The factors that control the long-term sustainability of a hot crater lake: Insights from a generic numerical model

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Hot crater lakes at volcanoes act as condensers of heat and volatiles released from magma bodies. Monitoring of physical parameters such as water level and lake temperature provides a means of quantifying the amount of heat and mass discharged from volcanoes. Pasternack and Varekamp (1997) showed that most steady-state volcanic lakes are unlikely to maintain a temperature in excess of 45-50 degree C unless the precipitation rate is more than 5,000 mm/yr, as required to achieve a mass balance, whereas the 1st cater at Nakadake in Aso caldera, central Kyushu, Japan, contains a hot crater lake with a water temperature of 60-70 degree C during periods of volcanic calm, in an area with average annual rainfall of 3,000 mm.

To understand the factors that control the long-term sustainability of a hot crater lake, we developed a generic numerical model of such a hot lake based on the conservation of mass and enthalpy. Temporal variations in the characteristics of the lake are investigated by performing numerical simulations of various crater shapes to identify the factors that control the sustainability of the lake.

The results of numerical simulations show that water level and temperature are controlled mainly by the enthalpy of bottom input fluids, the ratio of bottom input mass to lake surface area and crater topography. Suitable factors for the long-term sustainability of the crater lake are found even if the lake temperature exceeds 40-50 degree C. In the case that lake surface area is constant with changing lake level (e.g., a cylindrical crater), the lake is stable against perturbations in water temperature and level. However, in the case that the surface area varies with level (e.g., a conical crater), the mass and energy balances vary with level. Hence, in a conical crater, a decrease in water level results in increasing temperature due to reduced evaporation associated with reduced surface area of the lake, thereby leading to a further decrease in water level. This positive feedback causes shrinkage of the crater lake even in the case that the input of bottom fluid remains constant.

The modeling results explain how the hot crater lake at Aso volcano has been maintained with water temperatures in excess of 70 degree C for over 1,500 years: we consider that stable emissions of volcanic fluid from the crater bottom have continued throughout this period of volcanic calm, which is appropriate size of the crater topography.