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The impacts of volatile dilution on magma chamber dynamics: insights from the Aso-4 caldera eruption

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The presence or absence of an exsolved magmatic volatile phase has important influences on the dynamic behavior of magma chambers and their eruption. For instance, magma compressibility can increase with the exsolution of a water-rich volatile phase, enabling the storage of larger volumes of magma. This study investigates how the reduction and potential re-dissolution of an exsolved volatile phase impacts the dynamics and eruption of the sub-volcanic magma chamber of the Aso volcanic complex, Japan, prior to the Aso-4 caldera-forming event.

The Aso-4 eruption (86.4 ka BP) was preceded by a shift from water-saturated conditions to water-undersaturation in the last 5 ka before the onset of the caldera-forming event, suggesting the reduction and potential re-dissolution of an exsolved magmatic water phase in the system. Here, we employ thermo-mechanical modelling of chamber dynamics within the Aso system to establish the conditions under which such volatile dilution and partial re-dissolution can occur and explore its potential impact on triggering large-scale caldera-forming events. The key parameters varied throughout this study include the size and depth of the magma chamber within the crust, the water and CO_2 content dissolved in the resident and recharge magmas, the rate and temperature of recharge entering the system, and the initial crystallinity of the magma stored in the chamber. We find that recharging a magma chamber with drier and hotter magmas reproduces the observed reduction of exsolved volatiles in the pre-Aso-4 reservoir. A return to water-undersaturated conditions, however, is only achieved under specific conditions, which are strongly controlled by the initial mass fraction of exsolved volatiles present within the magma chamber. Here, only scenarios with low initial volumes of exsolved volatiles were able to reproduce such a return to water-undersaturated conditions. Upon water-undersaturation, we observe an increase of the pressurization rate within the system leading to an earlier onset of the caldera-eruption than in water-saturated systems. By combining petrological analyses and numerical modelling, this study provides valuable insights into the important role exsolved (or redissolved) magmatic volatiles can play in the eruption dynamics of large silicic systems.