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Tracking caldera cycles in the Aso-4 magmatic system

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Caldera-forming eruptions are among the most hazardous natural events on Earth and pose a significant risk for global consequences in the future. Recent petrological re-evaluations of caldera and intercaldera deposits in several volcanic systems worldwide suggest a cyclic behavior in the evolution of these subvolcanic reservoirs, comprising distinct maturation, fermentation and recovery phases. Here, we test the application of this caldera cycle framework on the Aso system in Central Kyushu (Japan) by evaluating pre-caldera activity of the Aso-4 caldera-forming event.

The Aso system is an archetypical example of a multi-cyclic caldera-forming volcanic edifice, which was built by four catastrophic caldera-forming events between 266 ka (Aso-1) and 86.4 ka (Aso-4). These caldera-forming eruptions are separated by extensive post- and pre-caldera activity from numerous vents inside and outside the caldera areas. The deposits produced from these vents range from basalts to rhyolites in bulk-rock compositions and are dominated by a mineral assemblage consisting of plagioclase, ortho- and clinopyroxene, Fe-Ti oxides and apatite.

Plagioclase and orthopyroxene are the most abundant minerals in the Aso system. However, their often wide compositional ranges, recording multiple stages of magma evolution, make it difficult to pinpoint chemical differences between pre- or post-caldera eruptions; geochemical analyses of orthopyroxene and plagioclase give overlapping ranges for pre-Aso-4 and Aso-4 caldera-forming events with Mg# between 71 to 75 and An% between 35 to 80, respectively. On the other hand, accessory mineral phases, such as titanomagnetite and apatite, chemically re-equilibrate fast with the melt and hence predominantly inherit conditions prevailing just prior to eruption. Average MnO contents in titanomagnetite record a distinct increase from ~0.8 wt% to ~0.9 wt% in pre-Aso-4 crystals to 1.2 wt% in the silicic cap of the Aso-4 system, indicating the progressive evolution of the system towards more differentiated compositions. Similarly, the F-Cl-OH record of apatite in the pre-Aso-4 and the Aso-4 system indicate the transition from water-undersaturated conditions during magmatic evolution in the pre-Aso-4 system to water-saturated conditions in the silicic cap of the Aso-4 system. Concomitant with these variations, changes in dissolved water contents in melts and storage temperatures are observed, with temperatures progressively decreasing from the pre-Aso-4 units (> 900 °C) to the silicic portion of the Aso-4 deposits (~860-880 °C). Dissolved water contents in the melt, in turn, increase from ~3-4 wt% in the pre-caldera system to ≥ 4.6 wt% in the Aso-4 silicic cap, close to or even at volatile saturation considering ~100-400 ppm CO₂ in the melt at storage depths (~1.5 - 2 kbar). These findings are in good agreement with the caldera cycle

framework and suggest the progressive differentiation of the Aso system during a maturation phase through volatile exsolution in the fermentation stage to the catastrophic Aso-4 caldera-forming eruption.