Relationship between the sequence of Eruptive episode C (Chuseri tephra) and the forming process of the Nakanoumi caldera, Towada volcano, NE Japan

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The Towada volcano is a double caldera volcano. The outer caldera, Towada caldera (11km diameter), was formed 15 ka. The inner caldera, Nakanoumi caldera (3km diameter), is a summit crater of the Goshikiiwa volcano, which is a basaltic post-caldera volcano. There are still several arguments for the timing of the Nakanoumi caldera formation.
The products of Eruptive episode C (6.2 ka) consist of the following three units in ascending order: Chuseri pumice (CP), Kanegasawa pumice (KP), and Utarube ash (UA); this is one of the largest activity at post caldera stage. CP is a plinian pumice deposit, KP is stratified lithic-rich pumice fall deposits, and UA is phreatomagmatic ash deposits. Although Hayakawa (1985) considered that the Nakanoumi caldera was formed in this episode from both lithic-rich features in KP and an eruptive sequence from magmatic (CP) to phreatomagmatic (UA). Because the activity at the last stage changed to phreatomagmatic eruption for almost eruptive episodes in post-caldera stage, it is difficult to discuss the timing of caldera formation from only their evidences. So to reveal the formation processes and timing of the Nakanoumi caldera, we investigated the episode C products in detail and reconstruct the eruptive sequences.
The intermittent activities of Eruptive episode C forming plinian columns suggest that these activities are independent activities with dormancy. CP is an almost homogeneous coarse pumice deposit except for the finer part at the bottom and uppermost, and this indicates that the eruption rate of the main part was constant for at least several tens hours. Lithic amount in CP deposit is constantly low in main part, but only at the top part, the lithic fragments sharply increase. The lithic fragments in KP deposits show high contents and articulate contrast. The kinds of lithic fragments in both CP and KP are rocks derived from only shallow part forming the Goshikiiwa volcano, not from deeper part. The density and chemical compositions of pumice clasts in CP and KP are constant and there are no cauliflower-like pumice clasts which show the participation of external water. The juvenile components of UA is poorly vesiculated dasitic clasts mainly and a few vesiculated particles. These features indicate that there is strong influence of external water only for UA, not so hard for CP and KP.
Macedonia *et al.* (1994) argued that the lithic fragments in tephra deposits derived from deconstruction of wall rocks by the fluid shear stress and conduit wall collapse. Roche *et al.* (2000) also argued that for small calderas like the Nakanoumi caldera, which the caldera roof aspect ratio (thickness/width) is high, high level reverse faults slice the subsiding blocks. This type caldera is considered as piecemeal type caldera by Lipman (1997). The tectonic movements by these blocks produce lithic fragments effectively and these fragments are taken by solid-gas flow in conduit. At the top of CP main part, the amount of lithic fragments increases sharply without grainsize changes, it suggests that some external factors affect the increment of lithics rather than the changes of eruptive intensity. So, it is valid that the factor is the beginning of caldera subsidence. This interpretation may explain some observed facts: the lithic-rich facies on the top of CP and KP derived from the entrainment of highly fragmented rocks around the vents by faulting; intermittent activities on KP result from the several blockades between small brocks; and the apparent changes of eruptive style between KP and UA show the inflow of external water. So, we conclude that the timing of caldera subsiding was the last stage of CP and it progressed during KP and UA.

CP emitted one eruptive column with once diminished accumulating and next grew the steady one at least half a day. In the last phase of eruption, the vent collapse occurred and started the caldera formation. Next, the eruption shifted to intermittent plinian activities (KP) with progression of subsiding. External water flew in the deepened vent and contacted with solidified magma, violent phreatomagmatic eruption occurred as UA. After these activities, the deep depression was stayed behind.
Particularly in smaller calderas like the Nakanoumi caldera, collapses take place after more than half of the total volume of the eruptive materials is already erupted (Geshi *et al.*, 2014). We constrain the timing of the beginning of subsidence and eruptive volumes. The ratio of the volume before collapse (1.86km^3) and total volume (3.04km^3), 0.63, is concordant with other smaller calderas. It suggests that the forming processes of smaller calderas are unable to explain with larger one, like Druitt and Sparks (1984).

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