.%) pumice, e.g., white (in all stages), gray (Stage-2) and banded ones (Stage-1 and -2). These materials show linear trends (SiO_2=73.5-76 wt.%) in all the Harker diagrams, suggesting two end-member magma mixing. Except for gray pumice, compositional variation for major phenocrystic minerals (e.g. plagioclase, orthopyroxene) is extremely bimodal, (An~42, Mg-value~46: Type A, An~87, Mg-value~70: Type B). On the basis of other elements (Wo of orthopyroxene, and FeO of plagioclase), the Type A phenocrysts can be divided into two types (Type A1 and -A2). The Type A2 phenocrysts were derived from more mafic magma, compared with the magma crystallizing the Type A1 phenocrysts. The Type A2 ones are dominant in Stage-1, and are mainly contained in the gray pumice. Because of the linear trends in all Harker diagrams, it can be concluded that the Type A2 phenocrysts crystallized from the mixed magma formed by mixing between mafic (Type B phenocrysts) and felsic (Type A1 ones) magmas. Considering the size of the Type A2 phenocrysts, mixing occurred several or several tens years before the 1663 eruption.

Before the eruption, the magma chamber was composed of three magmas to form a compositionally zoned chamber. Considering the eruption sequence, the mixed magma erupted during the initial stage (Stage-1), indicating that mixed magma spread at the top of the chamber. This compositionally reverse chamber could be formed by the convective entrainment proposed by Snyder and Tait (1996). In the case of the 1663 eruption, high temperature mafic magma (1070C) injected into felsic magma with low temperature (770C). Thus, thermal convection in the felsic magma would occur due to the injection of the mafic magma. The convection could entrain the mafic magma to form mixed magma between them. However, even if the mixed magma spread at the top, the magma would be settled beneath the felsic magma in the chamber, because a considerable interval existed between mixing and eruption. We estimate densities of these magmas; $2.27\text{-}2.35 \times 10^3$ (felsic) and $2.27\text{-}2.36 \times 10^3$ kg/m3 (mixed). This result is due to much high temperature of the mixed magma (850-950C). Similar density of the two magmas and high temperature of the mixed magma would prevent sinking of the mixed magma. In conclusion, injection of the mafic magma into the felsic magma occurred more then several years before the eruption to form a compositionally reverse zoned chamber. The 1663 eruption was started with tapping of upper part of the zoned chamber, followed by a large scale of withdrawal of the chamber.