Why was the 2000 eruption of Usu volcano not a sub-Plinian eruption?

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1. Introduction:
Usu volcano is one of the most active volcanoes in Japan (Soya et al., 2007). The historical eruptions since 1663 AD are characterized by sub-Plinian (or Plinian) eruptions with pyroclastic flows. The last eruption in 2000 AD was, however, not a sub-Plinian but a phreatomagmatic (small phreato-Plinian) eruption (Tomiya et al, 2001; Tomiya and Miyagi, 2002). The previous eruption in 1977 AD was a sub-Plinian eruption, and the magma compositions and conditions of these two eruptions are similar. Thus, there should be some process(es) that prevented a sub-Plinian eruption in 2000. To investigate this subject, I am trying to decipher what happened during the magma ascent by petrological analysis of the 2000 eruptive products.

2. The eruptive products of the 2000 eruption, in particular, magnetite:
This study focuses on magnetite, whose elemental diffusion is fast, so that we can investigate magma processes with short timescales (e.g., < several days). For example, Tomiya et al. (2013) investigated magnetite crystals from the 2011 eruption of Shinmoedake volcano and found that the crystals showed significant reverse zoning (increasing Mg concentration toward the rim), indicating heating by mixing of a hot mafic magma several days before the eruption.
Magnetite crystals from the 2000 eruption of Usu volcano, on the other hand, showed significant normal zoning; i.e., the Mg concentration and Mg/Mn decrease toward the rim within 20 to 30 microns (Tomiya and Miyagi, 2002). I analyzed magnetite using electron microprobe, in addition to the previous works, and revisited this issue.
The significant normal zoning is a common feature of all types of the magnetite crystals, regardless of their various textures. Thus, this zoning must have formed during magma ascent and corresponded to an event that caused Mg decrease, probably temperature decrease (cooling), in a short timescale.

3. The magma ascent process:
There are many studies on the magma ascent process of this eruption, including geophysical observations. Suzuki et al. (2007) proposed that the magma was stagnant for ca. 24 hours at a depth of ca. 2km, on the basis of magma decompression experiments, combined with seismologic and geodetic observations. They proposed that the stagnation was corresponding to the lateral movement of the magma from below the summit to below the foot, where the eruption began. According to this idea, the cooling event could be corresponding to the magma stagnation at ca. 2km.
The pre-eruptive magma temperature was estimated to be ca. 900-930 C, on the basis of the temperature dependence of Mg/Mn of magnetite and high-P, T phase equilibrium experiments (Tomiya and Takahashi, 2005; Ohnishi and Tomiya, 2018). If the decrease in Mg/Mn is due to cooling, the temperature decrease is estimated to be ca. 50-100 C. In addition, the time to diffuse Mg for 20-30 microns is estimated to be several hours to a day at 900 C.
In conclusion, the reason why the 2000 eruption of Usu volcano was not a sub-Plinian eruption is probably due to cooling (and degassing) during the lateral movement of the magma, in addition to abundant groundwater at the foot of the mountain. Usu volcano tends to cause sub-Plinian (or Plinian) eruptions from the summit, and phreatomagmatic or phreatic eruptions from the flank. Therefore,

understanding the event-branching process will be useful for effective disaster prevention measures in future eruptions.

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